Fundamentals
in the Production
and Design of Castings

Fundamentals in the Production and Design of Castings

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To
Emma Louise Marek

Preface

The casting process is one of the oldest and most basic of occupations. The mysteries and trade secrets developed and acquired by the relatively few artisans of the past are being broken down and reduced to a science. The foundry industry along with all others is developing into a highly mechanized technical industry whose engineering roots are embedded in the fertile soil of modern science. The casting of metals into shapes and their integration into machines to relieve the burdens of man have reached new levels of excellence surpassing the fondest dreams of yesterday. The inhibited ingenuity of man has been unleashed; the results are revealed in mass production of castings of intricate shapes and physical properties unheard of before.

Foundries located all over the United States produce millions of tons of aluminum, brass, gray iron, magnesium, malleable iron, and steel castings. They constitute a great and basic industry producing castings ranging from a few ounces in weight to over two hundred and fifty tons, from a fraction of an inch in size to seventy feet long, and with sectional thicknesses ranging up to four feet. Over ninety per cent of the metal-working industries use castings in their products. In the automotive industry each car requires six hundred pounds of castings, and a typical five-room house needs over two tons of cast products. No matter where one turns, castings are serving in the daily routine of life and comfort.

There are more than four thousand individual producers of castings in the United States. These foundries are generally classed as one of two types, namely, the jobbing foundry and the captive foundry. Jobbing foundries are independent concerns which sell their products to the user. Captive foundries are owned and operated by a manufacturing concern which produces castings, mainly for its own use. A few foundries, especially the captive foundries, are quite large, some producing as much as three thousand tons daily. It has been estimated that the total annual melting capacity of all the foundries in the United States and Canada is more than twenty-seven million tons, seventeen million of which represent the gray iron capacity.

To look back at the progress of man through science is flattering, but what lies beyond the horizon may be a spectacle that surpasses the keenest imagination of the present intellect. These opportunities stand as challenges to find facts and to lay the steppingstones of science in engineering development.

The engineer's responsibility in designing engineering parts is twofold. He must design the part so that it will perform a certain function, but he must also design the part so that it may be produced at the least expense of labor and material. It is the latter responsibility of the engineer with which this text is most concerned. In order to direct his design toward economical production, the engineer must be acquainted with the production process. For example, in the study of mold production, the objective is not to train the student to be a molder, but to acquaint him with the procedure involved in the production of a casting of a given design. With this knowledge as a background, the designer is better qualified to avoid unnecessary waste of labor and material.

CLARENCE T. MAREK

January 1950

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Casting Processes

The casting process consists of pouring molten metal into a mold containing a cavity of the desired shape of the casting. Sand molds are destroyed upon solidification of the metal. If the mold is of the permanent type, it is merely separated to remove the casting.

Green Sand Molds. Of all the methods in the production of castings, the most common is the green sand molding process. The sand is called *green* because it depends on moisture for bond. Molding sands have three principal ingredients: silica sand of specified grain size, shape, and uniformity; green bond of desired plasticity; and moisture. Chapter 3 of this book deals with the various types and properties of molding sands.

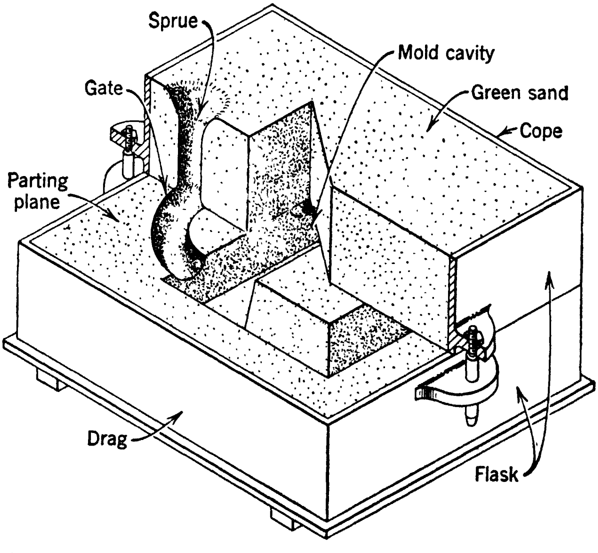


Fig. 1. Green sand mold with cope sectioned to show interior of mold.

Medium-sized green sand molds are enclosed in flasks that consist of two parts, the upper half or *cope,* and the lower half or *drag,* as illustrated in Fig. 1. The plane separating the cope and drag is called the *parting plane;* when viewed as a line, it is called a *parting line.* The shape of the desired casting is simulated by a pattern around which the molding sand is formed. When the pattern is removed, the shape of the mold cavity is identical with the shape of the pattern. Sufficient taper, called *draft,* is placed on the sides of the pattern to facilitate withdrawal of the pattern without damage to the mold cavity. The vertical passageway through which molten metal flows down to the parting plane is called the *sprue.* The horizontal connection in the parting plane between the mold cavity and the sprue is the *gate.* If there is more than one cavity in the mold, the common gate supplying a number of cavities is called a *runner,* and the branches from the runner to the respective mold cavities are referred to as *in-gates.*

Molds that are small enough to be lifted and manipulated by one man throughout the molding process are called *bench molds.* They are made on a specially constructed bench, designed for the molder's convenience. Large molds, called *floor molds,* are constructed on the foundry floor. A detailed description of molding processes is found in Chapter 2.

Dry Sand Molds. If greater mold strength is necessary to withstand the weight of a large volume of metal, or if a harder surface is required to avoid erosion due to flow of metal in the mold, the mold is made of a specially prepared sand and dried in an oven. The layer of *facing sand* which surrounds the mold cavity is usually composed of a mixture of molding sand, bank or river sand, and a bond such as flour or pitch. The remainder of the mold is composed of *backing sand,* a porous mixture of burnt facing sand, molding sand, cinders, and clay. After the green mold is made, its surface is sprayed with molasses water and dried in an oven at 300° to 600° F until the moisture is driven off.

The higher cost of a dry sand mold is often justified by the added assurance of a sound casting. Because of the lack of moisture in a dry sand mold, defects caused by the formation of steam are avoided. Defects caused by rapid chilling of metal are also eliminated in dry sand molds. Because of greater rigidity, a dry sand mold may resist shrinkage of the casting to the extent that the casting may break when cooling to room temperature. All these considerations are important in the production of castings of good quality at an economical figure.

In *skin drying,* only the surface of the mold is dried with a torch. The mold must be poured soon after it is dried or moisture will penetrate back to the mold surface.

Dry Sand Cores. Parts of a mold that are too difficult to form with a pattern are made independently of the mold and inserted in the mold cavity after the pattern is removed. These dry sand forms, called *cores,* are made of silica sand and bond which becomes hard when baked. They are made in boxlike forms called *core boxes.* Dry sand cores may be inserted in green or dry sand molds. Each core has one or more projections, called *core prints,* which fit into the core print cavity or cavities of the mold to prevent the core from shifting when the mold is poured. Core print cavities are formed by the pattern. The interior design of the gear reduction housing of Fig. 2*A* is formed by the core shown in Fig. 2*B*. The projection at the end of the pattern in Fig. 2*C* is a core print. Figure 2*D* shows the core in position in a completed mold.

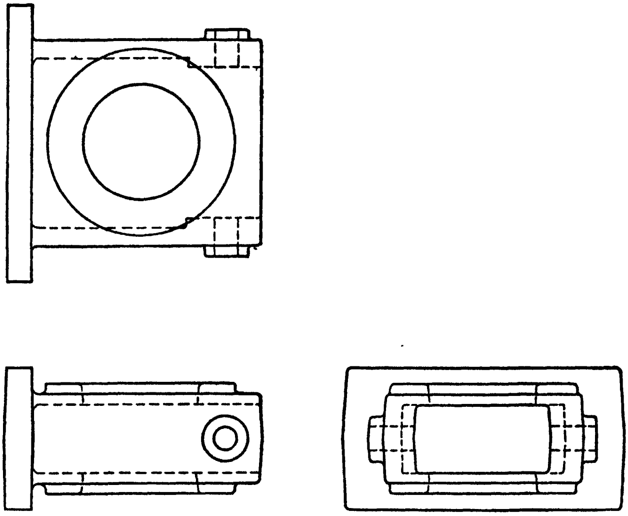


FIG. 2*A*. Gear reduction housing.

Loam Sand Molds. Large castings are sometimes made in *loam sand molds.* A loam sand mold is constructed of porous

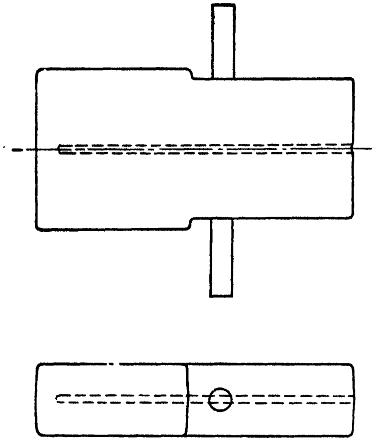


FIG. 2*B*. Core to make interior of gear reduction housing.

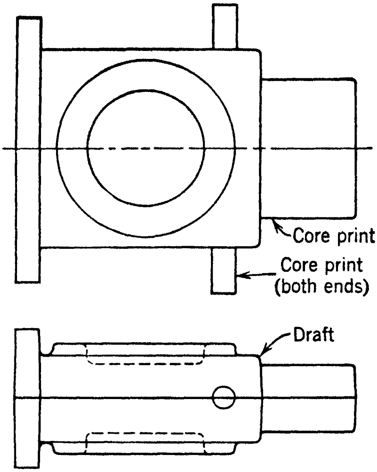


FIG. 2*C*. Pattern for gear reduction housing.

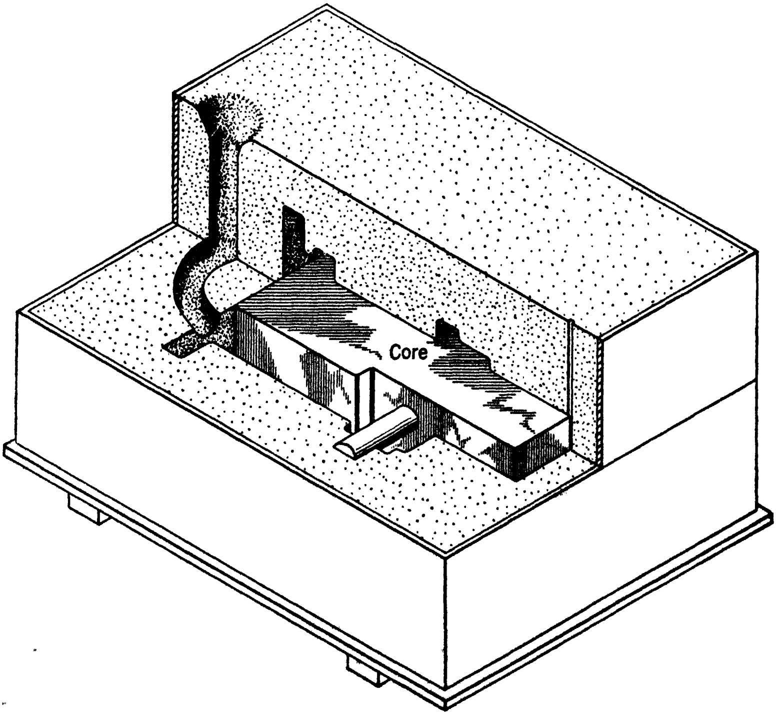


FIG. 2*D*. Sectional view of mold for gear reduction housing.

brick, cemented together with *loam mortar.* Loam mortar consists of a mixture of molding sand and clay, wetted to the consistency of mud. The inner side of the brick structure forms the contour of the casting. It is faced with a ¼- to ¾-in. layer of loam sand which is *swept* to the exact shape of the casting. A *sweep* for a cylindrical casting consists of a scraper which is rotated about a central spindle. After loam is plastered on the brick, the sweep is rotated about the spindle to shave off excess sand and form the circular contour. Figure 3*A* illustrates the construction of the base of a loam mold by means of a sweep. Noncircular surfaces may be swept to shape with a proper guide board to guide the sweep. The core of a loam mold is likewise constructed with brick, coated with loam, and swept to the desired shape. The exterior part of the mold, called the cope, and the core are constructed on individual iron bases provided with hooks so that they can be lifted with a crane for assembly. After all parts of the mold are dried, dough rolls or paste is placed on the matching surfaces of the parting plane to seal the joints. The mold is assembled and secured with tie rods or merely weighted down to prevent separation or shifting. A steel shell of ¼-in. boiler plate, called curbing, is then placed around the mold, and molding sand is rammed in the space between the shell and mold to prevent the mold from bursting when poured. A completed loam sand mold is illustrated in Fig. 3*B*. Several pouring points are required so that molten metal can be poured into the mold continuously from ladles carrying less metal than the whole casting requires.

Inexpensive patterns are commonly used in loam molds. Sweeps are substituted for patterns when practicable, and pieces of patterns are used to make those details that cannot be satisfactorily made with sweeps. The greatest handicap in loam molding is the lack of skilled personnel.

Pit Molds. Instead of curbing a loam sand mold, it may be lowered in a pit below the level of the floor and rammed firmly with molding sand to prevent the mold from bursting. This is not practicable when the height of the loam mold is greater than the depth of the pit, a condition common in the heavy industry.

As an alternative to loam molding, a casting too large for a flask may be made in a pit by the bedding-in method. The

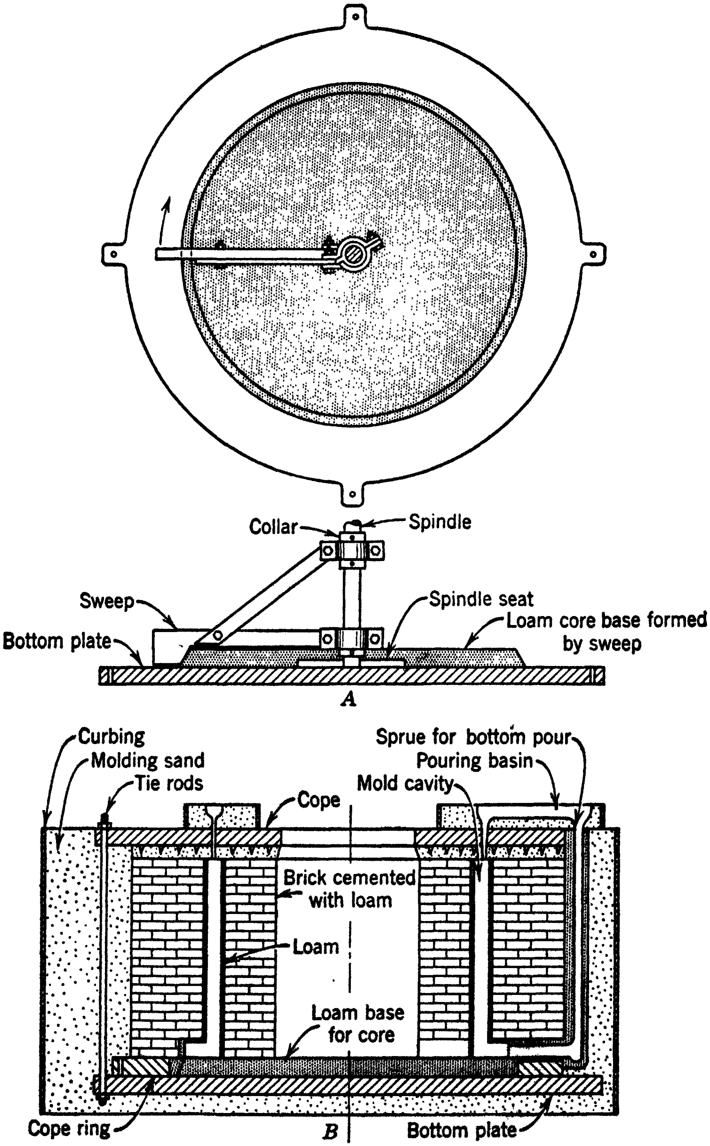


Fig. 3. *A*. Construction of base for a loam sand core with a sweep. *B*. Sectional view of a loam mold.

pattern is set in a pit in the position in which the casting is to be poured, and sand is rammed or tucked under and around the sides of the pattern. The cope of the completed mold, resting on the drag above floor level, may be bolted with long tie rods to the drag plate at the base of the pit, or it may be weighted down to prevent a run-out at the parting plane. Bedding-in practice is also adapted to floor molding, especially when the flask is so large that routine molding is likely to distort the mold.

FIG. 4A. Pattern for a large press casting partly rammed in a pit mold. The pouring weight of the casting was 245,000 lb. (Courtesy of Continental Foundry and Machine Co., East Chicago, Ind.)

Many foundries are equipped with a concrete-lined pit, the width and depth of which are equivalent to the size of the mold they customarily produce, and the length of which extends a distance equivalent to the number of molds desired at any one period of time. The length is then partitioned off with heavy steel portable spacers which can be moved to any desired position along the length of the pit to accommodate the job at hand.

When the design of the casting is such that a pattern cannot be drawn out of the mold, the entire mold cavity is constructed with cores, thus eliminating the pattern. A mold may contain a large number of cores, some of which may be set by hand, and others, too heavy to handle, are set with the aid of a crane.

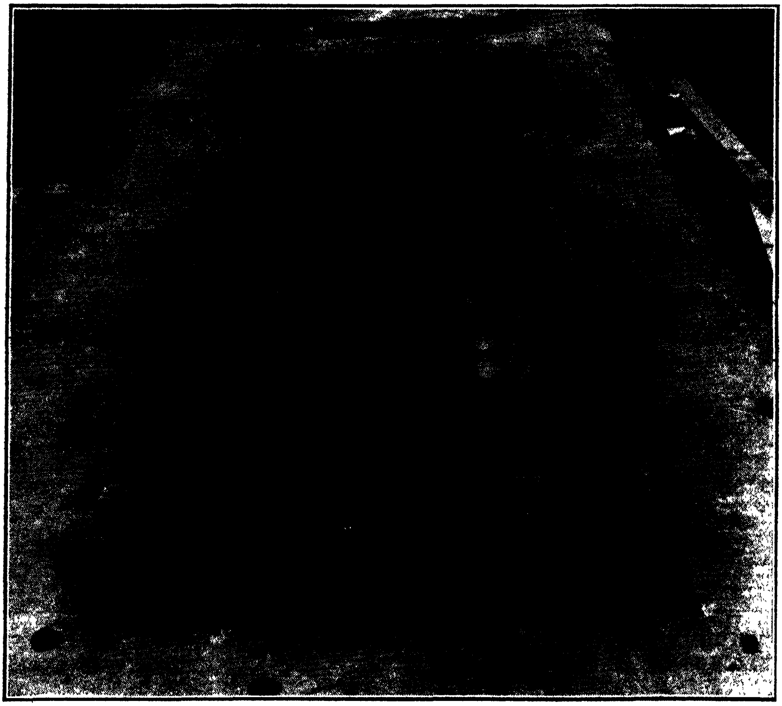


FIG. 4*B*. Bottom row of cores set and secured by chaplets. (Courtesy of Continental Foundry and Machine Co., East Chicago, Ind.)

Permanent Molds. In contrast to the sand mold, which must be destroyed to remove the casting, the permanent mold is designed so that it can be separated to eject the casting. The life of the mold depends on the characteristics of the metal being cast, the construction and design of the mold, and the design of the casting. Ordinarily, a die should produce 15,000 gray iron castings or 100,000 aluminum castings from a cast-iron mold with only minor repairs.

Because erosion due to high pouring temperature is a primary limiting factor of the life of the mold, the first consideration in mold construction is the selection of the best material at the most economical cost. Although cast iron is the usual choice, steel molds are also used. Bronze and nonmetallic materials such as graphite and loam are employed when ferrous metals are unsatisfactory because of mold cost or deterioration of the die.

FIG. 4*C*. A large pit mold poured with a double-nozzled bottom pour ladle. (Courtesy of Continental Foundry and Machine Co., East Chicago, Ind.)

The common gray iron mold consists of two or more parts which separate at the parting plane of the casting. Interior designs of castings are formed with gray iron or steel cores. Cores that can be withdrawn with the mold are fastened to the mold body, but others, called side cores, must be drawn out before the mold is separated. Greater corrosive wear is experienced on thin sections surrounded by molten metal, because heat cannot be effectively dissipated from that portion of the mold.

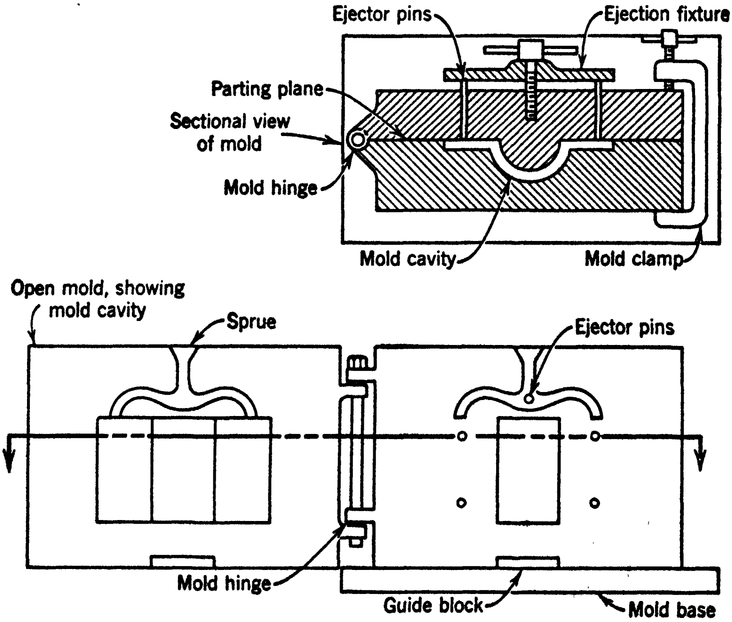


FIG. 5. Permanent mold. Top view shows closed mold in section. Front view shows interior of open mold.

With more rapid removal of heat, the metal solidifies quickly and shrinks, leaving an air space between the mold and casting. Although this air space protects the mold, it reduces the cooling effect of the mold. Projections, such as pins extending from exterior mold walls, are sometimes used to increase the radiating surfaces. For greater efficiency, a blast of air across the surfaces is very effective. When greater uniformity in solidification is necessary, cooling coils for circulation of oil or water are employed around the hot spots. The rate of solidification determines to a large extent the physical properties of the casting. For instance, if cast iron is cooled rapidly, the surface of the casting may become so hard that it cannot be machined; if it is cooled slowly, machinability may be excellent. When necessary, ferrous castings are annealed to remove internal stresses and improve machinability. When molds are to be cooled rapidly in the production of chilled castings, mold temperatures should be carefully controlled.

Surfaces of the mold cavity are coated with a refractory wash to reduce mold deterioration and to prevent the castings from sticking in the mold cavity. The wash may consist of a dilute refractory cement of core oil and graphite. A single treatment may last a long period of time before it has to be renewed, depending on the cutting action of the molten metal. Each time, before the mold is poured, it is smoked with an acetylene flame adjusted to burn with the minimum amount of oxygen to provide maximum soot or carbon. In the operation cycle, the mold is blown out with compressed air, smoked, closed, poured, and opened, and the casting is ejected.

In high production, a number of molds are placed on a circular table which rotates the molds through stations where various operations are performed automatically. Thus one casting is produced for each mold per revolution of the table.

Small slush castings are made in bronze molds, a process in which the metal is allowed to cool long enough to form a shell. As soon as the shell is formed, the mold is inverted and the remaining molten metal is poured out, leaving a hollow center. This process is best adapted to castings made of lead- and zinc-base alloys.

A loam mold constructed to produce more than one casting is sometimes referred to as a permanent mold. The brick work must be bolted together securely, and sufficient elasticity as well as strength must be provided in its construction to absorb the stresses imposed on it by the shrinking casting. After the mold is opened and the casting is removed, damaged portions of the mold must be patched up before it is assembled for the succeeding operation. As previously stated, loam molds are used for large castings.

A very small proportion of ferrous castings is produced by the permanent mold process. Those made in permanent molds are relatively small in size and less intricate in design. In nonferrous alloys a keener competition exists between sand casting and permanent mold casting, especially when the quantity of production exceeds 500. Not only is the rate of production in permanent molds more rapid, but low cost of unskilled labor and high percentage of good castings brings down the cost of production to a strong competitive basis. Some advantages claimed by the producers of permanent mold castings are as follows:

1. Freedom from sand and dirt.
2. Freedom from gas porosity.
3. Freedom from internal shrinks.
4. Smoother surfaces.
5. Closer tolerances.

The mechanical properties of aluminum castings from permanent molds rank higher than sand castings because of their fine grain size which leads to greater strength, hardness, elongation, resistance to impact and corrosion, and ability to take on a higher polish.

Die Casting. Die casting differs from the previously described permanent mold processes in that molten metal is forced into the die under high pressure. This is a highly mechanized process in which dies may be interchanged without altering the machine. One half of the die is fastened to the *stationary platen* containing the gate. The *movable platen* containing the other half of the die is activated by a hydraulic piston which separates the two die halves at the parting plane. The casting is pushed out with *ejectors* installed in the movable die. An *injector tube* connects the gate of the stationary die to the *plunger or piston* which produces the desired casting pressure.

The two basic types of machine, the *hot chamber* and the *cold chamber,* differ primarily in the way metal is admitted into the injector tube. The majority of hot-chamber die-casting machines have a *gooseneck injector tube* which is submerged in the molten metal reservoir, as illustrated in Fig. 6. As the piston approaches the end of its back stroke, it passes the cylinder ports which permit molten metal of the bath to flow into the cylinder; and, when the piston advances beyond the ports on its return stroke, it forces the entrapped metal into the die. In the cold-chamber process, the injector tube is not submerged in the melting pot, and molten metal must be introduced into the injector tube by a hand ladle or automatic feed prior to each "shot."

The cold-chamber process, illustrated in Fig. 7, is used in the casting of aluminum- and copper-base alloys where high pressures are required to eliminate blow holes and other casting defects. Pressure in the cold-chamber process normally ranges from 6000 to 12,000 psi and in some instances runs up to 100,000 psi. Hot-chamber pressures of approximately 1500 psi are satisfactory for casting aluminum, tin, and lead alloys. The fact that aluminum absorbs iron from the submerged injector tube may be reason enough to use the cold-chamber process for closely controlled physical properties.

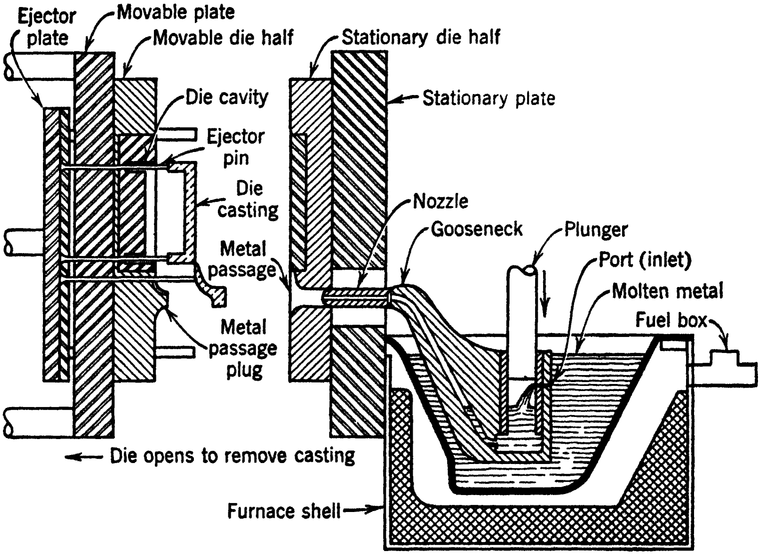
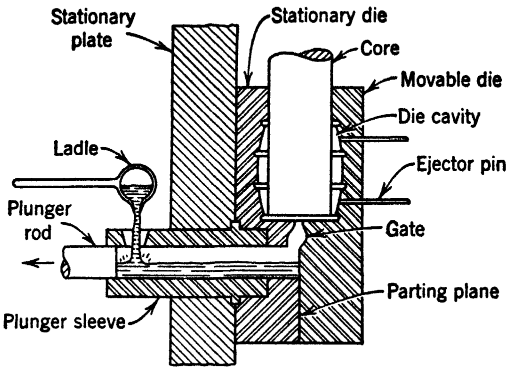
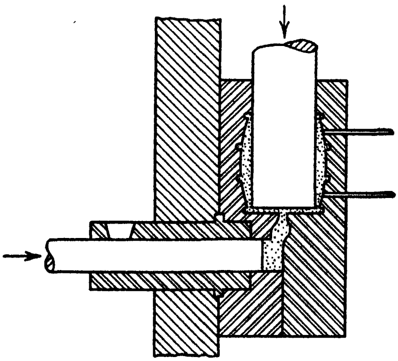


FIG. 6. Die-casting machine showing casting being ejected.

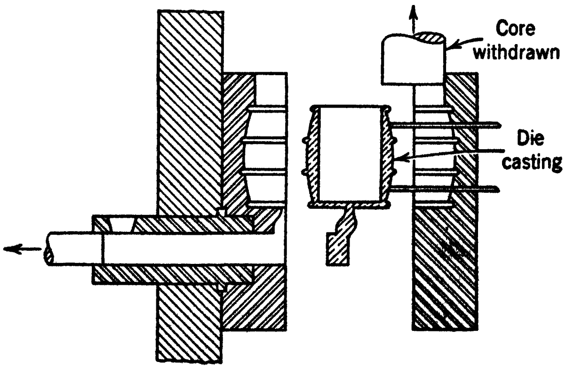
Dies for low-melting alloys, such as zinc, tin, and lead, are often made of carbon steel or low-alloy chrome steel without hardening, but the high-melting alloys, including aluminum and copper, must have dies of special corrosive-resistant steel in



A. Metal poured into sleeve



B. Plunger forces metal into die



C. Die separated and casting ejected

FIG. 7. Cold-chamber die casting.

The development of this process dates back to the nineteenth century in the field of dentistry, but it was applied to the casting industry only in recent years because of requirements in engineering designs of intricate contours on high-temperature and corrosive-resistant castings which were often too difficult to machine to the desired dimensional limits. With this new development, engineers have greater freedom in designing more complicated shapes such as are desired in turbine blades for maximum efficiency. Currently, the largest castings produced by this method on a commercial scale weigh up to 5 lb, but larger castings are in the offing. Castings as small as 0.002 lb and edges as thin as 0.012 in. are made by this process. Many castings are produced with tolerances of ±0.003 in.

FIG. 8*A*. This operator is mounting two wax patterns on a main gate with wax runners. (Courtesy of Haynes Stellite Co., Kokomo, Ind.)

The process begins with the preparation of one or more *master patterns* which are replicas of the desired casting except that they are oversize in sufficient amount to compensate for dimensional changes due to the effect of temperature on wax, metal, and mold material. A soft metal die is then cast from the master pattern. The die is finished off and assembled in a machine, similar to a die-casting machine, in which wax patterns are cast. A wax sprue and gates are sealed to the pattern, as illustrated in Fig. 8*A*, and the pouring mouth of the sprue is sealed to a steel base plate. After the assembly is dipped in a fine silica solution, a second application of coarser silica is "stuccoed" over the pattern as illustrated in Fig. 8*B*. The fine dip makes a smooth surface next to the pattern, and the stuccoed exterior surface aids in uniting the fine silica coating to the coarser investment of the mold.

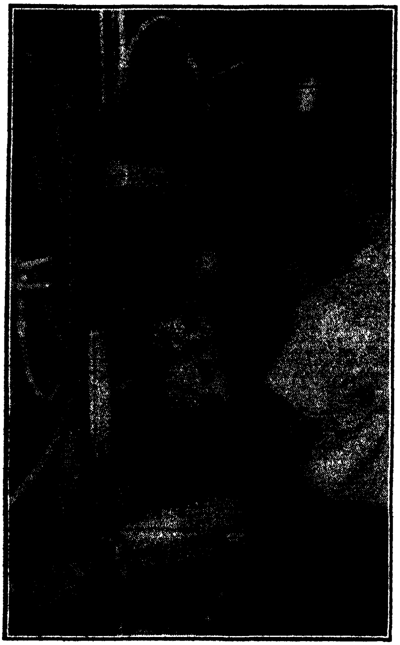


FIG. 8*B*. Somewhat coarser grains are then screened or "stuccoed" to the dip coating. (Courtesy of Haynes Stellite Co., Kokomo, Ind.)

A waxed paper flask is then set over the assembly and sealed to the base plate. The investment mixture is poured in, and the mold is vibrated for an hour to pack the mold and to remove entrapped air. When the investment hardens, the base plate is removed from the bottom of the mold, exposing the pouring mouth. A portion of the top of the mold containing undesirable fines is cut off to remove excess bulk. The mold, with pouring mouth down, is placed in a continuous oven where the temperature rises progressively to 1500° F. As the mold moves through the furnace, the wax pouring mouth, gate, and pattern melt and flow out of the mold. Any residue remaining in the mold will burn out when the mold reaches the higher temperature zone.

The exact amount of metal required for each mold is melted in a small electric melting furnace. The hot mold is then clamped over the furnace as shown in Fig. 8*C*, and the assembly is inverted about a pair of trunnions so that the molten metal in the furnace flows down into the mold. An air valve leading to the furnace is opened to increase pouring pressure. After a cooling period of about 4 hr, the casting assembly is knocked from the mold by a pneumatic hammer, as illustrated in Fig. 8*D*, and the casting is freed of investment.

This process was first developed on a mass-production basis in the production of turbo-supercharger buckets and later in the production of turbine blades, turning vanes, and axial-flow compressor blades for jet-propulsion engines. Among other applications are fuel parts for aviation carburetors, zipper slides, claws in movie-camera projectors, pawls for rock drills, and other parts for various machines which are difficult to finish, fabricate, form, or forge because of the intricacy of design or type of metal employed.

FIG. 8*C*. When the metal reaches the correct temperature, as checked by means of an optical pyrometer to insure proper grain size and other desired metallurgical properties, the hot, baked mold is inverted and placed directly over the pouring spout of the furnace. After the mold is clamped on the furnace, the metal is poured by inverting the entire furnace, and air pressure is turned on. The air pressure makes possible the casting of thin edges and also makes the metal sound and dense. (Courtesy of Haynes Stellite Co., Kokomo, Ind.)

Plaster Molds. The process of plaster casting serves to best advantage in the casting of bronze alloys. Other metals whose pouring temperatures are below 2300° F may be cast by this process, especially those with less tendency toward grain growth on slow cooling. The main advantage claimed for this process is that it promotes pouring uniformity with a minimum of turbulence at a lower metal temperature. Since the mold is dried and is made of a low-heat-conducting material, metal can be poured in at a lower superheat without danger of premature solidification; when the metal is poured at a slower rate, entrapped gases are more likely to permeate out through the mold. Dimensional tolerances and surface smoothness are claimed to be equal to those of permanent mold castings, if not better. The sizes of castings made by this process range in the same classification as those made on the bench in green sand molding.

FIG. 8*D*. The mold is allowed to cool slowly, and after about 4 hr the entire casting assembly is knocked from the mold by a pneumatic hammer. The excess investment material is removed, and the cast assembly is carried by conveyors for removal of gates and risers. (Courtesy of Haynes Stellite Co., Kokomo, Ind.)

Mold material for plaster molding consists of plaster of Paris to which various ingredients such as talc, asbestos fiber, silica flour, silica sand, oxide of aluminum, and silicon carbide may be added to obtained desired mold properties.

The mold is made by placing a form over the pattern plate containing the pattern and pouring the plaster into the form. When the plaster sets, the pattern is removed from the mold and processed, first by steaming and then by heating to dehydrate the mold. The parts of the mold are then assembled and poured.

Centrifugal Casting. The casting process of pouring molten metal into a rotating mold makes it possible for the foundryman to produce castings uniform in quality and free of defects. As metal is poured into the center of the mold at the axis of rotation, it is whirled out to the peripheral extremities by centrifugal force, leaving the impurities in the center. At constant speed, the centrifugal force in a mold is directly proportional to mass. The degree of separation between impurities and sound metal depends primarily on the difference in densities of slag and metal. A liberal finishing allowance is made on the inside diameter of the casting to permit the removal of the displaced impurities. Because centrifugal castings can be cast nearer to finished dimensions with equipment less expensive than is neces-

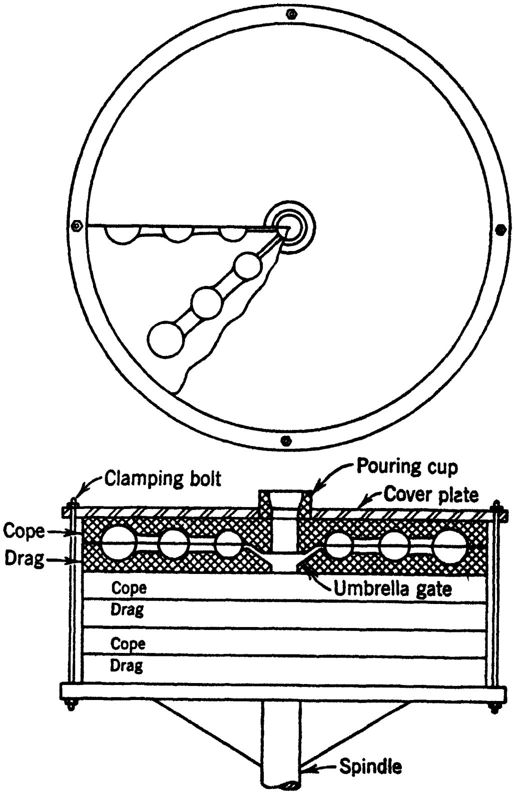


FIG. 9. Centrifuging process showing a dry sand stack of three molds. The above arrangement is known as Christmas tree formation.

sary in forging, considerable competition has developed between the two processes. Improved properties in forged and rolled steels are found in the direction of elongation, but in centrifugal castings equal strength is found in all directions. As an example, pressure cylinders made by the centrifugal casting process have less tendency to burst than forgings. Many castings are centrifuged merely to avoid the use of large gates and feeders needed in static casting.

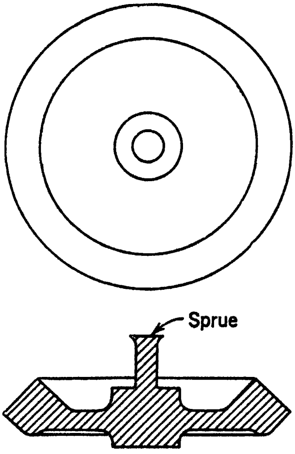


FIG. 10. Bevel gear blank produced by semicentrifugal casting process.

Centrifugal castings are classified into three different types: *centrifuging, semicentrifugal,* and *true centrifugal.*

In *centrifuging,* as seen in Fig. 9, the mold cavities of the casting are located off the center of rotation. A sprue extends down through the center, and runners, or in-gates, connect the mold cavity with the central gate. Flow of metal to the surrounding cavities depends on centrifugal action. Such cluster formations are sometimes referred to as *Christmas tree formations,* and the gate arrangement is referred to as an *umbrella gate.* A cluster of more than 150 small castings may be contained in one mold.

Larger castings which are symmetrical about their own axis (such as spoked or disked wheels, gears, and propellers) are *semicentrifuged.* The gate enters the center, forming a solid hub as illustrated in Fig. 10. With a spoked wheel, metal is forced to the rim through the spoke cavities.

In the *true centrifugal* process, the interior shape is formed by centrifugal force without a core. Plain cylindrical castings such as bushings, cast-iron water pipes, and barrels of guns are made by the true centrifugal process. The size of the cylindrical hole through the center depends on the quantity of metal poured into the rotating mold. Long cylindrical castings such as cast-iron pipes and gun barrels are centrifuged along a horizontal axis. Short lengths not exceeding four times the finished bore size are often cast inclined to the horizontal, as shown in Fig. 11; and lengths where the height does not exceed the diameter are cast vertically. Centrifugal force will cause the metal to climb up the vertical walls of the mold and to solidify in that position, forming a parabolic curved interior. The slope on the interior amounts to about ⅛ to ¼ in. per foot, depending on the height of the mold and the speed of the machine. The speed of the machine is calculated to obtain a radial force on the inside of the casting from 75 to 100 times the force of gravity.

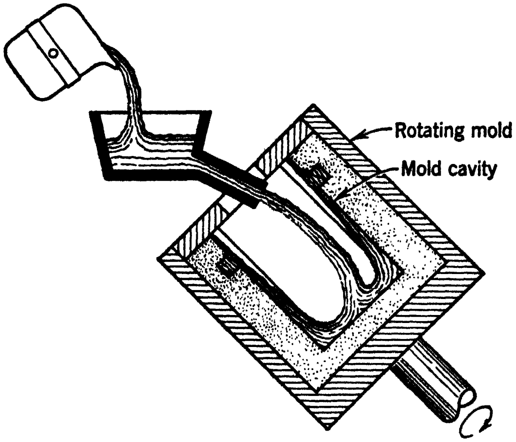


FIG. 11. True centrifugal casting process.

The mold material in centrifugal casting may be green sand, dry sand, carbon, or metal. The size of castings produced is limited by the size of the mold that can be successfully spun at the required speed to obtain required results. Cluster castings are often made in molds of dry sand core slabs which are stacked one on top of another. Slabs containing one half of a mold cavity are assembled in pairs and then stacked. Green sand, skin-dried, and dry sand molds are all spun successfully on centrifugal machines. The development of spinning green sand stacked molds without a flask has proved economical for small centrifugal and semicentrifugal work. A special sand, bonded with halloysite (a siliceous material with a very high fusion point), has been developed for this purpose. On air drying, the mold is sufficiently strong to withstand centrifugal pressure. True centrifugal molds are made of metal or carbon. Compositions of metal molds vary all the way from gray iron to alloy steel, depending on the various factors that tend to break down the die. Graphite molds are economical in that they are easy to machine. Some alloys that tend to wet the mold surface are best cast in graphite molds.

Shell Molding. In this process the mold consists of a shell ¼ in. to ½ in. thick. Shells are made by fastening a heated metal match plate (pattern side down) to the top of a container of resin bonded sand. The assembly is inverted, and the sand next to the hot surface forms the shell. It is then turned right side up, the plate is placed in an oven to completely harden the shell, and the shell is ejected. The mold is assembled, placed in a box, and backed up with metal shot for support when poured. Advantages of shell molding are close tolerances, smooth surfaces, thin sections, and a reduction in materials handling problems.

PROBLEMS

1. Give the names of the various parts of a mold, and define the terms.
2. What provisions are made to prevent mold damage when the pattern is removed from the mold?
3. Make a freehand sketch of the casting and attached gate of the casting produced by the mold in Fig. 1.
4. List the advantages obtained with skin-dried and dry sand molds.
5. How does a skin-dried mold differ from a dry sand mold?
6. How are dry sand cores held in position when placed in a mold?
7. Describe the customary procedure in forming the mold cavity of a loam mold.
8. How is the sand packed around a pattern in a pit mold?
9. What methods are used in controlling the rate of solidification in a permanent mold?
10. Why should the cooling rate be controlled?
11. List the advantages in the two basic types of die-casting machines.
12. List the advantages of sand casting over die casting.
13. Why are some castings preferably made by the lost wax method instead of by die casting?
14. Are ferrous metals cast by the plaster mold method?
15. Why are some castings produced by the centrifugal casting method instead of any one of the other processes?

2

Green Sand Molding

In practically all cases where castings are produced in large numbers, the molds are made on molding machines. Nevertheless, it is important to understand the fundamentals of molding in order to design castings, patterns, core boxes, fixtures, and jigs so that they may be adapted conveniently to molding-machine production. This chapter deals with the basic and fundamental molding processes referred to commercially as *jobbing shop molding*.. No special equipment is needed other than that which is found in all foundries. With this background, the production engineer considers each molding step and develops his production method on the basis of production cost with respect to the cost and availability of equipment.

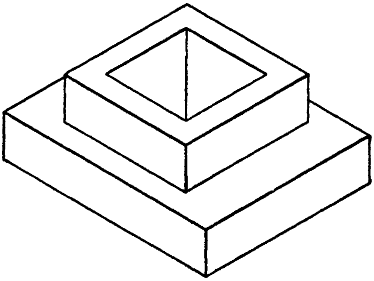


FIG. 1. Flat back pattern.

Bench Mold, One-Piece Pattern, Straight Parting. Castings that are produced on a straight parting in the mold are made more economically than any other type of design. The reason is obvious when one understands the molding process. The flat back pattern, Fig. 1, is so named because the entire pattern is molded in the drag, leaving no impression in the cope. The rectangular hole in the casting is formed by a green sand core extending through the center of the mold cavity. The mold is made in a customary flask consisting of two parts, the cope and the drag, as illustrated in Fig. 2.

The molding process illustrated in Fig. 3 begins with placement of the drag half of the flask on a *molding board* in an inverted position with the joint side resting on the board. A *molding board* for a flat back pattern is a smooth, rectangular, wood platform supported by two cleats. The dimensions of the board are equal to the outside dimensions of the flask. The pattern is then placed on the board in a desirable position inside the flask. By means of a foundry riddle (foundry term for screen or sieve), enough sand is sifted into the flask to cover the pattern to a depth of about ¼ in. The flask is then filled to the top with *heap sand* (sand from the heap, not sifted) which is *peen rammed* firmly around the pattern and along the perimeter of the flask. The function of the peen or wedge-shaped end of a bench rammer is to pack the sand uniformly throughout the depth of the flask. The *butt* or flat end of the rammer is used in the final operation to pack down the loose surface after peening. After more sand is added and the mold is butt rammed, excess sand is *struck off* (scraped off) with a straightedge called a *strike-off*. The mold is then *vented* by being perforated with a vent wire to a depth just short of striking the pattern. A thin layer of sand is scattered over the struck-off surface, and a *bottom board* is placed over the loose sand. A bottom board is similar to a

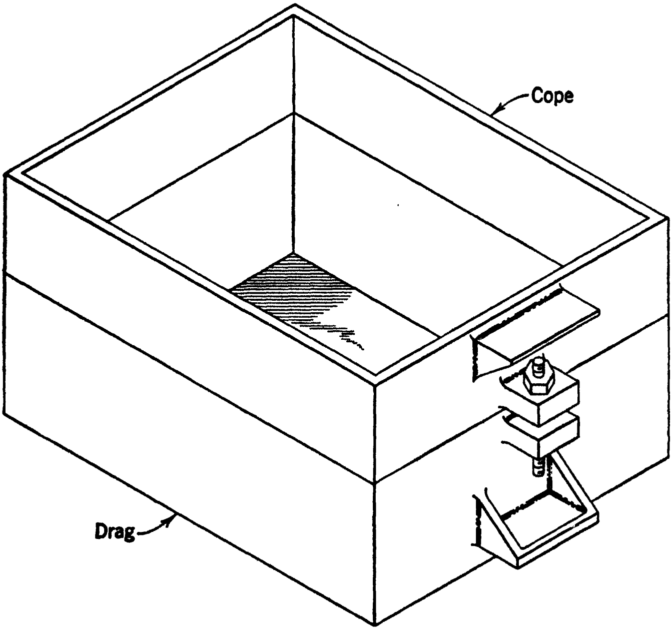


FIG. 2. Flask for a sand mold.

molding board but not necessarily so smooth. After the board is pressed down firmly and shifted from side to side, thus rubbing down the loose sand, it is raised, and, if necessary, more sand is scattered over those areas not appearing to bear against the board.

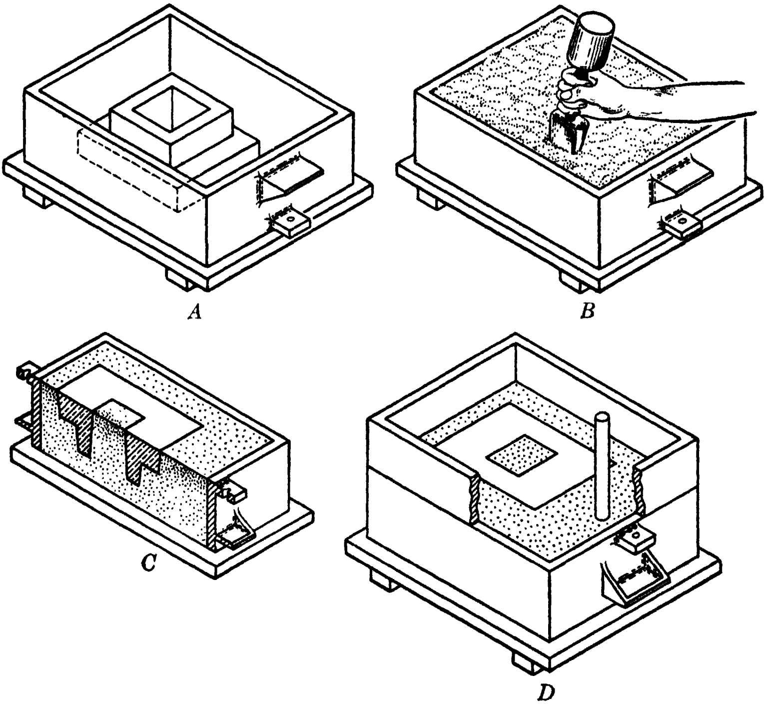
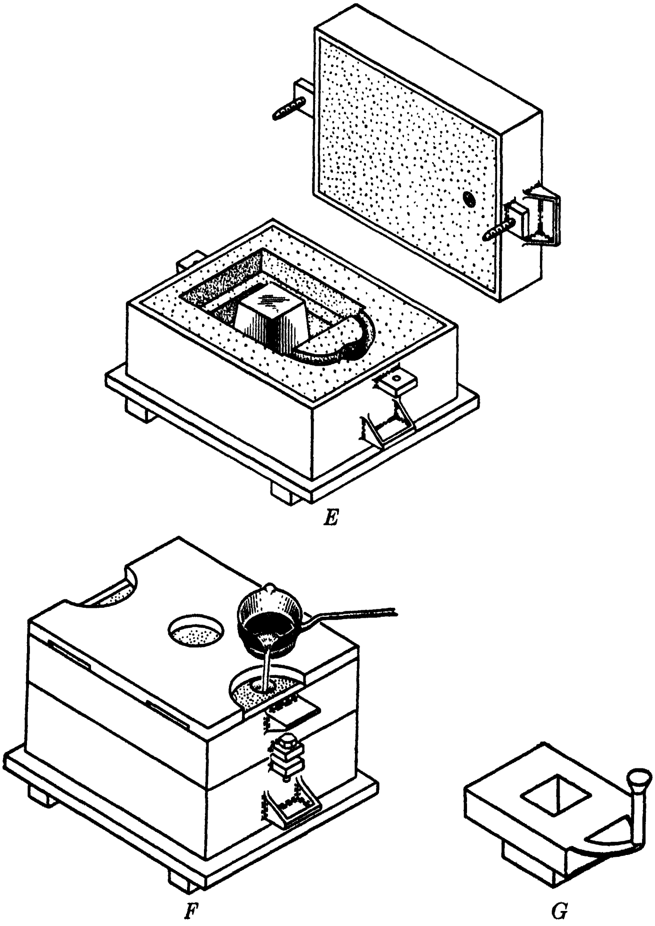


FIG. 3. *A*. Pattern and flask in position to be molded. *B*. Drag being peen rammed. *C*. Sectional view of drag after it is rolled over. *D*. Sprue is placed in position, and cope is about to be rammed up.

The whole assembly of drag with molding and bottom boards is rolled over, and the molding board is removed. The flat face of the pattern which was next to the molding board now rests in the parting plane of the mold. The parting plane is made smooth with a foundry *trowel*, and *parting sand* (fine-grained dry silica sand) is sprinkled over the sand surface to prevent the cope from sticking to the drag when the mold halves are separated. Various water-resistant powdered materials called *parting compounds* are also available for this purpose, but they are customarily used on the pattern only because parting sand



E

F

G

FIG. 3. *E*. The cope is drawn, the pattern is swabbed, rapped, and drawn, and the gate is cut. *F*. After the mold is closed, a weight is placed on top, and the mold is poured. *G*. When the casting solidifies, the mold is destroyed and the casting is removed.

is just as effective on sand surfaces and less expensive. Parting sand should not be sprinkled on the pattern because it is too coarse and does not produce so smooth a mold surface and also because it does not adhere to sloping pattern surfaces. The cope half of the flask is placed in position over the drag, and the *sprue pin* is located near the pattern where the gate will be constructed. A sprue pin is usually a slightly tapered round wood pin, used to form a hole through the cope for the purpose of admitting molten metal to the mold cavity.

The same procedure of sifting sand, filling the flask with heap sand, peen ramming, butt ramming, striking off, and venting is followed on the cope as was described for the drag. After the mold is vented, the sprue pin is removed and the top of the sprue hole is enlarged to the shape of a funnel to make pouring easier. The cope is then lifted off and set on its side near the drag. The lower edge of the sprue hole at the parting plane on the bottom side of the cope is then chamfered (the sharp edge of the sand is cut away) to prevent erosion or washing of the sand when pouring starts. Loose particles on the parting surface are blown off with hand bellows or brushed off with a soft brush. The pattern is then *swabbed* (swabbing is the operation of wetting the sand edges adjacent to the pattern at the parting plane). A swab is made of hemp, bound together at one end to make a handle and tapered off to a point at the other end. When the handle of the water-soaked swab is squeezed, a thin stream of water flows from the pointed end. The purpose of swabbing is to lessen the chances that edges of sand next to the pattern will break away during removal of the pattern. The pattern is then *rapped* to loosen it from the surrounding sand. This is often done by driving a sharply pointed *draw spike* into the center of the wood pattern and tapping the spike with a *rapping bar,* a bar heavy enough to jar the pattern and loosen it in the mold. The pattern is then *drawn* vertically out of the mold. Draft or taper on the exterior vertical sides of the pattern is such that the outside dimensions of the cavity at the parting plane are slightly greater than those at the bottom of the cavity. Conversely, the dimensions of a hole in the pattern are slightly smaller at the parting plane than at the bottom of the mold cavity. In other words, the mold cavity is larger at the parting plane; the green sand core is smaller at the parting plane.

The gate connecting the sprue to the mold cavity is cut with a *gate cutter,* a piece of sheet metal about 3 in. square, bent to the desired U shape. The mold cavity is then dusted with graphite or talc to reduce the tendency of molten metal to fuse with the sand of the mold. After the mold is *closed,* a weight is placed on top to prevent the cope from being raised by hydraulic pressure due to the column of molten metal in the sprue. The minimum weight needed to prevent a run-out is computed by subtracting the weight of the cope from the buoyant force on the cope. The buoyant force on the cope is the product of the horizontal area of the mold cavity in the cope, the head of metal above this area, and the density of the metal. It is common practice to use weights in excess of the minimum in order to overcome unforeseen circumstances. For example, if the metal is of below-normal pouring temperature, it must be poured rapidly. The strain on the mold resulting from added momentum may cause the mold to run out.

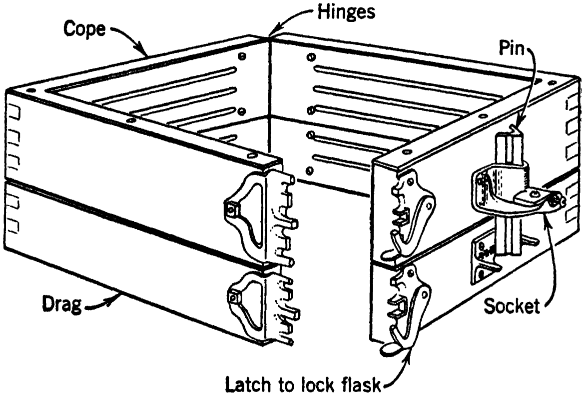


FIG. 4. Snap flask.

The mold is poured; after the metal solidifies and cools sufficiently, the mold is *shaken out* and the casting is removed. The gate is either broken off the casting with a hammer (in the case of gray iron) or sawed off with a metal-cutting saw (in the case of aluminum or brass). The casting is then cleaned, ground, and inspected for defects.

Bench Mold, Two-Piece Pattern, Straight Parting, Snap Flask. When the design of a casting is such that the parting plane passes through the pattern, it is possible to split the pattern so that the drag half may be molded in a manner similar to that of a flat back. In spite of the fact that half the mold cavity appears in the cope, the mold parting may remain flat.

A snap flask, Fig. 4, is specially designed with hinges on one corner and fasteners on the opposite corner to lock the flask. When the mold is completed and closed, the fasteners are unlocked and the flask is hinged open to remove it from the mold.

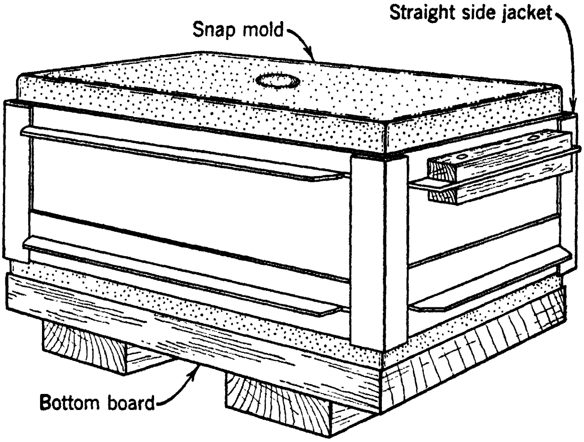


FIG. 5. Slip jacket on snap mold.

To prevent a *snap mold* from swelling or bursting when it is poured, a wood or metal *slip jacket*, Fig. 5, is slipped over the mold. A weight is usually necessary on the top. Snap flasks are obtainable in square, rectangular, or round shapes, and in conventional sizes suitable for bench molding.

If the casting to be molded has a hole that is too small to be made with a green sand core, as with the pulley of Fig. 6, a dry sand core may be used. The tapered projections at both ends of the hub of the pattern in Fig. 7 are core prints which locate and hold the core in position.

In molding a typical split pattern such as the pulley, the pattern half with *dowel-pin holes* is placed on the molding board and molded in the same manner as described for the flat back pattern. After the drag is rolled over, the pattern half with *dowel pins* is placed in position on the other half of the pattern already embedded in the drag, as illustrated in Fig. 8*C*. The cope half of the flask is then set in place, the sprue pin is located on top of the hub of the pattern to obtain a uniform distribution of metal, and molding operations are completed as before. When the cope is lifted off, each half of the mold contains one half of the pattern, and the operations of swabbing, rapping, and pattern draw are performed on both the cope and drag. No gate is necessary because the sprue enters directly into the mold cavity. The thin section of sand between the sprue and core print is removed to prevent its being washed down into the mold cavity by molten metal. A hole is pierced with a vent wire through the base of the core print down to the bottom board, and a cylindrical dry sand core of the desired diameter is set vertically in the drag. The purpose of the taper at the ends of the core is to guide the core into the print without damaging the mold. When the mold is poured, the gases formed by the burning ingredients of the core pass through the vent in the center of the core and down through the vent in the drag. Figure 8 illustrates the principal steps in the production of the mold.

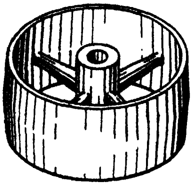


FIG. 6. Pulley.

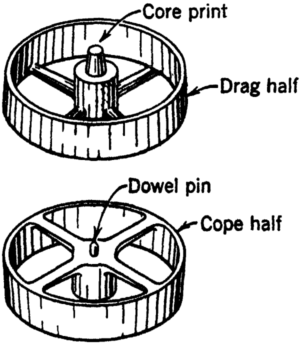


FIG. 7. Split pattern for pulley.

Bench Mold, Irregular Parting, Irregular Draw, Tapered Flask. The tapered flask, illustrated in Fig 9, is superior to the snap flask because of its rigidity and also because of the ease in shifting tapered slip jackets. As soon as a thin shell forms around the mold cavity after the mold is poured, the slip jacket illustrated in Fig. 10 may be conveniently transferred to another mold without disturbing the partially solidified casting. The bottom of the cope of the tapered flask has a metal frame which is split across one diagonal so that it may be shifted inward to support the sand when the cope is lifted. After the mold is completed and closed, the frame is shifted outward,

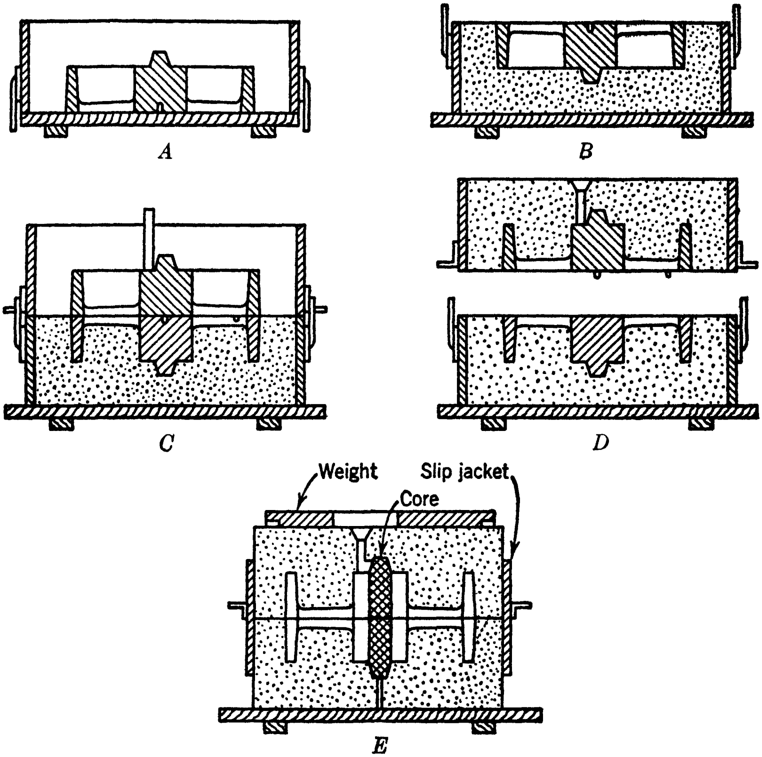


FIG. 8. *A*. Pattern and flask about to be molded. *B*. Drag rolled over. *C*. Cope half of pattern and flask in position. *D*. Cope being drawn. *E*. Completed mold.

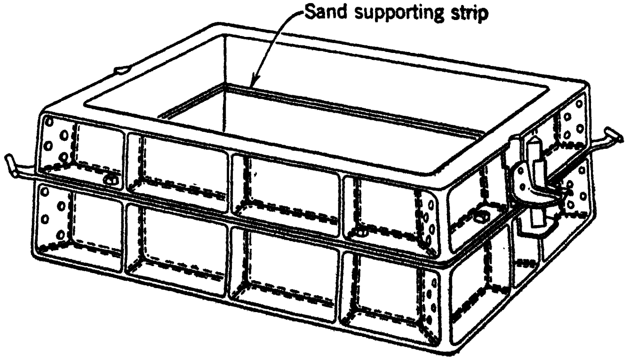


FIG. 9. Tapered flask.

leaving the cope resting on the drag unobstructed. A slight jerk upward easily separates the flask from the mold.

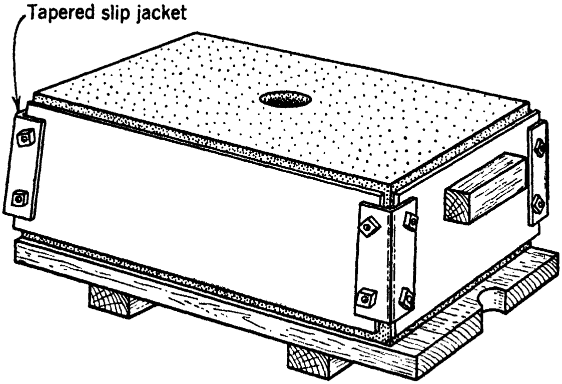


FIG. 10. Tapered mold with slip jacket.

When the parting plane of a mold coincides with the irregular contour of a pattern, production costs generally rise because of the time-consuming task of cutting the mold parting. A further

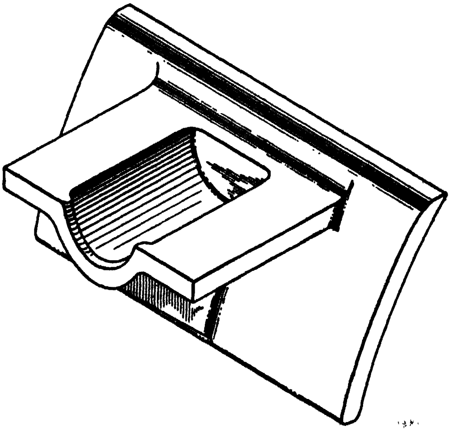


FIG. 11. Pattern of boiler bracket.

handicap may arise from the fact that the pattern may have to be drawn diagonally or along the path of an arc. Both conditions of irregular parting and irregular draw exist in the molding of the boiler bracket illustrated in Fig. 11.

The drag of the tapered flask is set on the molding board, and the pattern is located inside the flask. One side of the pattern is supported on a wood strip, as shown in Fig. 12*A*, to make the flat face of the pattern parallel to the molding board.

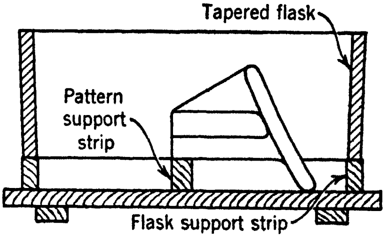


FIG. 12*A*. Pattern in position to be molded.

The flask is raised by placing wood strips under it so that the edge of the flask and the flat face of the pattern lie in the same plane. This allows part of the pattern to project upward in the cope when it is made, so that the irregular parting does not have to extend down so far from the joint between the halves of the flask. After sand is riddled in, a small amount of heap sand is added and tucked with fingers in the pockets formed by the center rib. *Tucking-in,* as it is customarily called, is done with fingers and hand in areas that cannot be adequately rammed.

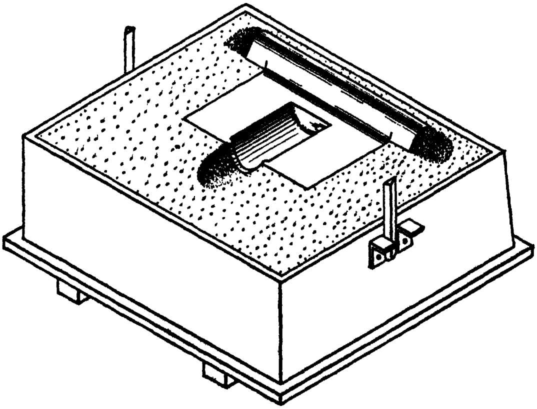


FIG. 12*B*. Pattern in drag, illustrating irregular parting plane.

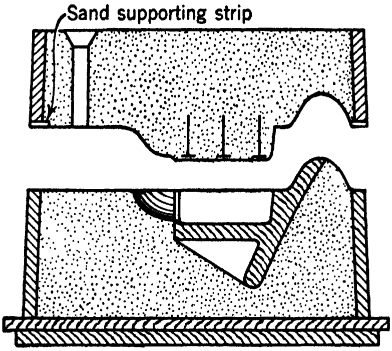


Fig. 12*C*. Cope is separated from drag.

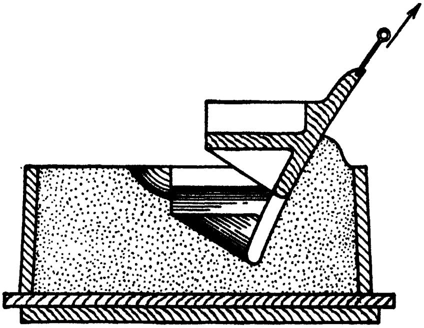


Fig. 12*D*. Pattern is drawn along an irregular path.

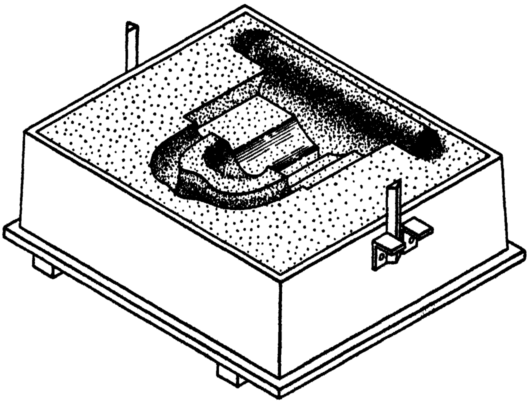


Fig. 12*E*. Gated mold cavity of drag.

When the drag is rolled over, the wood strips are removed and the sand surface is cut down to the parting plane of the pattern as shown in Fig. 12*B*. The cope and sprue are set in position, and about ¼ in. of sand is riddled over the pattern. Two or three nails are embedded, head down as shown in Fig. 12*C*, into the green core that forms the bearing of the casting. Wood sticks, called soldiers, and nails, used for reinforcing sand molds, are usually dipped in water, flour paste, or clay wash to make the sand adhere to them. The remainder of the molding procedure is performed in a conventional manner, except that the pattern must be drawn out of the drag along the path of an arc whose radius is equal to the curved surface of the pattern. Figure 12 presents the various steps in the production of the mold.

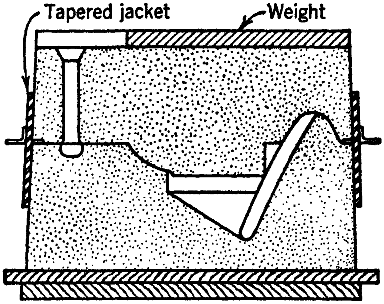


FIG. 12*F*. Mold is ready to be poured.

Floor Molds, Pouring Basin, Feeder. If the mold is over 12 in. wide by 18 in. long or if it has more than the average depth, in other words, if the amount of sand makes the mold too cumbersome to be manipulated on the bench, the molding operation is moved to the *molding floor*. The operation is then called *floor molding*. Operations may be more conveniently performed on the floor, and the mold may be handled by a number of men or by a crane.

Flasks for floor molds may be made of wood, cast iron, cast aluminum, or either rolled or cast steel. Because of the greater size of the flask, the cope must have crossbars to support or reinforce the sand. Crossbars are placed about 6 in. apart, and, when designed for a specific job, the contour of the bars at the parting plane must conform to the contour of the pattern, extending to within ¼ or ½ in. of the pattern. In a general-purpose flask such as shown in Figs. 13*A* and 13*B*, the bars are straight; if additional support is necessary, *gaggers* or L-shaped rods are placed in the mold with their vertical legs resting against the bars. The *toes* of the gaggers should have about ¼ in. of sand between them and the pattern. They should be set in positions where they will do the most good, near pattern edges and in projecting sand sections which would be most likely to drop if not supported. When large quantities of a casting are to be produced, it may be desirable to construct special flasks to contain the minimum amount of sand, such as illustrated in Figs. 14*A* and 14*B*, and with specially designed bars to avoid gaggers.

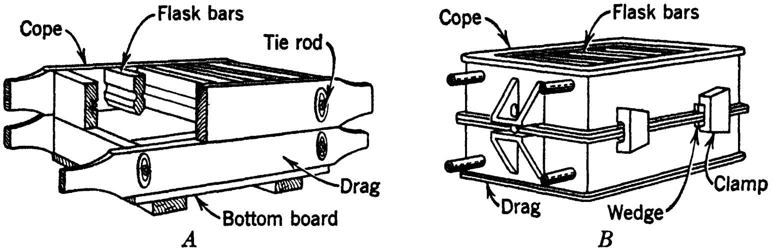


FIG. 13. *A*. All-purpose wood flask. *B*. All-purpose steel flask.

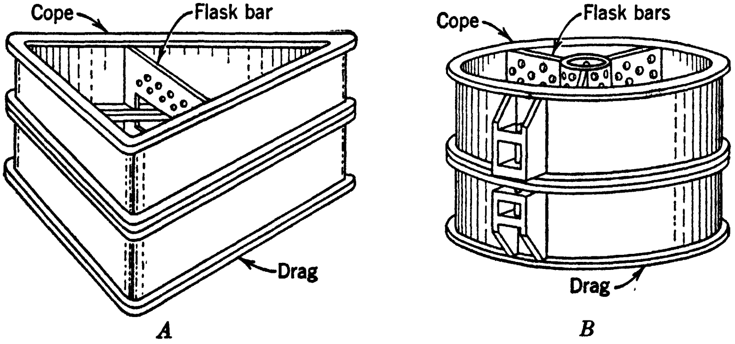
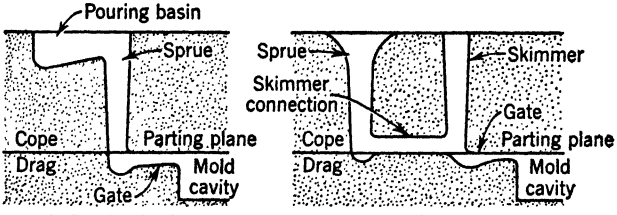


FIG. 14. *A*. Special-purpose steel flask. *B*. Special-purpose steel flask.

As the size of the mold and casting increases, the problem of safely and effectively filling the mold with clean metal without damage to the mold becomes more difficult. A *pouring basin,* illustrated in Fig. 15*A*, is a cavity on top of the mold, usually arranged with the sprue hole leading from one end of the basin and at a slight elevation above the bottom of the basin. It provides a sprue entrance whose purpose is to separate slag impurities from molten metal. Such impurities, being lighter than metal, float on top. In pouring, the metal is poured fast enough to keep the basin full; the impurities float on top of the pool, and the clean metal flows from near the bottom of the pool into the sprue.

A *skim gate,* shown in Fig. 15*B,* accomplishes similar results in keeping lighter particles of impurities out of the mold, but in a slightly different way. Two sprue holes are made side by side; they are connected by a rather large channel cut on the bottom side of the cope. The gate leading into the mold cavity is cut in the parting plane of the drag and is considerably smaller in section than the connection between the *sprue* and *skimmer.* The metal is poured into the sprue rapidly enough to *choke* the gate; therefore the metal rises into the skimmer. Since the connection between the sprue and skimmer is at a higher level than the gate, the slowly traveling stream of metal in this skimmer connection gives the slag and other light particles a chance to rise into the skimmer.



A. Pouring basin *B.* Skim gate

FIG. 15. Methods of separating lighter impurities from molten metal.

A *feeder,* illustrated in Fig. 16*D,* serves the function of supplying liquid metal to the mold cavity after pouring has ceased, to compensate for the reduction in volume as the metal changes to the solid state. Like most liquids, a given volume of molten metal expands when heated and contracts when cooled. Unlike other liquids, such as water, most metals continue to shrink through the solidification range; in fact, a large volumetric reduction may take place through a small temperature range. As metal cools in a mold cavity, a thin shell or skin is formed next to the surface of the cavity. This shell increases in thickness until the last portion near the center solidifies. *Volumetric shrinkage* leaves a void, or *shrinkage cavity,* equal in amount to the volumetric reduction, unless additional metal is supplied by feeders. The feeder must be of sufficient size so that its core will remain molten until the necessary metal addition to the casting takes place; in other words, the feeder should be the last thing to solidify in the mold. Castings made with metals of high-shrinkage characteristics often contain feeders that weigh more than the casting itself. Feeders may lead directly into the mold cavity, or they may be connected to the cavity with a feeder gate.

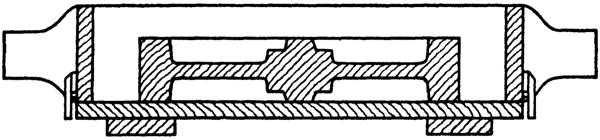


FIG. 16*A*. Pattern and flask in molding position.

Because of the complexity of some designs, it may not be convenient to attach a feeder to the largest section of the casting, and consequently the feeder is ineffective in supplying molten metal to the isolated heavy section. In order to cause the heavy section to solidify more rapidly and thus provide a channel of molten metal through the connecting members to compensate for volumetric reduction, metal *chills* may be embedded in the area of the large section. In other words, a part or all of the

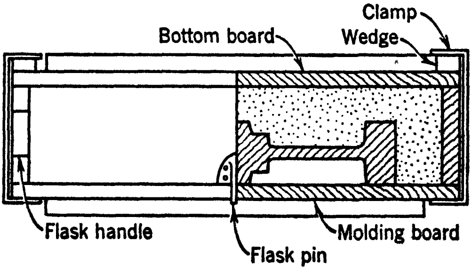


FIG. 16*B*. Side view of sectioned mold, illustrating drag in clamped position for rolling-over.

wall of this portion of the mold cavity may be of metal. The use of chills will be discussed in detail in Chapter 14.

The flywheel pattern resting on the molding board in Fig. 16*A* is a one-piece pattern with an irregular parting, but it should be observed that the irregular portion of the pattern is surrounded by a flat-faced rim which conveniently prevents the sand from entering the center of the pattern when the drag is molded. As shown by the flywheel pattern, not all irregular-shaped designs are difficult to mold.

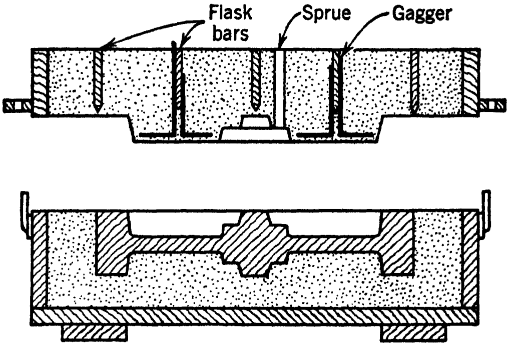


FIG. 16*C*. Cope is drawn.

In the molding process illustrated in Fig. 16, the drag and pattern are placed on the molding board, facing sand is sifted over the pattern to a depth of about 1 in., the flask is filled with heap sand to a depth of about 5 in., and the sand is peen rammed between the pattern and flask. The space above the pattern is not peened to avoid excess mold density which would prevent the escape of gases when the mold is poured. The mold is rammed with a *floor rammer* which consists of a ¾-in. pipe, about 4 ft long, with a metal peen and butt fastened to the ends. After peening, the flask is filled heaping full, stepped down, butt rammed, struck off, and vented. A bottom board is then laid on top over a ¼-in. cushion of loosely spread sand and shifted back and forth to produce good bearing. Clamps are fitted across the two boards and secured by wedges driven under the clamps. After the drag assembly is rolled over, the clamps and molding board are removed and the parting plane is smoothed down with a trowel. Before the cope is assembled to the drag, the bars are sprinkled with clay wash or merely wet down with water, and sand is riddled over the wetted area to absorb excess moisture and to prevent dripping on the pattern when the cope is set in position. The cope is then assembled to the drag, sprue pins for feeders and sprue are set in place, a ¼-in. layer of facing is riddled over the parting plane, and gaggers are set in position to reinforce the sand projection formed between the rim and hub of the pattern. Note that the shanks of the gaggers are supported by the flask bars and that the projecting toes of the gaggers extend out into areas where reinforcement is needed. More sand is then sifted over the gaggers, and the loosely sifted sand is tucked firmly under the bars with fingers and hand to prevent soft spots under the bars. The flask is then filled with sand and peen rammed (with care not to strike the gaggers), and, after the cope is butt rammed, sprue pins are removed and the cope is lifted off. The pattern is swabbed, rapped, and drawn. A fillet is made at the base of the sprue and feeders, gates are cut to the feeders, the core print in the drag is vented, and the core is set in.

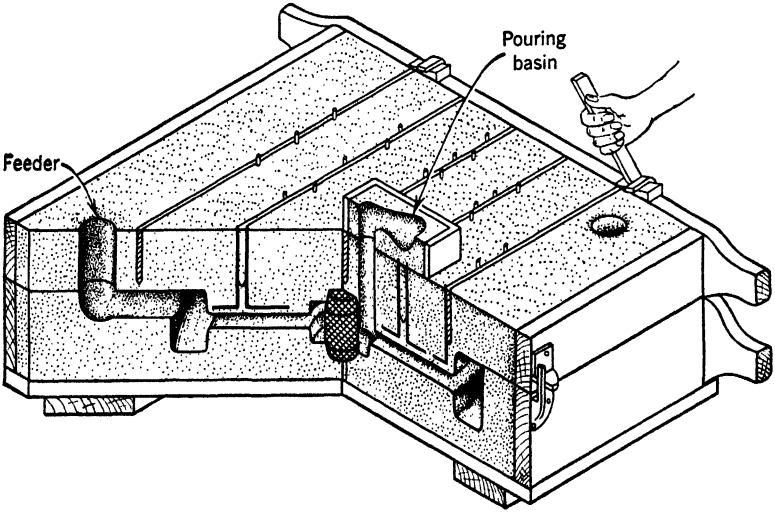


FIG. 16*D*. Completed mold of flywheel in section.

Before the mold is closed, the cavity is faced with a refractory material such as plumbago, soapstone, or talc. *Facing* may be dusted on with a small bag containing the material, or it may be brushed on with a soft camel's hair brush. To obtain a smoother surface, it may be rubbed on with fingers. When brushing or rubbing with fingers is likely to damage delicate details of the mold, the material may be dusted on and pressed into the mold by replacing the pattern, a practice referred to as *printing back.* Excess refractory may be blown out of the mold cavity before the mold is closed.

A pouring basin may be formed in the cope before the cope is lifted for pattern removal, but, if flask bars interfere with its construction, the pouring basin may be constructed after the mold is closed in a rectangular frame set on top of the cope, as shown in Fig. 16*D*. This is done by plugging up the sprue hole with a sprue pin, setting the frame of the pouring basin in position, packing sand in the frame and around the sprue pin, and carving out the basin to desired shape, with care that no sand drops down in the sprue when the pin is removed. All surfaces over which metal will flow must be pressed smooth to prevent erosion.

The mold is then *clamped.* The function of the clamps is to squeeze the mold together sufficiently to prevent metal from leaking out at the parting plane. A *wedge* is placed under the clamp (the clamps extend from the bottom board to the top of the cope), and the clamp is pried up the wedge with a *clamping iron.* Care must be taken not to crush the mold with too much pressure.

Three-Part Floor Mold, Down Gate, Strainer Cup. Many castings are of such form as to require more than one parting. Common examples are grooved wheels and flanged castings such as the machine base of Fig. 17. The part of the mold containing that portion of the pattern between the flanges is called a *cheek.* The pattern of the machine base, Fig. 18, consists of three parts. The core print and rectangular top are called *loose pattern parts* and are fitted on the pattern with *dowels.* To avoid an irregular parting, the height of the *cheek flask,* Fig. 19, should be equal to the height of the *cheek pattern.* Bars are sometimes constructed in the cheek to reinforce the sand. If the height of the cheek is excessive, it may be necessary to split the cheek into more sections, adding an additional parting for each split. Occasionally, gaggers placed against the sides of the flask are sufficient, but when the cheek is lifted off it should not be set on end as is customarily done with the cope, lest it collapse.

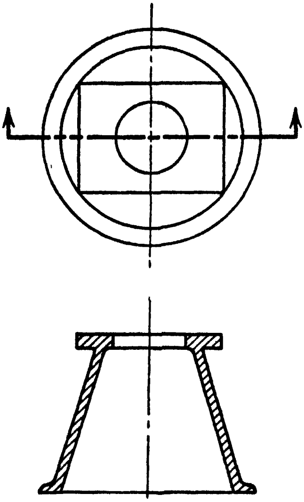


FIG. 17. Machine base casting.

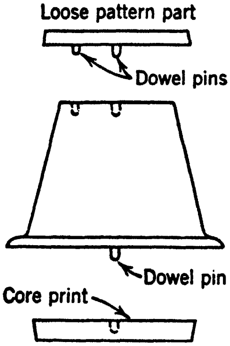


FIG. 18. Pattern for machine base casting.

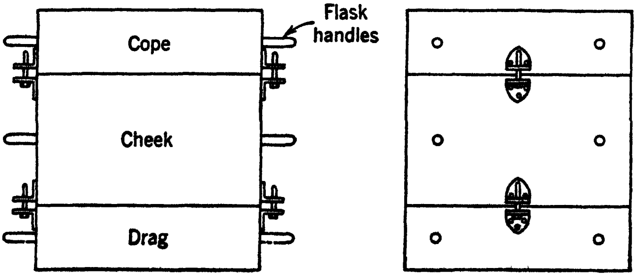


FIG. 19. Three-part flask.

Molds should be gated to prevent turbulence of inflowing metal. A three-part mold lends itself very satisfactorily to a *down-pour gate,* an arrangement by which metal enters at the bottom of the mold cavity. In order to reduce sand erosion caused when metal falls from an excessive height in a long gate, a *step gate* is made by offsetting the cheek sprue as shown in Fig. 20. As a further precaution against erosion, the bottom of the step gate may be made of a dry sand core. The function of the strainer cup is the same as that of a pouring basin, and its effectiveness depends on its being kept full of molten metal throughout the pouring operation. The holes in the bottom of the dry sand cup must be small enough to choke the flow of

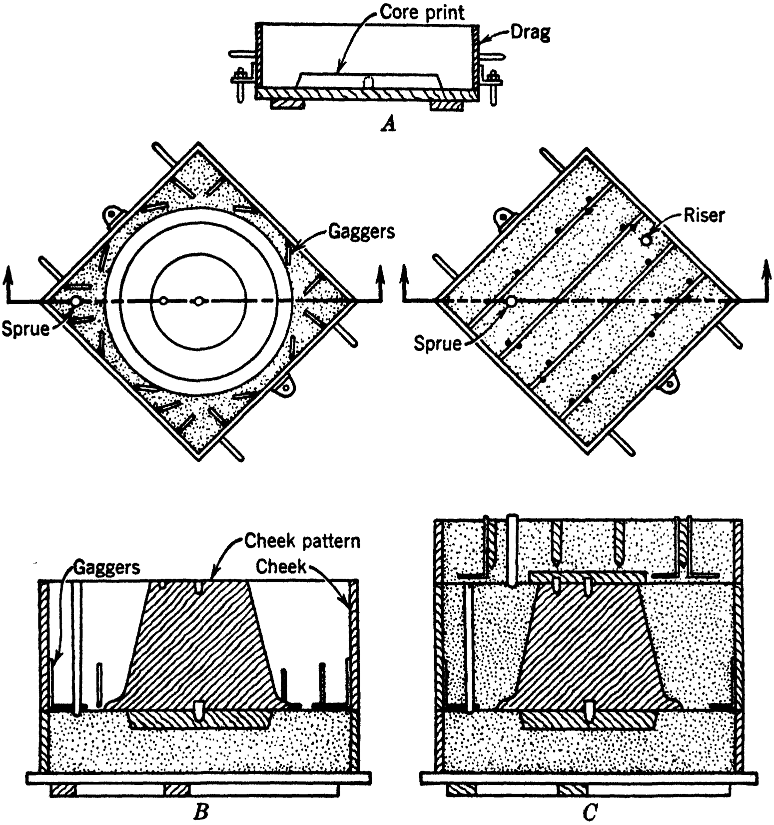


FIG. 20. *A*. Pattern for core print is molded in the drag. *B*. Check pattern and flask in position to be molded. *C*. All parts of mold are rammed and ready to be separated.

metal in order that the cup stays filled. To anchor the cup to the cope, a metal ring is placed around the cup, and molding sand is tucked in the space between the ring and cup. A strainer cup should not be used when more than 75 lb of metal is poured, because the core will burn up and be washed into the mold.

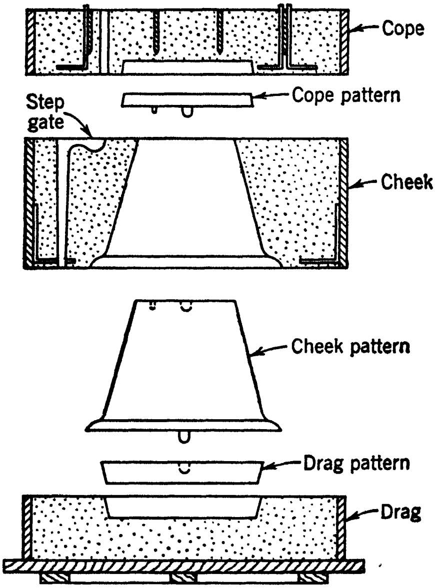


Fig. 20*D*. Mold is separated, patterns are drawn, and gates are cut.

The function of a riser, Fig. 20*E*, is to relieve mold pressure caused by displacement of air by the incoming molten metal. When pouring a mold, the operator watches the riser to know when the mold is about filled, thus preventing the overflow of metal and avoiding excess strain on the mold. Often the function of a riser is to remove cold metal from the point farthest away from the pouring source. If a riser is large enough, it may also serve as a feeder.

Molding of the machine base, Fig. 20, begins by molding of the core print in the drag. It should be noted that the dowel pin is located in the cheek pattern, leaving a flat parting on the core print. After the drag is rolled over and the molding board is removed, the parting plane is troweled, parting sand is sprinkled over the surface, the cheek pattern is placed in position, the cheek of the flask is placed on the drag, and ¼ in. of facing sand is riddled over the parting plane. Gaggers are set along the parting plane with shanks against the flask, as illustrated in Fig. 20*B*, the sprue pin is set in position, more facing is riddled in and tucked against the pattern, and the remainder of the cheek is filled with heap sand and rammed up in the usual way. After a parting is made at the top of the cheek, the loose pattern part is assembled to the cheek pattern, and the cope flask is put in place. The sprue pin for the pouring sprue and the riser are set in position, and the cope is made in the usual way. Before the cope is lifted, a reservoir run-off is cut into the riser to

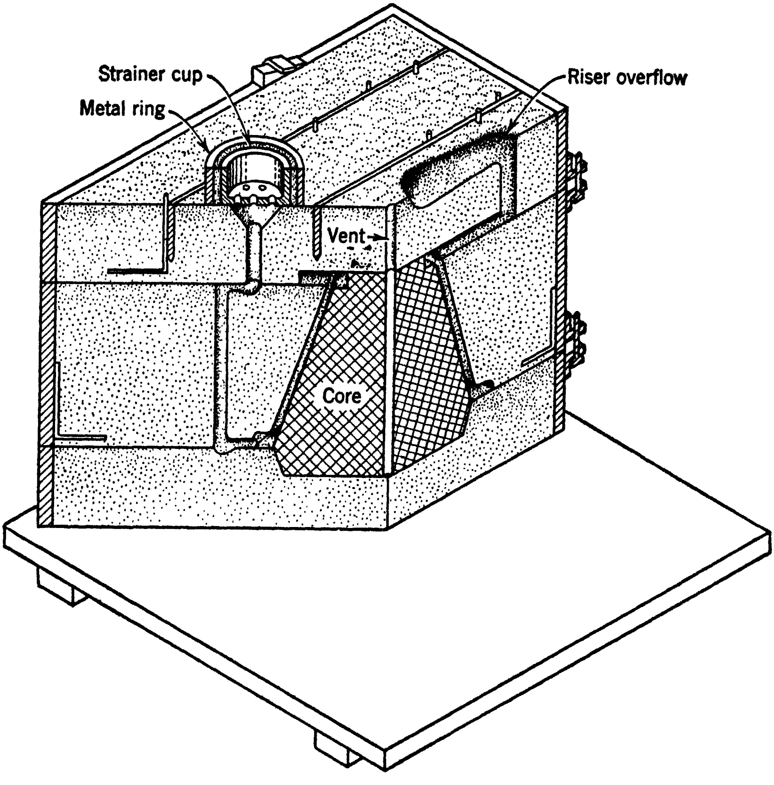


FIG. 20*E*. Completed mold.

collect any overflow of metal. The cope is then lifted off and set on trestles in an inverted position with the parting plane up. The loose pattern part in the cope is swabbed, rapped, and drawn; the sprue and riser openings in the cope are filleted; and a gate connecting the riser and mold cavity is cut in the cope.

The cheek pattern is swabbed and rapped, preparatory to lifting off the cheek. Because the pattern will remain stationary on the drag, care should be taken when the cheek is lifted not to damage the mold cavity. Lacking crossbar supports, the cheek cannot be rolled over or set on edge. After the cheek is set on trestles, a gate is cut in the top parting plane to join the cope and cheek sprues. A gate is also cut in the parting plane below to join the sprue and mold cavity.

The core print is drawn from the drag, and a vent is pierced through to the bottom. The core is then set in position, and the cheek and cope are closed over the drag. It should be noted that there is no core print in the cope and that the cope merely rests against the core to hold it in position. The strainer cup and metal ring are placed over the sprue, and molding sand is packed in between the cup and ring. The mold is then clamped and poured.

Molding a Flanged Pulley. Several methods may be used in molding a flanged pulley. If relatively few castings are to be produced, a jobbing shop method, such as shown in Fig. 21 or Fig. 22, may be employed.

With a three-part flask, molding begins by ramming of the two-piece pattern in the cheek, as illustrated in Fig. 21*A*. Next, the cope is made, a bottom board is placed on top, and the assembly is rolled over. The drag part of the flask is assembled to the mold and rammed up in the usual manner. It is then drawn to remove the top half of the pattern, and the drag is replaced, as shown in Fig. 21*B*. A bottom board is then placed on top of the drag, and the assembly is again rolled over. The cope is then drawn, and the remaining half of the pattern is removed from the cheek. The completed mold is illustrated in Fig. 21*C*.

False Cheek. If a three-part flask is not available, the flanged pulley may be molded in a two-part flask with a green sand core often referred to as a false cheek. This is done by molding the

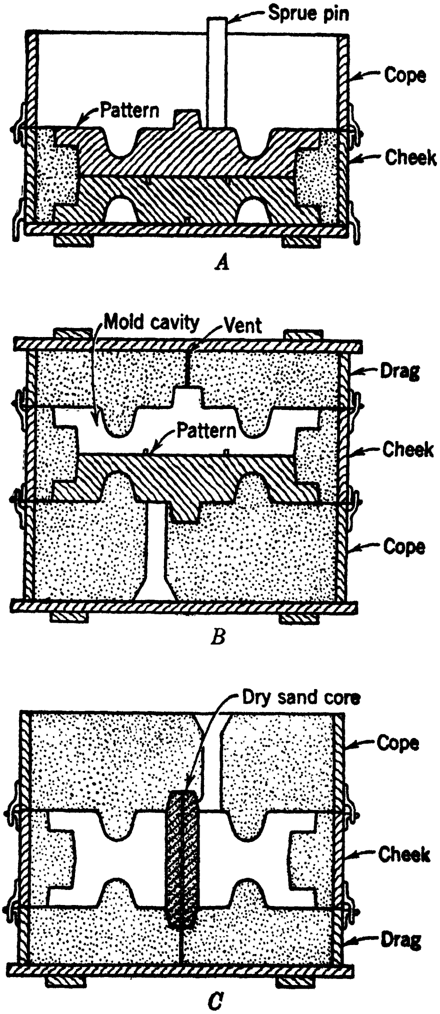


FIG. 21. *A*. Molding of flanged pulley begins by ramming the two-piece pattern in the cheek. *B*. When the drag is completed, it is lifted off, the pattern is drawn, and the drag is replaced. *C*. Completed three-part mold of flanged pulley.

cope half of the pattern in the cope and then rolling over the assembly. After the parting is formed around the pattern in the cope, a false cheek is constructed, as illustrated in Fig. 22*A*. Next, the drag is rammed over the false cheek. It is then drawn, the pattern is removed, and the drag is replaced. The mold is completed by rolling over the assembly, drawing off the cope, removing the remaining pattern half, and closing the mold.

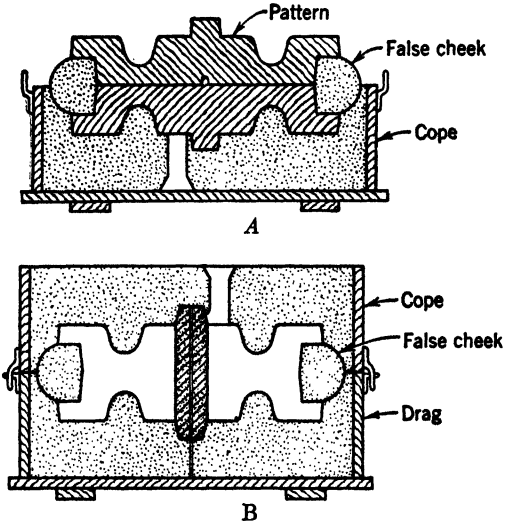


Fig. 22. *A*. In molding a flanged pulley in a two-part mold, a false cheek is formed between the flanges of the pattern. *B*. Completed mold of a flanged pulley made in a two-part mold.

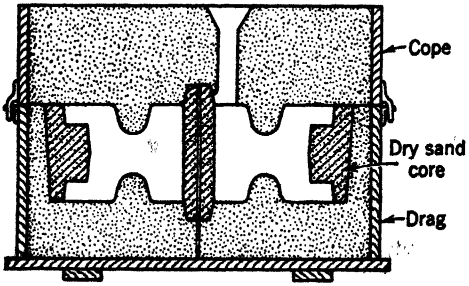


Fig. 23. Flanged pulley made with a dry sand core.

To Eliminate the Cheek. A dry sand core may be substituted for a cheek when the quantity of castings to be produced justifies the expense of equipment needed for the production of cores. Chapter 5 deals with the production of dry sand cores. A completed mold made with a dry sand core instead of a cheek is shown in Fig. 23.

PROBLEMS

1. Name the most desirable type of parting for economical mold production, and explain the reasons.
2. Why is the hole in a casting tapered if it is formed by a green sand core?
3. Itemize the molding steps in producing castings with the pattern in Fig. P3.
4. Itemize the molding steps in producing castings with the pattern in Fig. P4.
5. Explain the advantage of a snap flask over a plain flask.
6. How can gaggers be eliminated in a floor mold?
7. Explain the principle involved in separating slag impurities from molten metal by means of a specially designed gate or pouring basin.
8. What is the function of a feeder?

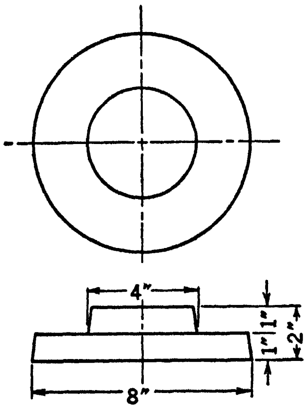


FIG. P3.

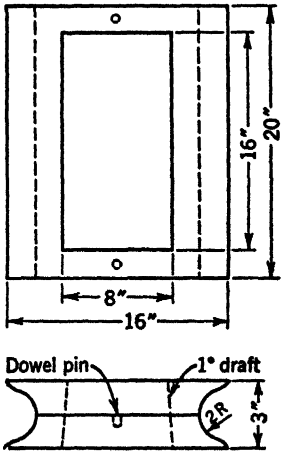


FIG. P4.

3

Foundry Sands and Sand Control

Origin of Foundry Sands. The basic constituent of foundry sand is silicon dioxide found in the form of quartz rock, which by nature has been disintegrated, graded, and deposited in dunes, in lakes, on seashores, and in substrata layers of the earth. Advancing glaciers of prehistoric times deposited a variety of excellent, natural bonded sands in various areas of the Middle West. Other deposits formed by the action of water in rivers, lakes and seas, and sands borne by inland winds produced a large assortment of foundry sands in many parts of the country. Many of these deposits are mined and used without alteration; others that lack certain characteristics are altered by additions of the necessary ingredients. The properties desired in molding sands depend on many factors, such as the type of metal to be cast, the size and design of castings, and various casting specifications including tolerances and smoothness of surface. When natural resources cannot supply the sands of desired specifications, the sand is made synthetically by compounding the various ingredients artificially and mixing them in a commercial mixer.

Sand Composition. Green molding sand is principally a mixture of three ingredients: (1) sand grains of desired size, shape, and uniformity of size, (2) bond, and (3) moisture. Among the various classifications for determining the purpose to which a sand may be adapted, the average grain size and clay content are of greatest value, but they are by no means absolute.

Grain Shape. The shape of foundry sand grains varies all the way from round to angular. Some sands consist almost entirely of one type, whereas others are a mixture of various shapes. Foundry sands are classified into four grain-shape classes: angular, sub-angular, round, and compound. Examples of the four shapes are shown in Fig. 1. Rounded grains have least contact with one another in a rammed structure and therefore produce molds of greater permeability. Permeability is based on mold porosity and is defined as the property of a sand that permits the passage of gases through it. Because of less contact between grains, sand molds made of rounded grains lack the strength of sub-angular and angular grains. Molding sands that are composed of angular grains need more bond and moisture. Sand grains that are cemented together to the extent that they fail to separate when screened are referred to as compound grains. They may consist of any one of the three grain shapes or a combination of them. Sands containing compound-grain structures are least desirable because of their tendency to break down at high temperatures.

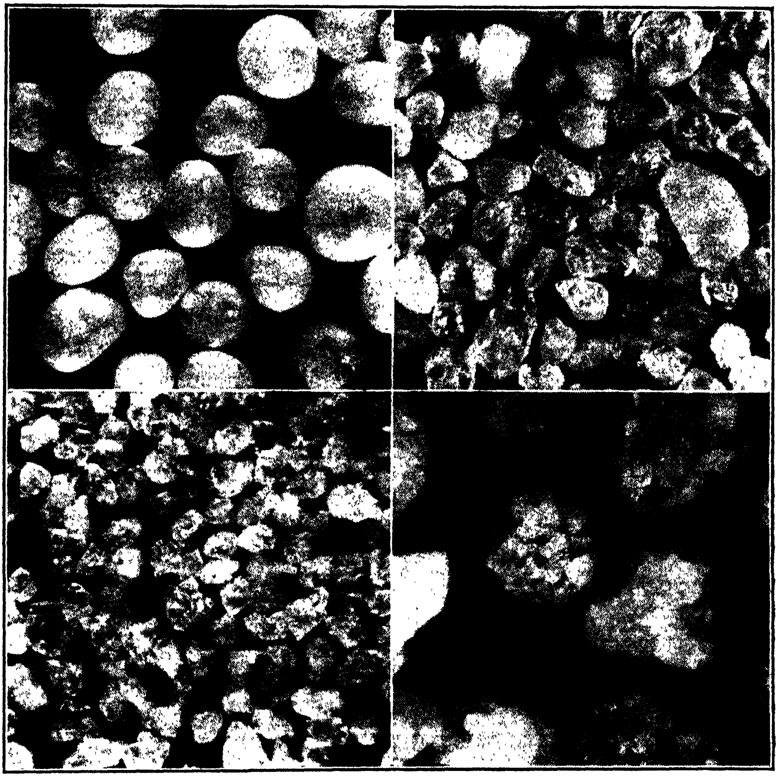


FIG. 1. Grain-shape classification: upper left, rounded; upper right, sub-angular; lower left, angular; lower right, compound. (Courtesy of Professor H. Ries, Emeritus, Cornell University.)

Foundry Clay. AFS clay, as defined by the American Foundrymen's Society, consists of all particles of sand (under 20 microns in diameter) which fail to settle a distance of 1 in. per minute when suspended in water. Such clay consists of two principal ingredients: (1) fine silt which has no bonding power and (2) true clay which supplies the necessary bond to molding sand.

Natural formations of clay are the result of chemical action, aided by the percolating of water through certain types of feldspathic rock. These minerals are carried into lakes and oceans by the action of rivers and deposited there as silt. A wide variety of characteristics is found in various clays, depending on the ingredients of the substance. Some clays are mined and transported half-way around the world because of some characteristic properties not found in other clays.

True clays consist of extremely minute aggregates of crystalline particles, known as *clay minerals,* which are classified according to structure and composition. Most clays are composed of flake-shaped particles about 2 microns (2/25,000 of an inch) in diameter. If sufficient magnification were possible, one would see these paper-thin flakes lying flat on one another, like shale. Although some clays contain nothing but aggregates of flakes, many others contain additional minute particles of quartz, pyrite, and organic matter which are usually granular in shape and do not contribute to bonding action.

If one were able to magnify these flakes many more thousands of times than previously suggested, he would observe that they are not a heterogeneous mixture of alumina, silica, and other materials, but an atomic configuration of oxygen, silicon, aluminum, and hydroxyls, arranged in definite fixed patterns. These clay minerals of which the flakes are composed have varying properties (bonding, plasticity, refractoriness, etc.), depending on composition and structure.

Some clay minerals have high *adsorptive* capacities. For example, if a sodium solution were passed through a certain type of clay, some of the sodium would be adsorbed, and the properties of the clay would be altered. Another property in clay, known as *base exchange,* is the capacity of some clay minerals to exchange one ion for another. If a calcium solution were passed through the clay after it had been treated with sodium in the above example, a certain percentage of calcium would be exchanged for the previously adsorbed sodium, thus producing a clay with different properties. A wide variety of properties is obtained in clays which possess the base exchange property.

Clay minerals are classified as montmorillonite, halloysite, illite, and kaolinite.

Montmorillonite. Having high adsorptive properties, montmorillonite clay minerals are subdivided into two groups, classes 1A and 1B, depending on the nature of the adsorbed ion. The chief exchangeable base in montmorillonite clay 1A is sodium which replaces aluminum in the general formula $(OH)_4Al_4Si_8O_{20} \cdot nH_2O$. Montmorillonite clay 1B possesses a considerable amount of iron as a result of base exchange. It also carries calcium and sometimes hydrogen as a chief exchange ion.

Southern bentonite (class 1B) is obtained from northern Mississippi. It carries a high percentage of hydrogen and calcium ions and gives a slight acid reaction. It is used in sands for the production of nonferrous and malleable iron because of its high green strength and good permeability, and also because it can be mixed into a sand heap without the use of an intensive mixer. Its moderate dry and hot strength properties are advantageous where mold collapsibility is necessary to prevent cracking of hot castings. It is often preferred to other bonds for gray iron foundry sands because it produces *high flowability* (the ability of sand to pack in and around a pattern with uniform density) and collapses readily when the mold is destroyed.

Western bentonite (class 1A) is found in greatest abundance in Wyoming. It produces a basic reaction because of a high concentration of sodium ions attached to the clay particles, and it has a high volumetric expansion when mixed with water. It is used mainly in steel foundries and occasionally in the production of large gray iron castings because of its high strength in dry sand molds and also because of its resistance to high temperatures. Since it is more difficult to ram sand that is bonded with western bentonite, a small amount of cereal may be added to the sand to improve flowability. In spite of their respective acid and basic reactions, the two bentonites may be mixed to produce a combination of bonding properties.

Halloysite Bonding Clays. Instead of being flake-shaped as most clays are, halloysite clay minerals are made up of lath-shaped units. These clays are very refractory and possess moderate shrinkage and plastic properties. The adsorptive capacity for basic ions is low. Halloysite is found in Utah and known as "white clay." A characteristic property of halloysite is that sand bonded with this clay does not gain its maximum strength until some period of time after the mold is made. This increase in strength is referred to as air-set strength. Because of lower strength when it is rammed in a mold, the sand has less resistance to ramming, yet, after it is allowed to stand, it gains the desired strength to withstand the forces exerted in pouring.

Illite Bonding Clays. There is a wide variation in the composition of illite clay minerals. Not all illite clays are satisfactory for bonding, but those with high bonding power have good dispersion properties and are quite satisfactory for commercial applications. These clays have moderate-to-low shrinkage properties but are low in refractoriness. Illite is often blended with other clays to obtain desired properties. This clay is obtained from the state of Illinois.

Kaolinite. Although kaolinite has the same composition as the halloysite group, it differs in properties because of a different atomic arrangement. The kaolinite clays vary in bonding properties from low to high, depending on the structural characteristics. These clays are refractory and have low shrinkage values. Like illite, kaolinite's adsorptive property for basic ions is low. Many fire clays produced in Illinois and Ohio are composed of kaolinite and small amounts of illite.

Action of Water in Clay. When water is added to a clay mixture, it penetrates the mixture and forms a film that coats the surface of each individual flake. The water molecules that form the film are not in a fluid state but fixed in a definite rigid pattern. As water is added, the thickness of the coating increases up to a point where rigidity tapers off and the physical state of water begins to revert toward fluidity. The cause for the formation of this rigid or solid state of water is based on the arrangement and effect of the atoms in the clay mineral. As the layer of water increases in thickness, the influence of the clay mineral on the top layer becomes less and consequently that layer of water loses rigidity.

The thickness of the water film varies with respect to the clay mineral. It was found that montmorillonite 1A reaches its maximum strength when the film is about three water molecules thick. Montmorillonite 1B reaches its maximum strength at a depth of four water molecules. Having a thicker layer of rigid water makes the latter clay a stronger bond. It is believed that water does not penetrate halloysite flakes as readily as other clays, and, as a consequence, the clay mixture possesses a combination of liquid and rigid water. However, after the sand is rammed in the mold and allowed to set, the remainder of liquid water will become rigid and cause the mold to be exceptionally strong.

✓ **Bonding Action.** The concept of bonding sand grains with clay and water is based on the so-called *wedge and block* theory. When sand is rammed in a mold, the sand grains are forced together. The clay coating on each grain acts as a wedge which locks the grain in position when it is forced between other grains.

Bonds that have high dispersal properties form a smooth coating and produce a better wedge. Also, with the same amount of bond, the clay which holds a thicker layer of rigid water will produce the better wedge. "If more water is added than is needed for maximum rigidity, the strength of the wedge is reduced but flowability of sand is increased."

Quantitative Sand Analysis. In determining the percentage of ingredients in sand, a 50-gram sample is accurately weighed and dried in an oven at a temperature of 220° to 230° F. It is then cooled in a desiccator and reweighed to determine the percentage of moisture, based on the original weight.

Various types of apparatus are available for routine moisture tests. Although their results are not so reliable as those of the standard test, they are considered satisfactory for routine work and are preferred because of the speed with which tests can be made. The sand is weighed in a small pan and placed in a drying apparatus, as shown in Fig. 2, which blows air at the required temperature through the sand. The percentage of moisture is calculated in the same manner as with the standard method. Another method depends on the pressure of acetylene gas, generated by the chemical reaction of carbide with sand moisture. Weighed samples of sand and calcium carbide are placed in separate compartments of the gage. When the cover is closed, the apparatus is shaken to mix the two ingredients.

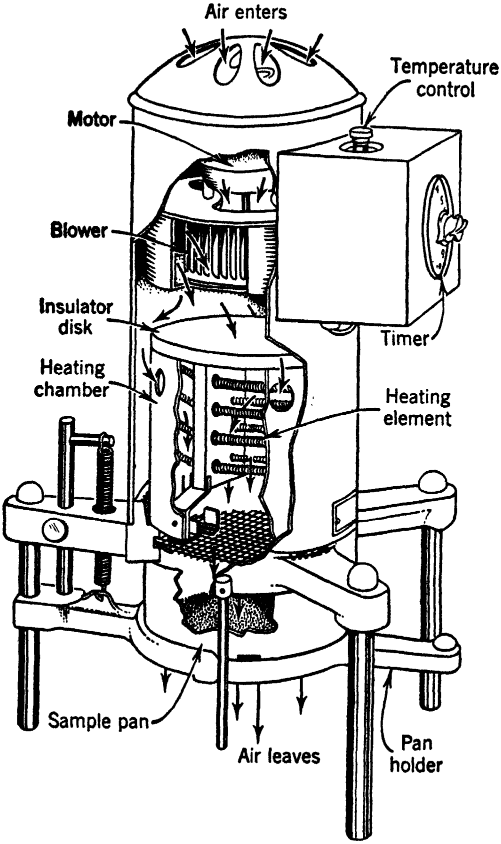


FIG. 2. Moisture teller for determining moisture content of sand. (Courtesy of Harry Dietert Co., Detroit, Mich.)

The resulting gas pressure is indicated on a scale, calibrated in percentage of moisture.

After the moisture test is completed, a 50-gram sample of dried sand is stirred in a weak solution of sodium hydroxide *

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*For details, refer to *Foundry Sand Testing Handbook,* American Foundrymen's Society, 1944.

to dissolve all the soluble clay substance. Several types of apparatus are available for agitating the solution. Distilled water is then added to fill the receptacle to a height of 6 in. above the sand. The solution is stirred again, allowed to settle for a period of 10 min, and then siphoned off to within 1 in. of the sediment. Next the sediment is again diluted with distilled water up to the 6-in. height, and the solution is stirred, allowed to settle, and siphoned as before. After the second siphoning operation, only 5 min is allowed for settling. This is repeated until the water becomes clear to a depth of 5 in. in 5 min. The remaining liquid is decanted, and the precipitate is filtered, dried, and weighed. The difference between the original dried sample and the dried precipitate is clay. The percentage of

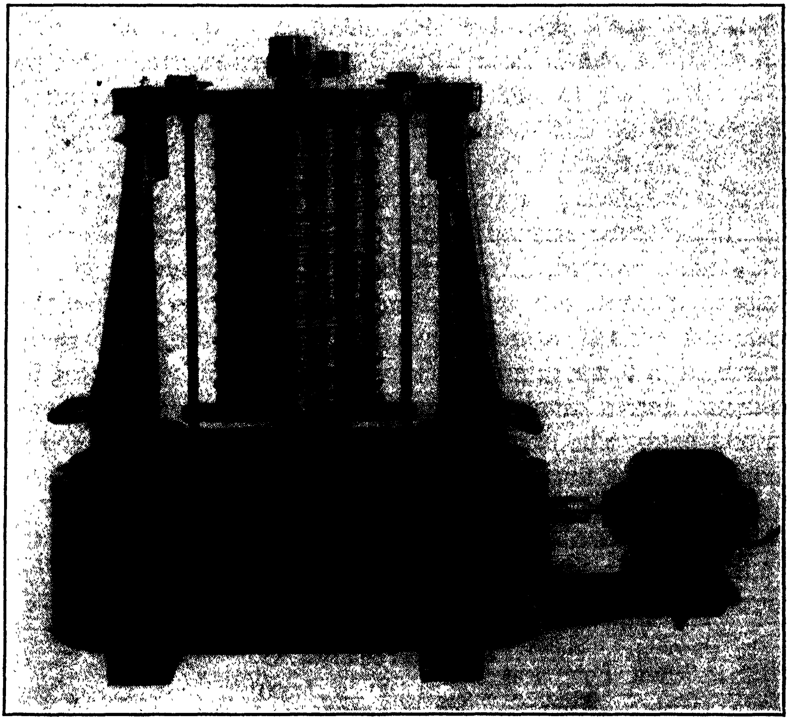


FIG. 3. Ro-Tap testing sieve shaker for determining grain distribution. (Courtesy of W. S. Tayler Co., Cleveland, Ohio.)

clay is calculated on the basis of the weight of the original dried sample.

The *size distribution* of sand grains is determined by screening the above sample through a series of eleven standard sieves. The sieves are assembled to fit, one on top of the other, the top sieve having the largest mesh opening and the bottom one the smallest. A pan is fastened to the bottom sieve to collect the fines that pass through the smallest openings. The series of sieves with the sand sample is placed in a sieve shaker such as the one illustrated in Fig. 3. The sand retained on each sieve is then weighed, and the percentage retained is computed on the basis of the original weight of the dried sample before the clay was removed. The results of this distribution may be expressed graphically on semilogarithmic paper, with grain percentages plotted against sieve numbers. Sands are usually specified in terms of grain fineness numbers which represent the smallest screen number through which the average-sized grain would pass. The example in Table 1 illustrates the method of computing the fineness number.

Table 1. METHOD OF COMPUTING GRAIN FINENESS NUMBER AND SPECIFICATIONS OF A MOLDING SAND

Size of Opening in Screen (in.)	U. S. Series Equivalent Number	Amount of 50-Gram Sample Retained on Sieve (grams)	Amount of 50-Gram Sample Retained on Sieve (%)	Multiplying Factor	Product
0.1320	6	None		3	
0.0661	12	0.3	0.6	5	3.0
0.0331	20	2.0	4.0	10	40.0
0.0232	30	1.45	2.9	20	58.0
0.0165	40	2.1	4.2	30	126.0
0.0117	50	4.0	8.0	40	320.0
0.0083	70	4.05	8.1	50	405.0
0.0059	100	4.7	9.4	70	658.0
0.0041	140	4.5	9.0	100	900.0
0.0029	200	2.45	4.9	140	686.0
0.0021	270	0.4	0.8	200	160.0
	Pan	13.25	26.5	300	7,950.0
Total		39.2	78.4		11,306.0

Table 1 (Continued)

SAND SPECIFICATIONS

Grain fineness number, 11,306/78.4 = 144
AFS clay, 21.6%
Permeability, 7.8
Moisture, 7.2%
Green compression, 14.2 psi
Dry compression, 100 psi

Graphic Representation of Size and Distribution of Sand Grains. The fineness number of molding sand merely discloses the average grain size of the sample. The same fineness number may be obtained from a large number of different distribution ratios. Although the fineness number is a valuable factor in judging sands, it may not reveal the entire story. A graph showing the percentage of each grain size or one showing cumulative percentage is more descriptive than the fineness number.

Figure 4 shows the cumulative percentages of various sand distributions plotted on a semilogarithmic graph. The ordinate of the graph is plotted in terms of the cumulative percentage of sand retained on each sieve. This is derived by adding the weight of sand retained on the sieves above to the one being weighed. Following are some significant factors for the interpretation of the graph.

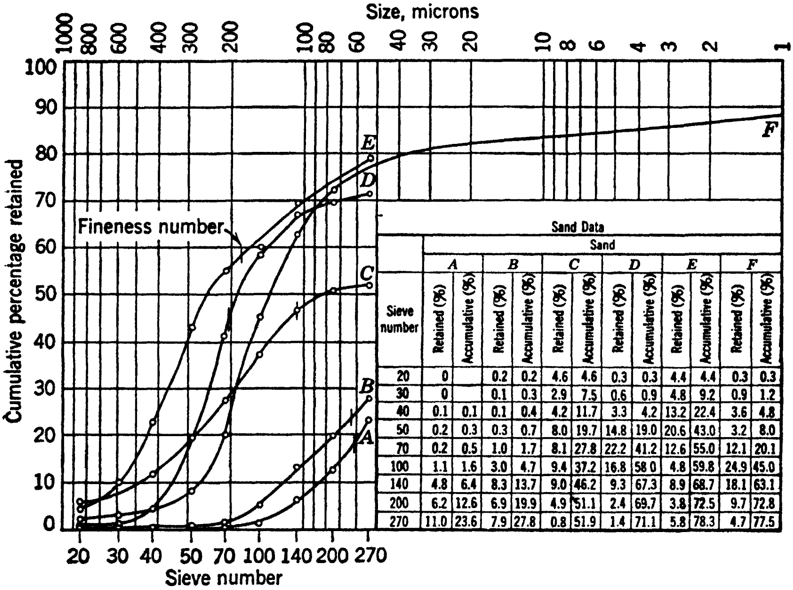
1. The tapering off to the horizontal, at the top of the curve, indicates that a diminishing quantity of sand is retained on the fine sieves.

2. The upward sweep of the curve indicates an increasing quantity of grains of equal size. With a steeper curve, fewer sieves retain larger amounts of sand.

3. The quantity of largest and smallest grains is indicated by the ends of the curve. The percentage of fines may be determined by subtracting the cumulative percentage at the No. 270 sieve from 100.

When the curves of the graph are compared, it is obvious that sand *E* has less fines than any other sand. This may indicate that sand *E* has less bond than the other sands. It should be noted that the larger fines are not bonding constituents, and a complete distribution of both sand grains and fines is desirable in a complete study.

Sand *D* has a large proportion of its grains retained on a few sieves. This is also true of sands *E* and *F*, except that the grain sizes are smaller in *F* and larger in *E*. The slope of the curve *D*, being steepêr than that of *E*, would indicate that slightly greater quantities of *D* sand are retained on the middle sieves. The straight line at the top of the curve *E* indicates a larger quantity of fine grains of equal distribution.



Sand Data

	Sand											
	A		B		C		D		E		F	
Sieve number	Retained (%)	Accumulative (%)	Retained (%)	Accumulative (%)	Retained (%)	Accumulative (%)	Retained (%)	Accumulative (%)	Retained (%)	Accumulative (%)	Retained (%)	Accumulative (%)
20	0		0.2	0.2	4.6	4.6	0.3	0.3	4.4	4.4	0.3	0.3
30	0		0.1	0.3	2.9	7.5	0.6	0.9	4.8	9.2	0.9	1.2
40	0.1	0.1	0.1	0.4	4.2	11.7	3.3	4.2	13.2	22.4	3.6	4.8
50	0.2	0.3	0.3	0.7	8.0	19.7	14.8	19.0	20.6	43.0	3.2	8.0
70	0.2	0.5	1.0	1.7	8.1	27.8	22.2	41.2	12.6	55.0	12.1	20.1
100	1.1	1.6	3.0	4.7	9.4	37.2	16.8	58.0	4.8	59.8	24.9	45.0
140	4.8	6.4	8.3	13.7	9.0	46.2	9.3	67.3	8.9	68.7	18.1	63.1
200	6.2	12.6	6.9	19.9	4.9	51.1	2.4	69.7	3.8	72.5	9.7	72.8
270	11.0	23.6	7.9	27.8	0.8	51.9	1.4	71.1	5.8	78.3	4.7	77.5

FIG. 4. Distribution of sand grains.

Determination of Fine Particles by the Hydrometer Method. The distribution of fine particles of silt and clay may be determined with a Bouyoucos soil hydrometer. The procedure consists of taking hydrometer readings of the solution of suspended sand particles at predetermined intervals of time. The data from this test are used in computing particle size and the cumulative distribution of the particles.

A 50-gram sample is prepared as previously described, but the liquid is not siphoned. Instead, it is diluted to 1 liter and placed in a cylindrical graduate. After being thoroughly mixed, it is allowed to settle. Temperature and specific gravity are noted at time intervals of 30 sec, 1 min, 2 min, 4 min, 8 min, 15 min, 30 min, 1 hr, etc. The largest particles precipitate first, leaving a liquid of lower density. This is followed by precipitation of smaller particles, etc. The cumulative percentage of particle size is then computed.

The hydrometer test is continued for a period of 1 to 2 hr and sometimes for as long as 18 hr, depending on the type of sand and the results to be desired.

After the hydrometer test is completed, the solution (including the precipitate) is passed through a No. 325 mesh sieve and washed to get rid of the fine particles. The retained sand is dried and screened to determine the sand grain distribution.

The results of both tests are plotted as a continuous curve on semilogarithmic graph paper. Curve *F* of Fig. 4 shows the results of a test.

Sand Control. It is important to the foundryman that the physical properties of his molding sand remain constant. In order to discover any variations at an early stage before the change affects the molding process or casting quality, he has at his disposal various types of routine sand-testing machines with which he tests samples of sand taken at various intervals from his sand-conditioning system. Among the tests that he may perform are those for moisture content, green and dry sand strength, hot strength, flowability, permeability, sintering point, deformation, toughness, and expansion or contraction due to changing temperatures. Of these tests, the most common are those for moisture content, green strength, and permeability.

Test Specimen. All three common tests may be made on the same test specimen. The specimen is prepared by placing sufficient sand in a specimen container to produce a 2-in.-long cylindrical sand specimen when rammed in a standard ramming apparatus. The rammer of a standard ramming apparatus, shown in Fig. 5, is raised three times by the action of a cam and allowed to fall freely on the sand in the specimen container.

Moisture Indicator. A routine moisture indication may be obtained by the moisture indicator, shown in Fig. 5, which is rotated into position about a spindle to contact the rammer rod for a reading and then back to its original position to avoid interference with ramming. Once the indicator is adjusted to a standard specimen that contains the desired moisture content, indicator readings on succeeding routine sand tests represent an approximate variation of moisture content of the sand, if the exact weight of the standard sample is used in the preparation of all the specimens. If the sand is too moist, the specimen will be smaller and will be so indicated on the dial. The degree of deformation is proportional to the amount of excess moisture.

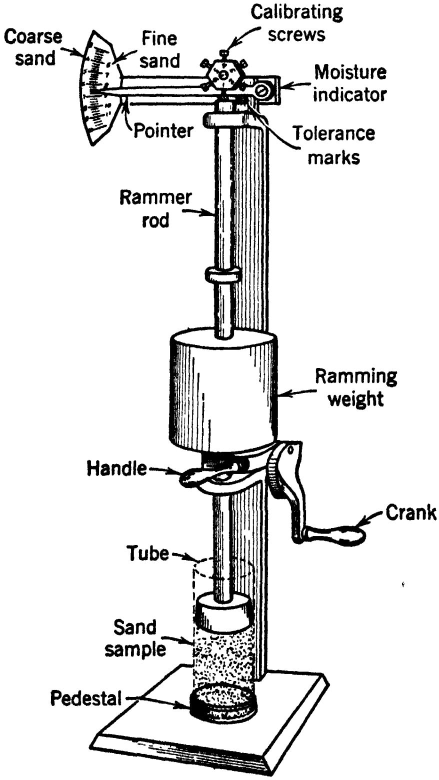


FIG. 5. Standard ramming apparatus for ramming standard test specimen with auxiliary moisture-testing accessory. (Courtesy of Harry W. Dietert Co., Detroit, Mich.)

Permeability. As the mold is poured, the displaced air and the gases formed by combustion must frequently find their way out of the mold cavity through the sand. The rate at which air passes through a standard AFS sand specimen under pressure is an indication of ability of the sand to perform this

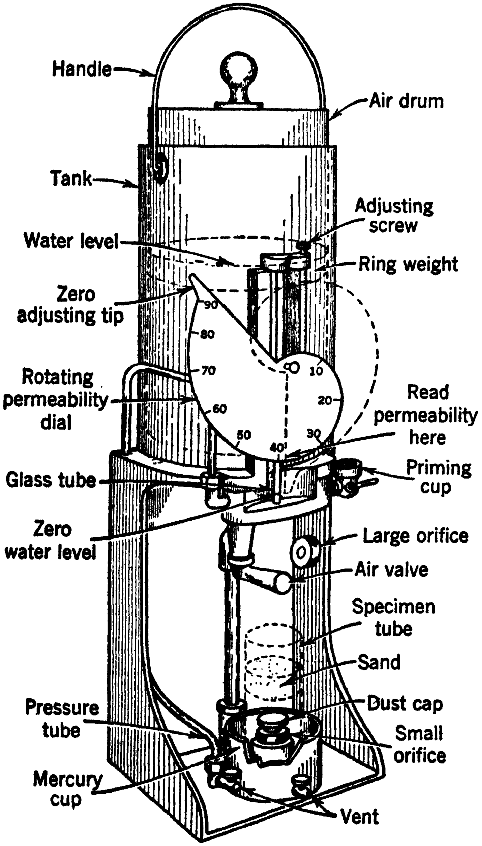


Fig. 6. Permeability meter for testing permeability of sand specimens. (Courtesy of Harry W. Dietert Co., Detroit, Mich.)

function. In the green permeability test, the container in which the specimen is rammed is inverted over the opening of the pressure tube of the permeability meter illustrated in Fig. 6. The bottom of the container dips into a mercury bath to seal the container so that the air must pass through the specimen. Before the test begins, a three-way valve is turned to the vent position, and air is drawn into the pressure chamber by raising the bell. When the valve is closed and the bell is released, the confined air supports the bell, the open end at the bottom of the bell being sealed in water. The test begins when the valve is turned to the "on" position. The air (compressed by the weight of the bell) passes through the pressure tube, into the specimen container, and on through the sand specimen. When the flow becomes constant, the pressure and the time required for 2000 cc of air to pass through the specimen are recorded. The volume of air passing through a sand specimen 1 sq cm in area and 1 cm in height at a pressure of 1 gram per square centimeter in 1 min is called the permeability number and is computed by the formula

$$P = \frac{vh}{pat}$$

where P = permeability number.
v = volume of air passing through the specimen (cubic centimeters).
h = height of specimen (centimeters).
p = pressure of air (grams per square centimeter).
a = cross-sectional area of specimen (square centimeters).
t = time (minutes).

Permeability tests on foundry sands in routine shop control are made more rapidly with a standardized orifice which is attached to the end of the pressure tube of the air-flow apparatus. Because volume of flow through an orifice is a function of pressure drop, only the pressure need be observed. A table of permeability numbers corresponding to given pressures eliminates all computations. For further convenience, the permeability number is read directly from a permeability dial. To get the permeability number, the dial is merely rotated until the edge of the dial corresponds to the bottom of the meniscus on the pressure gage, and the number is read directly above the scale.

Baked and *dry permeability* tests differ from green permeability tests in that the sand specimen must be removed from the specimen container before it is baked or dried. The specimen is then clamped in a special core permeability tube, and a liquid seal of mercury is poured in between the specimen and the tube to prevent air from flowing around the specimen instead of through it. The baked permeability test is distinguished from the dry permeability test in that in the former the sand is baked at temperatures in excess of 230° F; in the latter it is dried within the temperature range of 220° to 230° F. Permeability of sands containing no bond is called *base permeability.* The sand is retained in the specimen tube between two retaining screens.

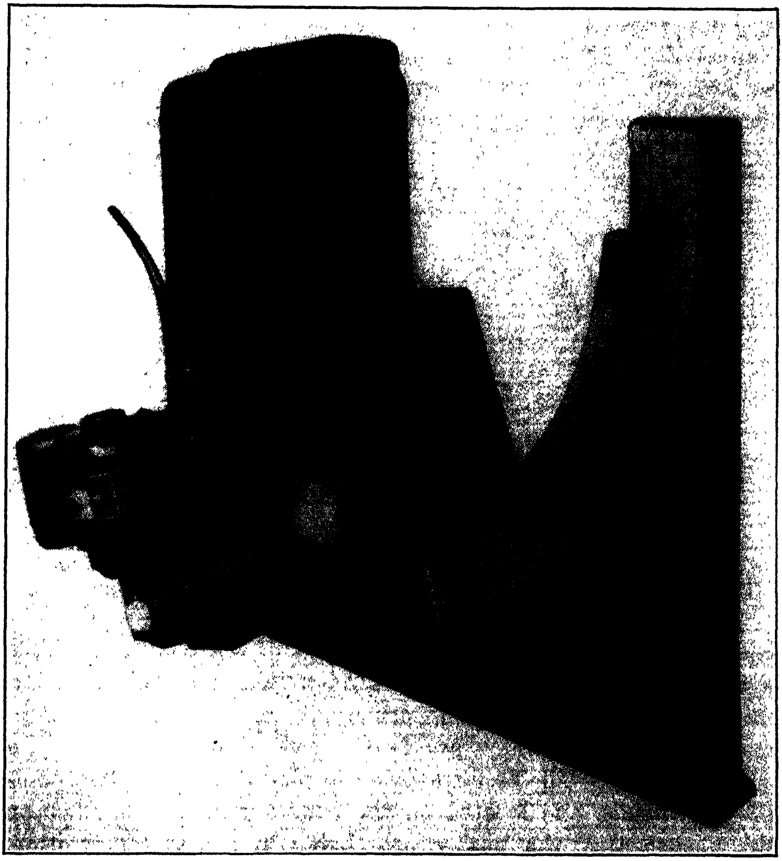


FIG. 7. Sand-strength machine. A dead-weight type of apparatus. (Courtesy of Harry W. Dietert Co., Detroit, Mich.)

Although permeability numbers range from 1 to 2000, green sand permeability ordinarily ranges from 5 to 200, depending on the sand.

Strength. Foundry sands may be tested for strength in compression, tension, and shear. The choice of test for routine sand control depends largely on the kind of stress most likely to cause failure in the sand in question. In the green compression test, a standard test specimen is stripped from the specimen container, placed between the two heads of the testing machine, and squeezed until it breaks. A dead-weight compression tester, illustrated in Fig. 7, consists principally of a pendulum weight and a pusher arm which are free to swing independently on a common shaft. The test specimen is placed between two compression heads, one located on the pendulum and the other on the pusher arm, the pusher arm being in a vertical position. To make the test, the pusher arm is moved from the vertical position toward the horizontal through a 90-degree arc. As rotation proceeds, the weight of the dead-weight pendulum bears down on the specimen with increasing force until the specimen breaks. The full weight of the pendulum would be applied if the horizontal position were reached. A magnetic rider is pushed along a scale by the pendulum, and, when the specimen breaks, the pendulum and pusher arm return automatically to their

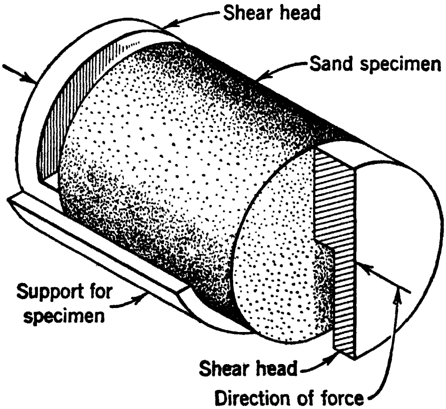


FIG. 8. Test specimen in position to be tested for shear strength.

original position, leaving the rider at the point where failure takes place. The scale is calibrated in terms of pounds per square inch. The pusher arm is usually motor-driven and geared to produce an axial force at a rate of 30 psi per minute on the specimen.

Dried sand samples may be tested on the same machine by placing the specimen between the compression heads at a point nearer to the axis of rotation to produce a greater breaking stress.

In the shear test, a semicircular shear head (Fig. 8) is substituted for the circular compression head. The test is performed in the same manner as described for the compression test. Pressure is applied to half the face of the specimen by the pusher arm and to the opposite half by the pendulum, causing the specimen to fail in shear.

In the tensile test, the specimen is rammed in a two-part specimen container, illustrated in Fig. 9. The container is then placed in a testing machine and pulled apart. The force necessary to pull the specimen apart is registered on a scale by a magnetic rider in the same manner as described for compressive tests.

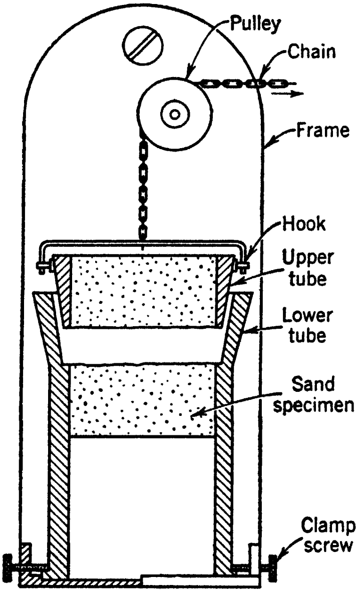


Fig. 9. Test specimen rammed in a two-part specimen tube and tested for tensile strength.

Temperature Resistance. The smoothness of a casting depends largely on the ability of molding sand to maintain its original characteristics at elevated temperatures. As molten metal comes in contact with the mold, the sand grains tend to soften and adhere to the metal, often making the casting difficult to clean.

The incipient fusion temperature at which sand begins to sinter is called the B sintering point. The test is made by holding a platinum ribbon over a standard sand specimen and passing an electric current through the ribbon. A variable resistance controls the ribbon temperature which is observed with an optical pyrometer. Tests are begun at a temperature known to be below the sintering point and increased by 50° F at each succeeding trial until fusion is apparent. After each trial the ribbon is observed under a low-powered microscope for traces of fusion. A mechanical scraper is often used to eliminate errors of observation. The scraper is designed and standardized to require no fewer than 50 passes to remove the adhering sand from the ribbon when the B sintering point is reached.

At some temperature below sintering point B, the ribbon will adhere to the specimen sufficiently to cause the ribbon to buckle, forming a V when removed from the specimen. The two tests for sintering points A and B give the foundryman a working knowledge of the temperature qualities of his sands so that he may use his sands to best advantage. Various sand characteristics and their relation to temperature resistance are discussed in subsequent paragraphs.

Considerable progress has been made in the testing of sands at high temperatures by a self-contained laboratory apparatus called the dilatometer. The sand specimen is sandwiched between two refractory disks, and a thermostatically controlled furnace with heating capacity up to 3000° F is lowered over the specimen. The test is operated from a control panel equipped with the necessary metering devices to indicate and direct the progress of the test. In the hot compression test, for instance, the specimen is squeezed between the upper and lower furnace posts at a chosen temperature and rate of loading. The results of the test are observed on a control panel. The dilatometer affords the foundryman an opportunity to observe the characteristics of his sand when it is exposed to temperatures typical of actual pouring conditions. Among the tests of general interest are hot strength, sand collapsibility, contraction, and expansion tests. With dilatometer accessories, gas pressure, permeability, and volume of generated gas may be determined at mold-pouring temperatures. These accessories are shown in Fig. 10.

✓ **Optimum Sand Condition.** The strength and toughness of molding sand may be readily increased by increasing the amount of clay bond, but this is done only with a great sacrifice of permeability. Excess clay reduces flowability, increases moisture content, and often lowers the refractory properties of sand. As far as clay is concerned, a molding sand mixture is at its best when all the clay content is used to coat the sand grains, leaving air spaces in the interstices.

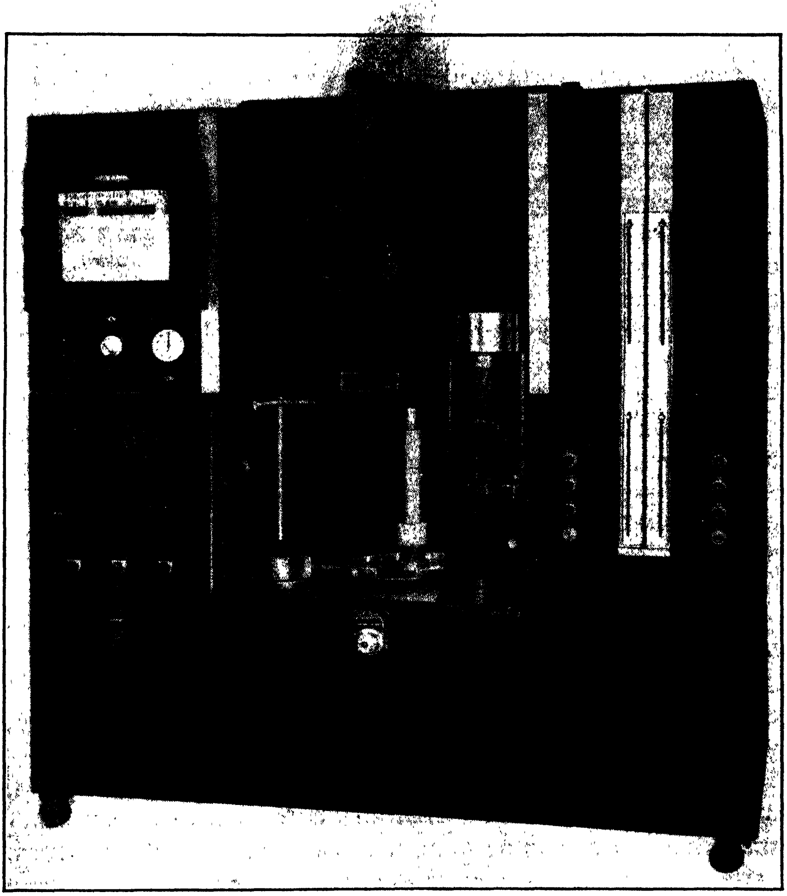


FIG. 10. Dilatometer for testing sand specimens under mold-pouring temperatures. (Courtesy of Harry W. Dietert Co., Detroit, Mich.)

The size, shape, and distribution of sand grains have a strong effect on the various properties of molding sand. Sands of a high fineness number produce smoother mold surfaces but require more clay bond because of increased grain surface area. The permeability of such sands drops rapidly with reduction in grain size. Also, the sintering point of coarse sands is usually higher than that of fine sands. Coarse sands have lower expansion properties when exposed to heat. Sands of uniform grain size have higher permeability properties than sands of a wide distribution because the fines will pack in the spaces left by the coarser grains.

Moisture content is probably the most important factor in sand preparation because it affects almost every physical property of molding sand. The physical condition of sand due to moisture is referred to as *temper*. In general, the correct temper is found where all the physical properties reach a satisfactory condition. For example, a certain sand containing 6 per cent moisture may be considered as being correctly tempered because at that point it reaches its maximum permeability and green compression strength. Although certain characteristics such as tensile strength, toughness, and flowability could be improved with increased moisture, a sharp decrease in permeability and green strength would result. The optimum sand condition depends on the properties and characteristics desired by the foundryman.

Synthetic Bonds. For many years, chemists have been attempting to develop better bonds for foundry sand. One such development is a nonthermal-setting hydrocarbon plastic bond which, it is claimed, makes sand more refractory and reduces the formation of mold gases.

The sand is prepared synthetically and consists of silica sand, synthetic bond, and clay. Because only one-half the normal amount of clay is needed in this sand mixture, the moisture content of the sand is reduced to approximately 3 per cent. The same sand would contain from 5.5 to 5.8 per cent moisture if bonded entirely with clay bond. Because of less moisture, permeability requirements are lower, and sands of higher fineness number may be used to obtain smoother castings.

Casting Defects Caused by Sand. Casting defects may be caused by sand, metal, molding practices, and molding equipment, but the most common cause of defective castings is sand condition.

When molten metal comes in contact with a green sand mold, the moisture of the sand turns to steam. The steam permeates the mold without obstructing the flow of metal, provided that the moisture content of the sand is correct and the sand possesses proper permeability. If permeability is low, owing to excessive clay and improper ramming, or if the moisture content is too high, the inflowing metal may be blown out of the mold with explosive violence. On the other hand, a *blow* may be hardly perceived, but, when the casting is inspected, a *blow hole* may be discovered in the casting.

Many casting defects are caused by expansion properties of sand. The remedy is to decrease moisture and clay bond, increase grain size, and reduce mold hardness. A common defect called a *scab* is formed when the mold skin fractures and a portion of the skin rises, permitting metal to flow under the skin. The resulting defect has the appearance of a scab. Occasionally, when fracture occurs, one edge of the fracture slides up over the other, forming a streak on the casting. This is referred to as a *rat tail* and is usually found on a thin flat section. The same defect may occur in heavy castings where expansion is much greater, causing the sand mold to crush at the point of fracture. This is referred to as a *buckle.*

Molding sand must be continually replenished with the ingredients that deteriorate when the sand is exposed to the high temperatures of molten metal. Unless new sand or the proper clay bond is added to used sand, the sand soon begins to lose strength, causing sand *drops* from the cope. This usually happens when the mold is being closed. A small portion of the cope may break off and drop into the drag unnoticed, and the casting will have two defects. It will lack the detail of that portion which dropped from the cope, and it will contain a *dirt inclusion.* Sands that lack strength, or molds that are improperly gated, may be eroded by the inflowing metal. If a heavy stream of metal is allowed to flow through a single passage for an extended period of time, the sand surfaces may be eroded in spite of good sand characteristics. Proper gating is very important in eliminating erosion. This type of defect is called a *cut;* when a portion of the mold is washed away by inflowing metal, it is called a *wash.* Excessively porous sands cause metal penetrations which

Table 2. CASTING DEFECT CHART

Casting Defect	Fineness		Moisture		Permeability		Green Strength		Flowability		Molding	
	Cause	Remedy	Cause	Remedy	Cause	Remedy	Cause	Remedy	Cause	Remedy	Cause	Remedy
Blow	Fine	Reduce clay and fines, increase grain	High	Reduce moisture	Low	Reduce fines or increase grain size	High	Reduce bond Increase aeration			Improper venting	Increase or improve venting
Drop			Low or high	Control moisture			Low	Increase, mixing time or increase bond	Low	Improve ramming	Hot sand, improper flask bars, weak flasks, placement of gaggers, rough handling, wrong molding machine adjustment	
Scab	Fine	Increase grain size Reduce fines	High	Reduce moisture	Low	Increase grain size Reduce fines	High	Reduce bond and moisture	High	Increase grain size	Excessive tooling, improper gagger practice, wrong gating	
Cut			High or low	Control moisture			Low	Increase mixing time or clay bond			Improper gating, hot sand	

Rough surface	Coarse	Improve grain distribution Reduce fineness or add fines			High	Reduce coarse sand grains Add fines or silica flour			Low	Reduce excessive cereal and clay or grain size	Porosity of rammed sand, lack of refractoriness	Use facing sand and protective coatings for cores and mold
Hot casting cracks	Fine	Increase grain size Reduce fines	High	Reduce moisture								See Chapter 14
Rat tails	Poor distribution	Increase grain distribution by one sieve	High	Reduce moisture								
Dirt			Low	Control moisture at correct temperature			Low	Increase mixing time or clay bond			Poor molding practice	Improve handling, finishing, and gating of molds
Penetration			High	Reduce moisture			Low	Increase mixing time or clay bond			Soft mold	Improve ramming
Difficult shake-out	Fine	Increase grain size Reduce fines	High	Reduce moisture	Low	Increase grain size Reduce fines	High	Reduce clay or select new binders				

result in castings of rough surfaces. This may be due to insufficient ramming, low flowability of sand, or large grain size. Table 2 lists the causes of casting defects due to sand and suggestions for their remedies.

Facing. It is customary to face the surface of the mold cavity with a refractory material to obtain smooth casting surfaces and to prevent sand from adhering to the casting. Light castings are often dusted with talc or soapstone, and large castings are surfaced with Ceylon lead or East India plumbago. It may be dusted on, or, if a thicker coating is required, it may be brushed on with a camel's hair brush. Molds that are dried before pouring may be sprayed or brushed with refractory solutions containing ingredients such as silica flour, molasses, and water.

Special sands containing refractory materials and fines are often used to cover the pattern in order to impart certain desirable qualities to the mold surfaces. *Sea coal,* a finely ground bituminous coal of high carbon and low ash content, is a common ingredient for *facing sand* in the casting of ferrous metals. It reduces the adherence of sand to the casting, often leaving a bright smooth surface. It is believed that this phenomenon is a result of the reducing atmosphere caused by the burning of sea coal. Because sea coal lacks bonding power, new molding sand is added to the mixture to prevent the cutting action of inflowing metal. Cereal is added to impart a tough surface to facings that are to be skin dried. Silica flour may be mixed with the facing to improve surface smoothness and increase refractoriness. Certain fire clays are sometimes used to improve refractoriness and increase bond.

Nonferrous Sands. Pouring temperatures of nonferrous metals seldom range higher than 2400° F. Because of relatively low refractory requirements, fine sands may be used to produce smoother surfaces. Grain fineness numbers for nonferrous sands range from 225 for small castings to 80 for heavy castings. Because of low pouring temperatures, less gas is generated and consequently sands of lower permeability may be tolerated. The permeability numbers of fine nonferrous sands range from 5 for very fine sands to 50 for coarse sands. Sands used in nonferrous work are often weaker than sands used in ferrous work, ranging from 3 to 6 psi in compression. When facing is used, it is made up of equal amounts of new and old molding sand. The mold cavity may be dusted with flour or sprayed with molasses water to improve the surface. Molds for metals that tend to oxidize, such as magnesium, are often faced with an ingredient containing an inhibitor (consisting of sulphur, boric acid, and fluoride salts) to retard the oxidizing action.

Gray Iron and Malleable Iron Sands. The pouring temperature of iron ranges from 2400° to 2800° F. Because of higher temperatures, a coarser sand is required. The fineness numbers of gray iron and malleable iron sands range from 40 for large castings to 150 for small castings, and permeability numbers range from 20 for the fine sands to 200 for the coarser sands. Talc is commonly used to face small molds, and plumbago is employed on large molds. A typical facing sand is composed of 1 part of sea coal to 10 parts of sand, the sand consisting of 25 per cent new and 75 per cent old sand. Results of green compression tests vary from 3 to 12 psi.

Steel Sands. The pouring temperature of steel ranges from 2750° to 3000° F. Because of the devastating effect of high temperatures, a highly refractory sand must be used, and it must be rebonded after each heat. To eliminate the necessity of rebonding the entire system, two types of sand are used, facing sand and backing sand. The facing sand may consist of half new and half old sand with fire clay or bentonite for added bond. Coarse steel sands may be rammed much harder than other sands without much danger of hindering permeability because of the low flowability and large interstices between grains. Facing sands range in fineness from 25 to 75, and permeabilities range from 100 upward. Compressive strength averages from 4 to 8 psi. Mold surfaces are often painted or sprayed with a solution of silica flour and molasses water and dried. Table 3 gives the properties of various natural bonded sands and pure silica sands and the application to which they are commonly put.

Table 3. Properties of Typical Molding Sands

(Courtesy of Warren Sand Company)

Source	Name of Sand	Foundry Use	Fineness Number	Moisture (%)	Clay (%)	Permeability Number	Green Compression (psi)	Sintering Point (°F)
Albany	Fine #00	Small brass and aluminum castings	222	6	16.6	8	6.5	2950
	Medium #1	Light gray iron (stove plates) and medium-sized nonferrous castings	158	6	16.6	16	5.5	2950
	Coarse #3	Medium-sized gray iron and heavy nonferrous castings	78	6.8	11.8	50	4.0	2950
Ohio	Warren #7	Light gray iron (stove plates) and some medium nonferrous castings	150	6	13.0	28	3.5	2500
	Gallia Red #5W	Medium to fairly large castings	82	6	22.0	120	14.0	2903
	Gallia Red #7W	Sandslinger sand for large gray iron castings	60	6	23.0	170	11.0	2903
Tennessee	#4	Medium-sized gray iron castings	104	8	20.0	31	12.0	2850
	#5	Medium and heavy gray iron castings	78	9	23.0	58	14.3	2850
	#6C	Sandslinger sand for real heavy gray iron castings	51	6.5	18.8	146	11.8	2850
Illinois	#1 Silica #50 Silica #60 Silica	Core sand and base for synthetic sands for gray iron and steel castings	40–45 65–70 80–90	Nil Nil Nil	Nil Nil Nil			
	#1 Empire	Medium-sized gray iron castings	78	6	18.7	110	12.0	3000
	#2 Empire	Medium to heavy gray iron castings	62	6	22.0	150	11.0	3000
	#3 Empire	Heavy gray iron castings	50	6	22.0	201	12.8	3000

PROBLEMS

1. How does the shape of sand grains affect the properties of sand?
2. Give the types of clay commonly used in foundry sands, and state how clay affects molding sand properties.
3. How does moisture content affect molding sand properties?
4. Describe three methods for determining the moisture content of molding sand.
5. How is bond separated from molding sand in a quantitative sand analysis?
6. Define "grain fineness number."
7. The following table represents the amount of sand retained on each sieve in the analysis of a certain grade of molding sand. Compute the grain fineness number.

Sieve Number	Percentage Retained on Sieve
6	0
12	0
20	0.3
30	0.6
40	3.3
50	14.8
70	22.2
100	16.8
140	9.3
200	2.4
270	1.4
Pan	2.7

8. What is the advantage of a test performed on a dilatometer as compared to other methods?
9. List the casting defects resulting from the following sand deficiencies:
   (*a*) Low compressive strength.
   (*b*) High expansion due to temperature change.
   (*c*) Low sintering point.
   (*d*) High moisture content.
10. What is the function of facing sand?

4

Patterns and Related Equipment

Choosing the Proper Pattern. Patterns may be made of wood, metal, plaster, or plastic. The type of pattern chosen depends on the design of the casting, the number of castings to be produced, and the production methods of the foundry in which the castings are to be made. All these factors are considered primarily with respect to the ultimate cost per casting. When a large number of castings is to be made, elaborate pattern equipment can be justified to increase efficiency in production. With lower production cost as a result of elaborate pattern equipment, and with initial pattern cost distributed over a large number of castings, the ultimate cost per casting can often be reduced considerably. There is an optimum condition under which each method of production is most profitable. Decisions on the method of production and on the equipment employed for any specific job are made from cost estimates based on past experiences with similar jobs.

Old Casting Used as Pattern. The use of the old casting as a pattern is a crude but expedient method, sometimes adopted in an emergency due to a breakdown when the time element is an important factor. Work of this type requires the skill of experienced molders who are acquainted with many unique and ingenious procedures often applied in jobbing shops. Surfaces of the casting to be machine-finished must be *lagged* by gluing on a thin strip of wood or leather to increase the sectional thickness. The casting must be cleaned and made smooth so that it will draw, and holes are tapped in the casting for draw screws. If cores are necessary, core prints must be built on the casting, and necessary core boxes must be made. Sometimes a core may be filed out of a larger stock core. The cost of making the mold is considerably higher than if a special pattern were used, but the cost of the pattern is relatively low. It should be noted that the new casting will be somewhat smaller than the original casting because of shrinkage.

Wood Patterns. When only a few castings are to be produced, a single, loose wood pattern made of white pine is most economical. White pine is light in weight, is inexpensive, can be easily shaped, and has a sufficiently fine-grained structure to take a good coat of shellac or varnish. It has the disadvantage of being a soft wood that is easily nicked or broken. If the number of required castings is less than 30 and the castings are small (under 2 ft) and not too intricate, white pine patterns are usually the most desirable; but, if the number of required castings is greater (30 to 100) and the design has slender sections, the choice of a harder and more durable wood, such as mahogany, may be preferred. Mahogany wood is moderately strong and close-grained, and it warps less than most woods when exposed to moisture. Patterns having thin sections or long, slender projections are more likely to be damaged and must be constructed with utmost care. Reinforcing ribs, called *stop-offs,* Fig. 1, are sometimes placed on patterns to prevent distortion in the molding process. The impression in the mold made by a stop-off must be filled in to prevent its appearance on the casting.

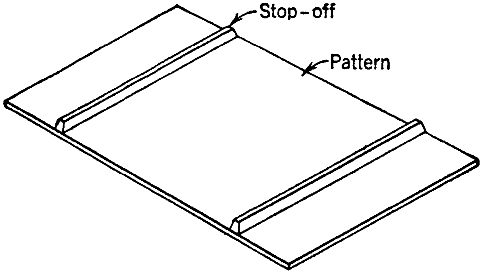


FIG. 1. Pattern with stop-off to prevent warpage.

A loose wood pattern is the only practical type of pattern for the production of a large casting. This type of pattern is usually constructed of a well-reinforced frame, covered with wood sheeting to reduce weight. Large patterns are subject to distortions causd by swelling of the sheeting due to absorption of moisture from the molding sand. Improper construction may cause the bottom of the pattern to expand sufficiently to prevent the pattern from being drawn out of the mold. The pull on a large pattern due to friction and possibly to vacuum between the pattern and mold cavity is enormous, and, unless a *draw strap* or *draw bolt* is built firmly in the pattern, distortion of the pattern results. Draw straps and bolts are fasteners concealed in the pattern for the purpose of grasping the pattern in order to remove it from the mold. In large patterns the bolt or strap should extend down through to the bottom of the pattern.

Occasionally, large patterns are split up into smaller sections and assembled to a center or body portion. In drawing the pattern out of the mold, the center portion is withdrawn first and the other sections are then easily removed.

Pattern Draft. To facilitate the withdrawal of a pattern from a mold, proper draft should be applied to the pattern surfaces that are parallel to the direction in which the pattern is drawn. The slope should be in the proper direction to provide clearance between the pattern and the mold cavity at the instant that pattern draw begins; and, as draw continues, the gap should increase until the pattern is clear of the mold. The amount of draft on the average pattern varies from ¼ to 1 degree, depending on the method of molding, the design of the casting and various complications arising in machining and assembly. If the draw is excessive, the difference in sectional thickness in the casting will be considerable and often objectionable, especially if the surface is to be machined. For example, the diameter of a cylinder 1 ft long will be approximately ¼ in. greater at the parting plane than at the opposite end, if a draft of ½ degree is used.

Occasionally, additional slope improves the appearance without obstructing functional design, and in such cases a liberal draft is most desirable. The internal design of a pattern should have more draft than the exterior design, especially with green sand cores of small cross-sectional area. The force necessary to overcome friction between the core and the surrounding pattern must be less than the cross-sectional strength of the core in tension. If a narrow margin of safety exists between the breaking force and the frictional force, variations in molding procedure and sand conditioning will cause considerable difficulty. This should be avoided by making the pattern as smooth as possible and by increasing the draft to a fair margin of safety. If a liberal draft causes finishing difficulties or if it affects the performance of the casting at assembly, a dry sand core may be considered as a replacement for the green sand core.

Finishing Allowance. The amount of metal to be added to the surface of a casting for machining purposes depends on the (1) machining method, (2) characteristics of the metal, (3) size and shape of the casting, and (4) casting method.

Physical properties of the various cast metals vary all the way from those that are most readily machined, as in certain grades of gray iron, to those that are most difficult to finish, as in white iron. Some metals have a hard surface, referred to as *skin,* which the machinist prefers to remove with a single cut to protect the cutting edge of the tool. The rough cut may be followed by one or more finishing cuts, depending on the degree of smoothness required. Some metals are too hard to finish with a cutting tool and must be ground to the proper smoothness. Additional allowances must be added to surfaces that have a tendency to warp. This is especially true of large, flat surfaces and of castings having a variation in metal thickness.

Surface characteristics such as fineness of grain structure and freedom from impurities may be controlled to a large extent by the casting and molding process. Occasionally a metal insert is contained in a mold to chill a portion of the casting, or the casting may be composed of varying sectional thickness. The sections being cooled more rapidly are harder and more difficult to machine. The bottom surfaces of a mold cavity are less likely to have defects because the impurities that are lighter than cast metals rise to the top before solidification. Sections cast in the upper position should therefore be given a more liberal allowance for finishing. Castings made by the centrifugal process should have a liberal allowance on the surfaces nearest to the center of rotation because of the tendency of impurities to be displaced to the center. Variations in casting dimensions resulting from the technique of pattern rapping and draw, ramming, and pouring can be reduced with improved equipment and intelligent controls. This is more possible in highly specialized production where finishing allowances are reduced to the mini-

Table 1. GUIDE TO PATTERN MACHINE FINISH ALLOWANCES (UNLESS OTHERWISE SPECIFIED)

(Courtesy of American Foundrymen's Society)

Casting Alloys	Pattern Size (in.)	Bore (in.)	Finish (in.)
Cast iron	Up to 12	1/8	3/32
	13– 24	3/16	1/8
	25– 42	1/4	3/16
	43– 60	5/16	1/4
	61– 80	3/8	5/16
	81–120	7/16	3/8
	Over 120	Special instructions	Special instructions
Cast steel *	Up to 12	3/16	1/8
	13– 24	1/4	3/16
	25– 42	5/16	5/16
	43– 60	3/8	3/8
	61– 80	1/2	7/16
	81–120	5/8	1/2
	Over 120	Special instructions	Special instructions
Malleable iron †‡§‖	Up to 6	1/16	1/16
	6– 9	3/32	1/16
	9–12	3/32	3/32
	12–24	5/32	1/8
	24–35	3/16	3/16
	Over 36	Special instructions	Special instructions
Brass, bronze, and aluminum alloy castings ¶	Up to 12	3/32	1/16
	13–24	3/16	1/8
	25–36	3/16	5/32
	Over 36	Special instructions	Special instructions

* Allowance ranges from 1/8 to 1 in. Values given for finish are normal for ordinary finishes on the drag side or on vertical surfaces where distortion is an unlikely factor. If necessary to have finished surfaces on the cope side of the castings, it frequently is necessary to double the finish allowance.

† When castings are constructed so that they will warp more than the average amount, the allowances given should be increased.

‡ Disk grinding—only sufficient finish required to take care of draft and possible warpage.

§ Coin pressing—practically no finish allowance required. As the properties of malleable iron particularly lend themselves to this method of finishing, it should be employed to a much greater degree than it is.

‖ For small parts, an allowance of 1/32 to 1/16 in. is satisfactory. Large parts require a slightly greater allowance. The allowance necessary depends on (1) whether the part is to be made in sufficiently large quantities to justify the making of straightening dies, (2) the fact that many finishing operations on malleable castings can be performed in a coining press, which practically eliminates finish allowance in the case of those particular operations, and (3) the further fact that many disk-grinding operations are performed on malleable castings, for which only a few thousandths finish is required.

¶ For small medium-size nonferrous castings, 1/8 in. is a customary allowance, with correspondingly larger allowances on larger castings. On split railway motor bearings, the allowance is about 1/64 in. at the parting for a grinding operation and 3/32 in. each on the outside and inside diameter on a side for machining.

mum because of low tolerances in dimensional variations in castings.

Shrinkage Allowances. Because of the inherent characteristic of metals of expanding and contracting with temperature change, the sizes of castings vary at different temperatures. At the temperature of solidification, the casting occupies the entire space of the mold cavity; but, when it cools to room temperature, the casting separates from the cavity because of the contraction of the metal. Although a slight dimensional compensation may occur in the sand mold when it is heated by molten metal, for ordinary purposes the variation in the size of the mold is negligible compared to the contraction of the casting. The difference between the size of the casting and the pattern therefore represents the amount of shrinkage of the casting.

Differences in coefficients of expansion exist not only between types of metals but often in an alloy that has undergone a slight change in composition. Close metallurgical control is often very necessary to control shrinkage. Many other factors besides uniform composition of metal enter into the problem of shrinkage. During the solidification and cooling cycle, definite changes occur in the metal constituent, and those changes often influence the rate of solidification. The amount of shrinkage depends on the type of metal formed. If, for example, a gray iron casting of a certain composition were cooled rapidly, the result would be a very hard casting of high shrinkage characteristics; but, if it were cooled slowly, a soft machinable casting would result, with considerably less shrinkage.

Reduction in casting size is also dependent on the solidification temperature of the metal. Of two similar alloys having the same coefficient of contraction, the one having the higher solidification temperature will contract more than the one with the lower solidification temperature. On the other hand, the advantage of a lower solidification temperature is often counterbalanced by a high coefficient of shrinkage, and nothing may be gained. The solidification temperature of aluminum, for example, is approximately one-half that of cast iron, but, because of the high coefficient of contraction of aluminum, the total reduction is less for cast iron. To avoid errors and erro-

Table 2. Pattern Shrinkage Allowances (Before Specifying Consult the Pattern Maker and Foundryman

(Courtesy of American Foundrymen's Society)

Casting Alloys	Pattern Dimension (in.)	Type of Construction	Section Thickness (in.)	Contraction (in./ft)
Gray cast iron *	Up to 24	Open		1/8
	25–48	Open		1/10
	Over 48	Open		1/12
	Up to 24	Cored		1/8
	25–36	Cored		1/10
	Over 36	Cored		1/12
Cast steel †	Up to 24	Open		1/4
	25–72	Open		3/16
	Over 72	Open		5/32
	Up to 18	Cored		1/4
	19–48	Cored		3/16
	49–66	Cored		5/32
	Over 66	Cored		1/8
Malleable cast iron ‡			1/16 §	11/64 ‖
			1/8	5/32
			3/16	19/128
			1/4	9/64
			3/8	1/8
			1/2	7/64
			5/8	3/32
			3/4	5/64
			7/8	3/64
			1	1/32
Aluminum	Up to 48	Open		5/32
	49–72	Open		9/64
	Over 72	Open		1/8
	Up to 24	Cored		5/32
	Over 48	Cored		9/64–1/8
	25–48	Cored		1/8–1/16
Magnesium	Up to 48	Open		11/16
	Over 48	Open		5/32
	Up to 24	Cored		5/32
	Over 24	Cored		5/32–1/8
Brass				3/16
Bronze				1/8–1/4

* A standard pattern maker's shrinkage for common gray cast iron is 1/8 in. per ft. For higher-strength irons (those of 40,000 psi tensile strength and over) and for white cast iron, the shrinkage allowance averages 5/32 in. per ft. Allowances given in table are quoted from *Specifications for Wood Patterns*, formulated by a special committee of the Milwaukee branch, National Metal Trades Association, and published as AFS Preprint 32-1 (1932).

† The shrinkage allowances for cast steel may vary somewhat according to the design of the casting, pouring temperature of the metal, restraint of projecting lugs, cores, whether cast in green or dry sand, etc., and should be verified by the producing foundry. Allowances given in the table are quoted from *Specifications for Wood Patterns* formulated by a special committee of the Milwaukee branch, National Metal Trades Association, and published by the AFS as Preprint 32-1 (1932).

‡ Patternmaker's shrinkage for malleable cast iron customarily is figured at from 1/8 to 3/16 in. per ft. Factors which must be taken into consideration are:

1. Thickness of section—net contraction of a casting 1/4 in. thick is greater than that of a casting 3/4 in. thick.
2. Length of casting—the net contraction of a casting 5 in. long is greater than that of a casting 20 in. long.
3. Carbon content—the net contraction of a low carbon casting is somewhat greater than that of a high carbon casting. In uniform, standard-quality malleable cast iron, there will be insufficient variation in the carbon content to require consideration of this factor.

§ The values given under malleable cast iron are the average results of shrinkage tests conducted by seven foundries on rectangular, 15 by 1 1/2-in. bars with various thicknesses and are reported by the Malleable Iron Research Institute, Cleveland.

‖ Contraction results reported in the table are *net contraction values;* that is, the original white iron casting, which shrinks 1/4 in. per ft when cast, expands 1/8 in. during the anneal, resulting in a net contraction of 1/8 in.

neous conclusions, it is customary in pattern making to use the total shrinkage value instead of the coefficient. A shrinkage of ⅛ in. per ft represents the customary shrinkage for cast iron. This means that a casting measuring 12 in. at solidification temperature will be 11⅞ in. at room temperature. If it is desired to have a casting 12 in. long, the pattern will have to be 12⅛ in. to compensate for shrinkage. The pattern maker is equipped with special scales, called *shrink rules*, to compensate for shrinkage values without computing the necessary additions. On a ⅛ in. per ft shrink rule, each foot is ⅛ in. longer, and each graduation on the rule is oversized a proportionate amount. Shrink rules of allowances commonly specified for standard metals and alloys are available in both the English and metric systems.

The influence of design on the rate of shrinkage is a very important factor. Flanges and similar projections extending from the body of a casting are often responsible for reduced shrinkage because of mold obstruction. In extreme cases, the casting may crack or break in several pieces, owing to such obstruction to shrinkage. The consideration of machining allowances must be closely correlated to shrinkage, especially in large castings or designs where shrinkage will be obstructed. A cylindrical casting, for example, may be prevented from shrinking on its diameter because of the obstruction of a core. If a normal machining allowance is made for both the inside core and the exterior of the cylinder, the machine shop may find insufficient allowance for boring and excess allowance on the exterior finish unless the abnormal shrinkage is taken into consideration. Manufacturing concerns producing castings in large quantities have accumulated considerable data and can predict exact shrinkage rates on their products. More than one shrink rule is often employed in the production of a pattern.

Pattern Colors. Frequently, a print of the finished casting is not furnished with a pattern, and as a consequence the foundryman is not able to take the necessary precautions to produce the best results. Many mistakes may be eliminated by indicating the functions of the various parts of a pattern with proper colors. A loose pattern part may get lost, and, unless the pattern is marked to indicate the seat of the loose piece, it is quite possible that the casting will be made from the incomplete pattern. If a molder knows what surfaces are to be machined, he will, if possible, mold the pattern in a position to produce a surface more nearly free of impurities. Even if he has no choice of position, many other things may be done to obtain best results. With properly marked core prints, the molder is constantly reminded that cores must be set in the mold before it is closed. Patterns with stop-offs should be marked to remind the molder to fill the mold cavity made by the stop-off. Errors resulting from improperly marked patterns are both embarrassing and costly to both the producer and purchaser of the casting.

A standard color scheme was agreed upon by a joint committee of all associations dealing with the production of patterns and castings, and approved by the National Bureau of Standards, Department of Commerce. The same standards are applied to core boxes as well as patterns. They are as follows:

1. Black—surfaces of the casting to be left unfinished.
2. Red—surfaces of the casting to be machined.
3. Yellow—core prints and seats of and for loose core prints.
4. Red stripes on a yellow background—seats of and for loose pattern parts.
5. Black stripes diagonally on a yellow background—stop-offs.

Unfortunately the above color scheme applies only to wood patterns and core boxes. Metal patterns should not be painted because of the possibility that the paint will chip, leaving a rough surface.

Metal Patterns. Metal patterns are made of brass, bronze, white metal, cast iron, and aluminum alloys. Small patterns are frequently made of brass or bronze. They draw well from the mold and maintain a smooth finish because of their resistance to atmospheric corrosion. Certain alloys, called white metals because of their characteristic white color, are often used for patterns because of their low shrinkage characteristics. They are softer and therefore less durable, but they are less expensive to produce because of the ease of finishing. Cast-iron patterns are sometimes used in machine molding. Patterns for small, light work are not ordinarily made of cast iron because of their tendency to rust. Special care and treatment to prevent rusting may be justified for iron patterns where stiffness is an important factor, as in machine molding.

Aluminum for patterns is gaining popularity in all fields of production molding because of its light weight. Other common pattern metals weigh at least three times as much as aluminum, and with modern metallurgical advances aluminum alloys compare favorably with the other metals in strength, corrosion resistance, and machining characteristics. Frequently, aluminum patterns are supplemented with other metal parts to gain certain advantages. For example, parts of a large pattern that are subject to considerable wear may have steel inserts called *wear strips* fitted in the pattern at focal points of wear. A portion of a pattern that is very complicated and difficult to form may be made of brass or white metal, the remainder of the pattern being aluminum.

Metal patterns are more expensive than wood patterns and can be justified only in high production work. There is a limit to the size of a metal pattern because of weight, even with aluminum. The density of aluminum is from five to eight times as great as the density of a wood pattern, depending on the type of wood.

Master Patterns. Except for simple elementary shapes, metal patterns are cast in molds with master patterns made of wood. Double allowances in shrinkage must be applied to the master pattern, and, if the casting is machined, allowances must be made for finishing the pattern as well as the casting. Figures 3 and 4 illustrate the allowances made on the aluminum production pattern and the wood master pattern in the production of the cast-iron stop block shown in Fig. 2. It should be noted that alterations in dimensions from the finished casting are made for finishing only and that shrinkage allowances are specified with notes, indicating the shrink rule to be employed in the construction of the pattern. Because only one exterior surface of the casting is to be finished, the overall dimensions specified on the drawing of the production pattern will remain the same as the dimensions of the casting except for the height. If $\frac{3}{32}$ in. is allowed for each finished surface, the width of the groove in the production pattern will be reduced by 3/16 in. and an additional reduction equal to twice the finishing allowance for aluminum will be made on the groove in the master pattern. The diameter of the core must be smaller than the bored hole by the specified allowance of 1/8 in.

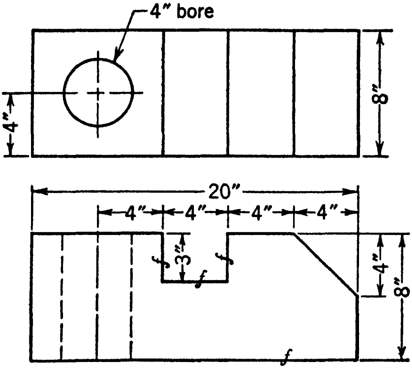
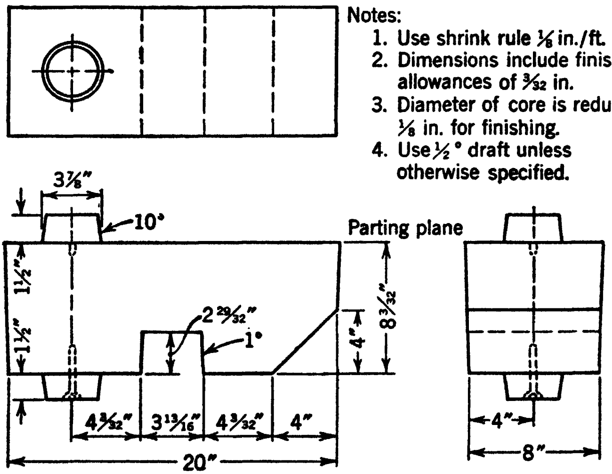


Fig. 2. Cast-iron stop block.

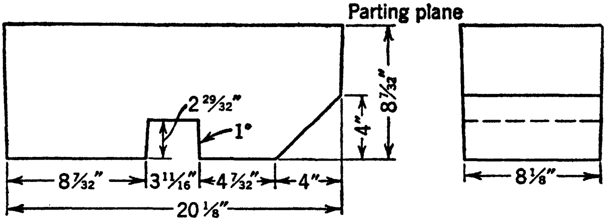


Notes:

1. Use shrink rule 1/8 in./ft.
2. Dimensions include finishing allowances of 3/32 in.
3. Diameter of core is reduced 1/8 in. for finishing.
4. Use ½° draft unless otherwise specified.

Fig. 3. Aluminum production pattern.

It is easier to machine core prints from round aluminum stock than to cast them on the pattern. The drag print is fastened on the pattern with a countersunk screw, and the cope print is rigged up as a loose print so that the pattern may be molded as a flat back pattern. A liberal draft is placed on the grooved slot to insure a clean draw in both the master and working patterns.



Notes: 1. Derive shrink rule as follows:
Shrinkage of cast iron____ ⅛ in./ft.
Shrinkage of aluminum___1/16 in./ft.
Master pattern shrink rule_3/16 in./ft.
2. Dimensions include overall finish allowance of 1/16 in. for all exterior and interior surfaces.
3. Use ½° draft unless otherwise specified.
4. Core prints for production pattern to be machined from bar stock.

Fig. 4. Wood master pattern.

Plaster Patterns. The development of gypsum cements of controlled expansion characteristics and high compression strength has given rise to a new type of pattern, the plaster pattern. In contrast to metal, gypsum cement expands upon solidification. Various commercial grades of cement have been developed with expansion properties ranging from 0.02 to 1.25 per cent by volume. When pattern dimensions must be held to close limits, a low-expansion cement is used. Occasionally it is desirable to use a high-expansion cement to offset the shrinkage of the metal casting. Gypsum cements with compressive strengths ranging up to 4000 psi have been developed for pattern making, and, when properly constructed with fiber or metal reinforcements, structures with strength up to 15,000 psi have been developed. The common cement, plaster of Paris, known for its many commercial applications, has a compressive strength of 1600 psi.

When gypsum cement is mixed with water, it forms a plastic mass which may be cast in a mold or swept into desired form.

With the casting process, the cement is poured into the mold immediately after it is mixed and while it is still in a free-flowing state. If it is to be swept into shape with templets, it is allowed to stand until the period of plasticity sets in. The cement remains in this thickening or "creaming" stage from 15 to 30 min, depending on the type of cement. In this period of controlled flow, the pattern is built up and modeled into desired form with specially prepared templets, commonly called sweeps. If the plaster hardens before the job is completed, another mix is made and applied to the partially constructed pattern. Suffi-

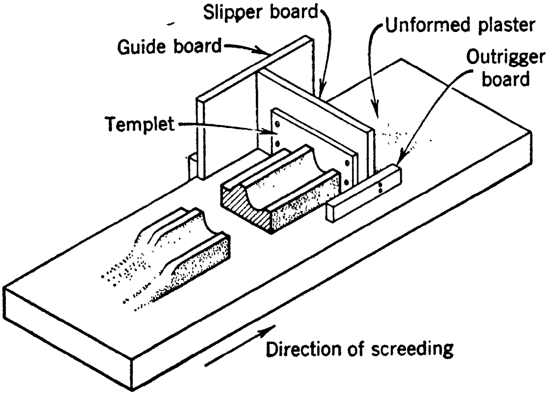


Fig. 5. Screeding a plaster pattern.

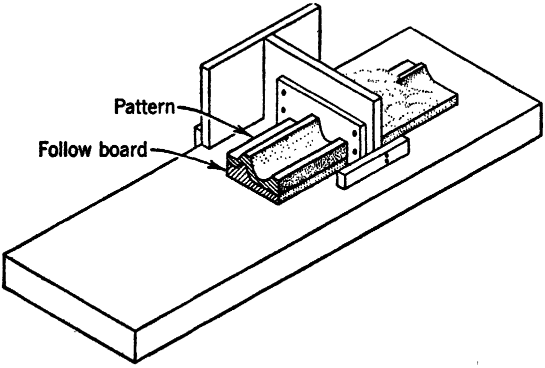


Fig. 6. Screeding pattern over a plaster follow board.

cient bond is obtained between layers of successive applications without loss of strength, and therefore any number of applications may be used to complete the job. In many cases a stronger pattern is obtained by inserting hemp or wire mesh with each application of cement.

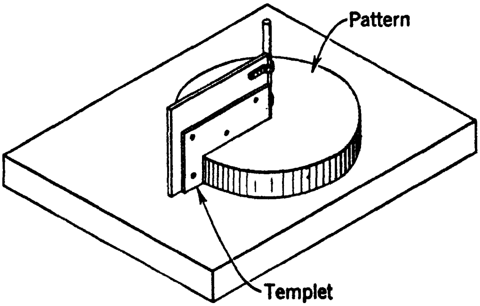


Fig. 7. Screeding a round, flat disk.

The straight-run molding process, illustrated in Fig. 5, consists of passing a templet through the plaster to form the desired shape. This is referred to as *screeding*. The steel templet is assembled to a sled which holds the templet in its proper position with respect to the work and guides it uniformly throughout the length of the sweep. As soon as the creaming stage is approached, the plaster is spread over the area in the path of the sweep. With the edge of the table as a guide, the sled containing the templet is screeded through the plastic mass with a single, continuous stroke. The templet is then cleaned off, additional cement is added to the model, and it is screeded again. This process is continued until the pattern is completed. Fabrication, carving, and scraping may be performed on the pattern after plasticity ceases, if the pattern is still moist. The pattern is then cut to the proper length by cutting the ends off with a carpenter's handsaw. If the top and bottom of the pat-

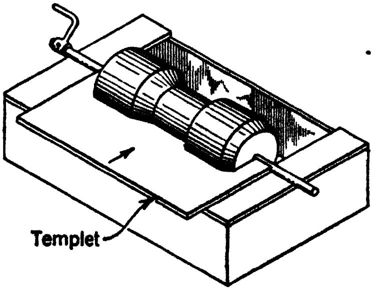


Fig. 8. Screeding a cylindrical pattern.

tern are to be irregular in shape, a base contour, referred to as a *follow board* (Fig. 6), is first formed. A thin film of oil or other parting material is applied to its surface, and the pattern is screeded over the follow board. This same method may be used to make loose pattern parts for three- or four-part molds.

With proper guides and fixtures, all geometric forms and irregular contours may be formed with plaster. A round slab, Fig. 7, is formed by rotating the templet about a spindle. The long cylindrical pattern of Fig. 8 is formed by applying the cement to a rotating spindle, and, when the form is built up to proper size, the circular contour is formed by setting a templet against the rotating mass at the proper distance from the center of rotation.

Pattern Parting. Pattern parting may be classified as straight and irregular. The flat back pattern (Fig. 1 of Chapter 2) and the split pattern (Fig. 7 of Chapter 2) are the most desirable for small- as well as large-quantity production. Many castings do not have flat back partings, nor can the pattern be split because of the nature of the design. In small-quantity production the laborious task of cutting the parting may as much as double the molding time. This handicap may be overcome, at least in part, with more elaborate equipment such as follow boards, cast pattern plates, or special core designs, described in detail in this chapter and in Chapters 5 and 13. However, one should bear in mind that such equipment is usually costly and often cannot be justified on the basis of the number of castings to be produced. Occasionally, loose pattern parts must be added to the pattern, and, if there is no other way of holding them in place, the parts must be pinned into position. This requires a special molding technique. Some designs may require more than one parting, each of which may be either straight or irregular, depending on the design. With a given design, the pattern maker and the foundryman have a limited latitude in which to work, and beyond that it is the sole responsibility of the casting designer to plan economical production.

Follow Board or Pattern Match. The least expensive equipment to facilitate a parting without the necessity of cutting it by hand is the *follow board* or *pattern match.* The two terms are almost synonymous, the former being an all-inclusive term. The term "match" is usually preceded by a descriptive modifier to indicate the material from which it is made. The green sand match is the least stable and must be carefully handled to avoid damage. Other common types are the hard sand match, the plaster match, and the wood match. A hard sand match may be composed of a mixture of 20 parts of burned molding sand to 1 part of litharge, moistened with linseed oil to the dampness of molding sand. The wood match is the most costly because of the labor required to carve the shape of the parting in the wood base.

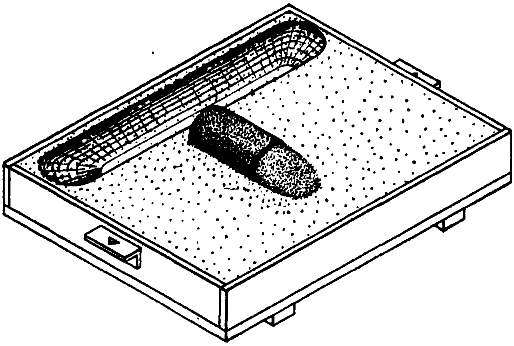


Fig. 9. Follow board for a boiler bracket pattern.

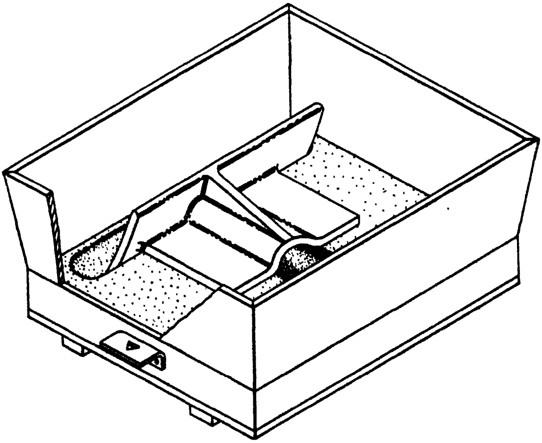


Fig. 10. Pattern and tapered flask, assembled on follow board.

Figure 9 shows a follow board designed to form the parting of a boiler bracket. (For a description of the molding of the boiler bracket without a follow board, see Fig. 12 of Chapter 2.) The parts of the pattern that form the cope cavity fit down into the follow board so that they project above the plane of the drag when the board is removed from the drag. The cavity in the follow board is identical with the cavity to be formed in the cope. The drag half of the flask is set on top of the follow board, with the pattern in place as shown in Fig. 10. After the drag is rammed up, the drag assembly, including the pattern and follow board, is rolled over and the follow board is replaced by the cope. The molding process is not interrupted by the necessity of cutting a parting because the exposed surface of the follow board, with the pattern in place, has the contour of the desired parting plane.

In making a follow board, the drag is molded in the customary way by means of a plain molding board, and the parting is cut by hand as previously described in the molding of an irregular parting. The rectangular frame of the match is placed over the completed drag, and the match material is rammed in and struck off level with the top of the frame. A bottom board is then fastened to the frame with screws, the assembly is rolled over, and the drag is lifted off the follow board. The surface of the follow board is slicked down, and minor repairs are made where necessary. The follow board is then set aside in a warm place for 24 hr to harden. Finally, it is given a number of coats of shellac before it is used.

Follow boards, with the exception of those made of wood, are usually bulky and make the rolling-over operation more difficult. They are subject to damage and must be handled with care, the green sand match being the least permanent.

Gated Patterns. A pattern for the gate may be fastened to a pattern to reduce molding time. If a group of patterns is to be placed in one mold, the gate pattern has a further function of holding the patterns in the proper position with respect to each other. Figure 11*B* shows a cluster of four patterns fastened together by a gate. Because of the irregularity of the parting surface, a wood match, Fig. 11*C*, was made by drilling four holes through a plain molding board. Figure 11*D* shows the pattern in position to be molded. Before the cope is drawn, a rod is passed down through the sprue and fitted into the hole in the center of the gate, as illustrated in Fig. 11*E*. The top end of the bar is held firmly and rapped to loosen the pattern in the mold. The disadvantage of gated patterns is that the assembly is fragile and must be handled carefully. This is especially true of wood patterns.

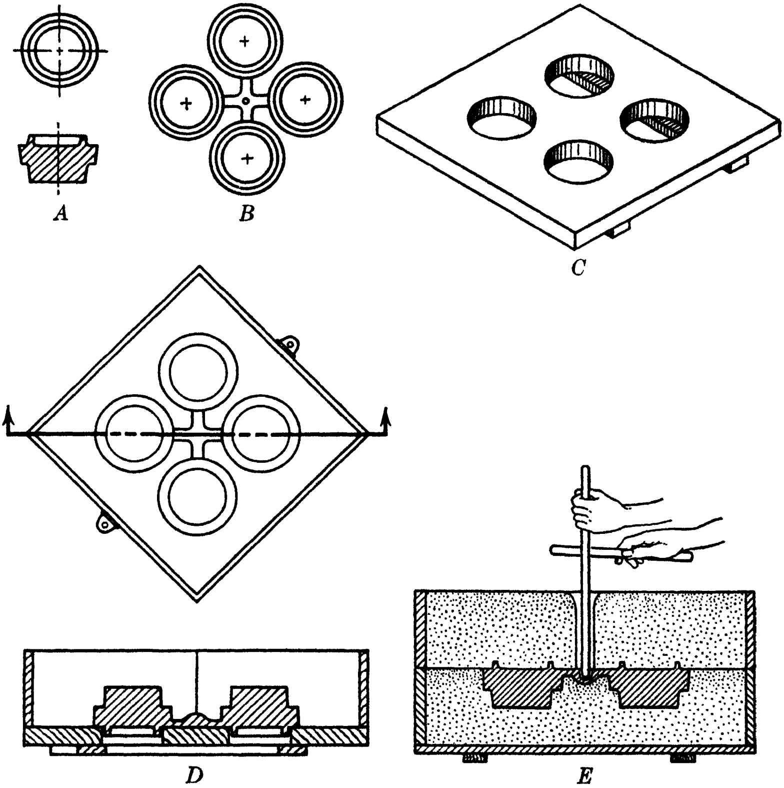


FIG. 11. *A*. Pattern. *B*. Gated patterns. *C*. Follow board (wood match). *D*. Gated pattern and flask, assembled on follow board. *E*. Pattern being rapped before cope is drawn (section taken diagonally through mold).

Match Plates. Highest and most efficient production is achieved with patterns that are mounted, cast, or fabricated to a plate. The match plate is indispensable, not only in machine molding but often in hand molding where a fairly large quantity of small castings is to be made in bench molds. The efficiency of the molder is not only increased many times over, but the quality of the castings is improved and the yield is increased by reduction in the amount of scrap. Vibrators fastened to match plates provide better lifts, make less draft necessary on patterns where draft is unwanted, eliminate swabbing which is undesirable because excess moisture contributes in many ways to defective castings, and produce castings of greater dimensional accuracy as a result of uniform rapping.

Flat back patterns and split patterns may be conveniently fastened to a standard flat plate called a *master* or *universal match plate.* Universal match plates may be purchased to fit standard-type flasks and are specified according to the mold size in the same way that flask sizes are specified. Although universal plates may be obtained in wood, magnesium, and steel, the most popular plate is made of aluminum. Magnesium plates are lighter and possibly stronger than aluminum, but they are more costly to produce. Steel plates are the most rigid but have the disadvantage of excess weight. Prior to the development of aluminum as a popular casting alloy, wood match plates were the most desirable. Wood plates have the advantage in that patterns may be fastened in position with wood screws, making it easier to interchange them. Wood plates are made of glued strips to prevent warping. Their flat surfaces are marked with center lines extending from the centers of the flask pin holes for locating and aligning patterns. Lines at various intervals from the center line and also at right angles to the center line are located for the same purpose. Metal strips are fastened along the perimeter of the top and bottom faces to protect the wood plate from wearing when in contact with the flask.

Figure 12*B* shows a metal universal match plate equipped with vibrator, two patterns, and gates. Vibrators are operated by air or electricity. Electrical vibrators produce more uniform vibration, but where average dimensional accuracy is required the air-operated vibrator is preferred. Air vibrators are rugged and simple in construction, and, because molding machines are supplied with air lines for blow-off, it is convenient to use air for as many purposes as possible.

Metal patterns may be riveted to universal match plates, or they may be fastened on with countersunk head screws. The gate is assembled to the plate in the same way. A match plate is especially desirable when a large number of small patterns are to be made in one mold. In order to get the top and bottom halves of a split pattern directly opposite each other, the two halves of the pattern are assembled and drilled through. One half of the pattern is then set on the plate, and the plate is drilled, with the hole in the pattern as a guide. The two halves of the pattern may then be fastened to the plate by countersunk rivets. Figure 13*B* shows a match plate containing two split patterns.

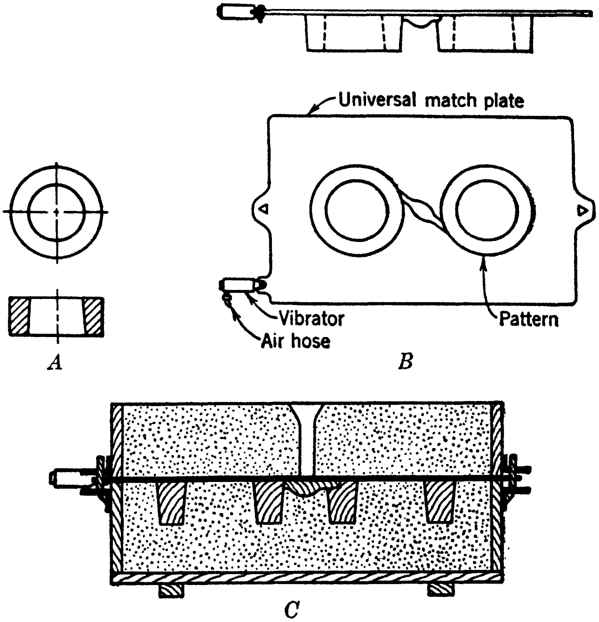


FIG. 12. *A*. Pattern. *B*. Universal match plate with pattern and vibrator attached. *C*. Sectional view, before cope is drawn.

A pattern with an irregular parting cannot be assembled to a universal match plate. If the plate and pattern are to be made of wood, the entire assembly may be built up as an integral unit. Metal match plates and irregular parted patterns are cast in one piece. The cost of finishing such plates is usually high because of the amount of hand work necessary.

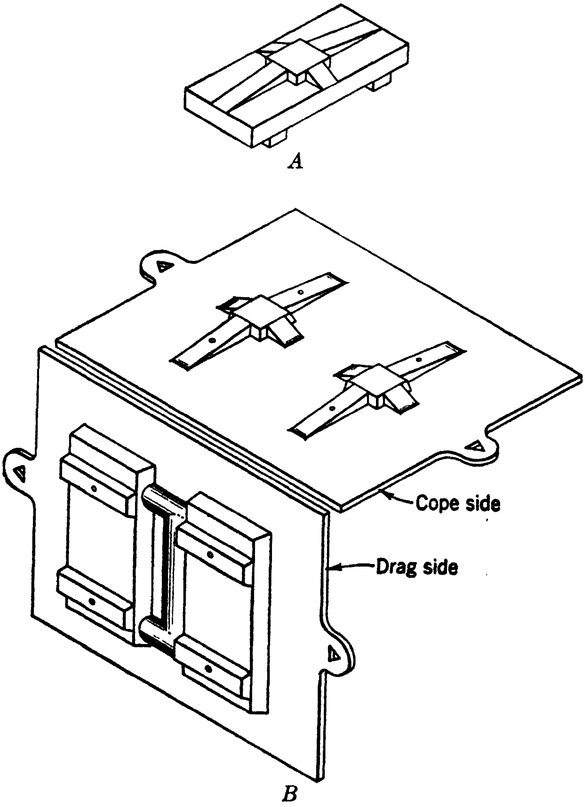


FIG. 13. *A*. Casting. *B*. Split pattern mounted on a universal match plate.

To make a cast plate, such as illustrated in Fig. 14, the master patterns are molded in the customary way in a flask large enough to accommodate both the master patterns and the plate pattern. When the cope is lifted, a frame representing the pattern of the plate is set over the mold cavity and the space between the frame and edge of flask is packed with molding sand and struck off level with the top of the frame, shown in Fig. 15*A*. The frame pattern and master patterns are then drawn, leaving a mold impression of the plate, the bottom of which contains the cavity of the part of the pattern to be molded in the drag. The irregular parting on the top side of the plate is formed by the cope. The completed drag as it appears before closing is illustrated in Fig. 15*B*.

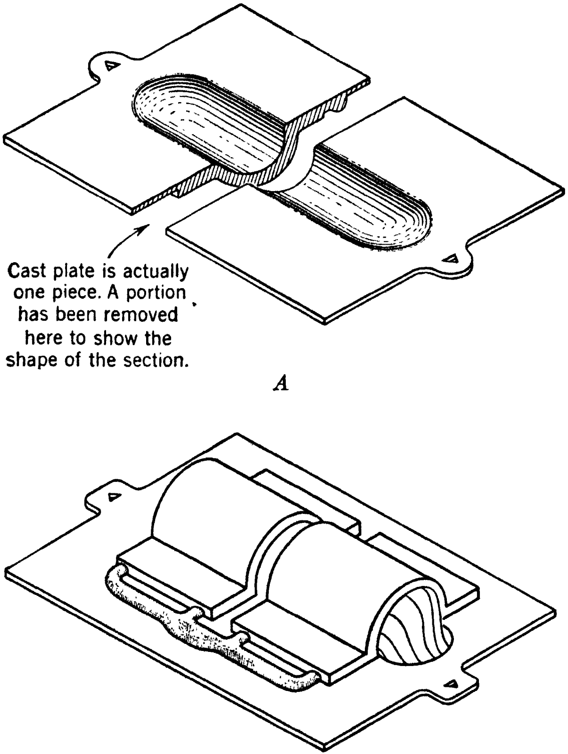


Fig. 14. *A*. Cope side of cast plate. *B*. Drag side of cast plate.

Considerable experimentation has been performed on plaster match plates, and the process has been successfully applied in some foundries. The plate is cast similar to a metal plate, except that a steel frame is set in the mold instead of the match plate pattern. The cope is closed over the embedded frame,

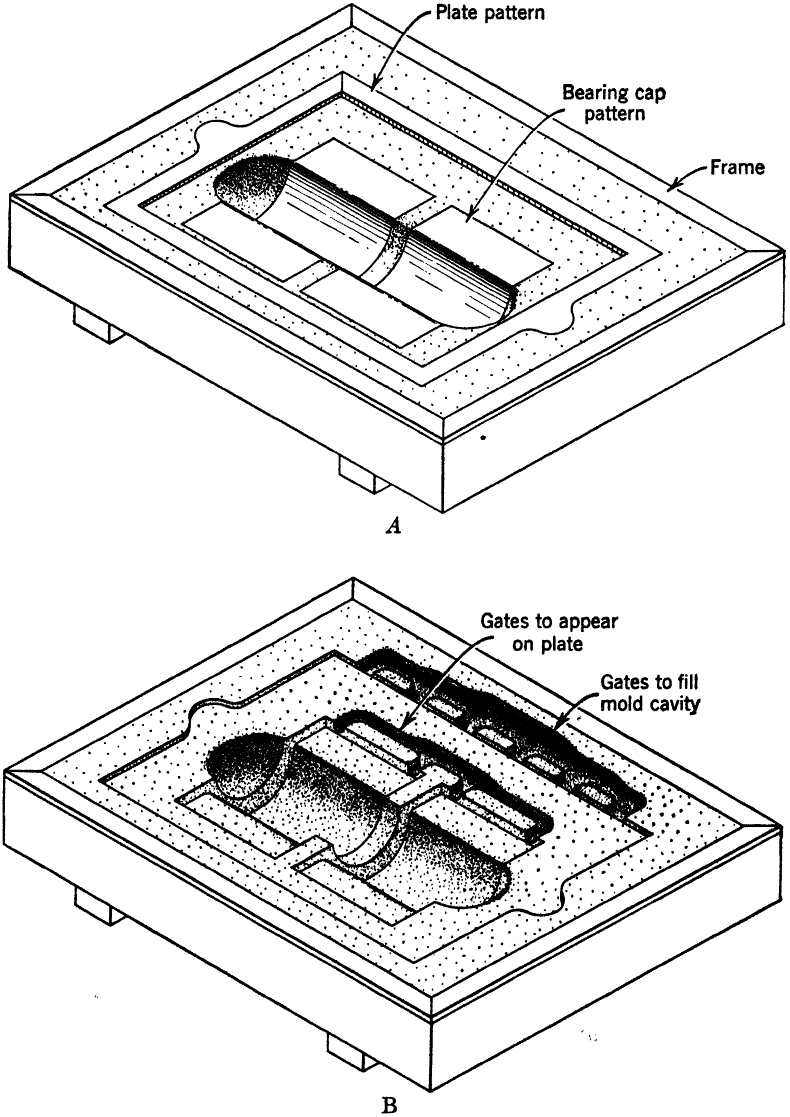


FIG. 15. *A*. Drag for cast plate before patterns are removed. *B*. Completed drag for cast plate.

and plaster is poured in the mold, filling the area within the frame. The plaster is supported by a maze of reinforcing straps extending across the structure. It is claimed that a more economical plate is obtained because the plaster pattern is more easily finished.

Plastic Patterns, Match Plates, and Core Boxes. The use of *thermosetting plastics* (liquid plastic that becomes solid when heated and remains solid, regardless of temperature thereafter) is becoming increasingly popular, especially for duplication of patterns, match plates, and core boxes. In the production of castings in large numbers, more than one pattern is frequently necessary, and the cost of reproducing these patterns in plastic is often less than the cost of wood or metal patterns.

Plastic patterns are water resistant and therefore need no protective coating. Because of their porcelain-like finish, plastic patterns are readily cleaned with a blast of air, no parting compound is needed, and less vibration or rapping is necessary in pattern draw.

Plastic patterns and core boxes are made in molds of various materials, such as wood, plaster of Paris, rubber latex, synthetic rubber, low-melting bismuth-lead alloy, and other materials that will stand the curing temperature of the plastic material, the temperature being in the neighborhood of 140° F. The mold is preferably made with a master pattern which compensates for dimensional changes in solidification. Shrinkage of these plastics is relatively low, the value of one material varying from 0.0047 to 0.0025 in. per in., depending on the amount of catalyst added to accelerate solidification.

A plastic pattern may be cast into a wood or metal match plate in the following manner. The drag half of a gated pattern is sprayed with a low-melting alloy, such as that mentioned above. If the pattern is irregular it is placed in a follow board and sprayed. A metal shell of about ⅛-in. thickness may be sprayed on the pattern with a common paint-spray machine, operated at a temperature of about 200° F. When the shell cools, it is removed from the pattern and rammed up in a drag as if it were a pattern. The mold is rolled over, the pattern is placed back in the metal shell, and the exposed cope portion of the pattern is given the same treatment as the drag. After necessary details are completed, such as separation of shell from pattern and trimming of shell, the shell, containing the pattern, is rammed up in a new mold. When the mold is separated, the pattern is removed from the embedded shell and the drag half of the shell is filled with plastic. A wood or metal plate is then placed over the filled cavity, and the cope is closed over the drag, the cope resting on the plate. The portion of the plate that is located between the cope and drag cavities is perforated with holes so that the plastic material will flow through and join the two halves of the pattern to the plate. The sprue in the cope leads directly into the mold cavity through a small hole in the shell. When the mold is filled with plastic, it is placed in an oven and heated to the curing temperature at which the plastic will solidify. The amount of time and the type of treatment depend on the characteristics of the plastic and the method of casting.

PROBLEMS

1. State the factors to be considered in pattern design when determining (*a*) pattern draft, (*b*) machining allowances, and (*c*) shrinkage allowances.
2. State the types of mold parting, and discuss briefly their advantages and disadvantages from the standpoint of economical mold production.
3. Under what conditions is a follow board preferable to a match plate?
4. What types of patterns may be mounted on a universal match plate?
5. When are cast plates necessary, and why are they costly to make?
6. Make a sketch of the production pattern and the master pattern for the production of the angle bracket in the following figure. Dimension the sketches.

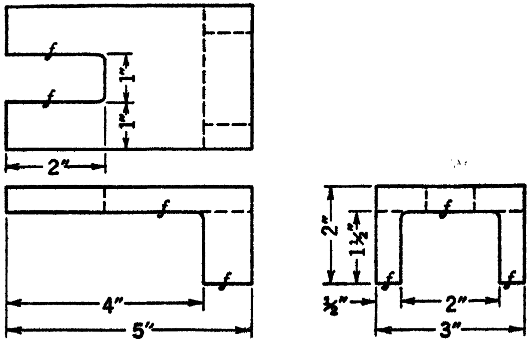


Fig. P6. Angle bracket. Material C. I. No. Reg. 10,000.

5

Cores and Their Applications

Green and Dry Sand Cores. Although a core is properly defined as that portion of a mold which forms the interior of a casting, the term is loosely used. The common *green sand core* is formed by a cavity in a pattern which produces a sand projection in the mold when the pattern is drawn. In general, this projection ceases to be recognized as a core when it does not form a hole through the casting. It is then considered as a part of the mold contour. Green sand cores reinforced with rods, called arbors, are sometimes made in core boxes and transferred to the mold after the pattern is drawn, but this practice is limited because of the consequential breakage due to the weakness of green sand. If the design is such that it cannot be formed in the pattern with green sand, it is common practice to use a *dry sand core* which is made in a *core box,* baked in an oven, and then placed in the mold. Occasionally a core is made in two parts, the bottom half being dry sand to produce the necessary support, and the top half, green sand. All dry sand forms that are made independently of the molding process and inserted in the mold to form external or internal parts of the casting are customarily referred to as cores.

Core Properties. Among the properties of cores about which the foundryman is most concerned are hardness, green and dry strength, permeability, smoothness of surface, resistance to temperature, collapsibility, gas generation, and moisture absorption. The type of core desired in the production of a casting depends on many factors. In developing a production process, the foundyman studies the design of the casting, the number and type of cores involved, specifications on tolerances and finish, and other details that may be affected by the physical properties of cores. If, for example, a part of a core has slender projections which may tend to sag or collapse when in the green state prior to baking, the core mixture must be compounded to make a strong green core. Emphasis on this characteristic may be obtained only at a sacrifice of other desirable properties, such as permeability and collapsibility. If the core is long and slender, it must possess sufficient dry strength to withstand the pressure of the impinging metal stream when the mold is poured. It must have sufficient strength to support its own weight when suspended or supported by slender core prints, and if surrounded by molten metal it must withstand the force of buoyancy.

In some designs the core must be supported by a single core print. Such a core must possess high permeability to facilitate the removal of gases caused by its burning. It may be necessary to vent isolated portions of the core with *vent wax,* a wax taper which is embedded in the green core. When the core is baked, the wax melts, leaving an escape channel for the gas.

Cores must keep their form until solidification takes place. An ideal core should collapse and revert to sand after the metal solidifies. Metals poured at high temperatures require high-temperature-resistant cores. If the core strength is in excess of that required to resist the pouring temperature, the core may fail to disintegrate, and difficulty may be encountered in removing it from the casting.

Core Sand. The ingredients in cores may be classified as sand and binder. Various qualities of sand are used in making cores, depending on the properties desired in the core. A high-silica sand containing very little, if any, clay bond is generally used. Sands of various grades and characteristics are obtainable in all parts of the United States, but because of the cost of transportation it is most desirable to use local sands. When this is not possible, it may be desirable to install sand-reclaiming equipment to re-use a certain percentage of the burned sand. Especially small foundries and even large ones which are located near the source of supply find it most economical to use new sand in their core mixtures.

A satisfactory core sand for malleable and gray iron castings is found in the Lake Michigan area. The grains are sub-angular and vary in fineness number from 43 to 69, depending on the deposit. An extensive deposit of sand known as St. Peter sandstone extends in a belt several hundred miles wide from the central part of Minnesota to Arkansas. The coarser grades of this deposit are excellent for the manufacture of steel castings, and the finer grades are used in nonferrous work. Sand deposits in the Ottawa district of Illinois are most easily reached because they lie near the surface, whereas other areas have considerable overburden of soil. The deposit in Minneapolis, Minnesota, was discovered as a result of the construction of a series of sewer tunnels many feet under the city. St. Peter sandstone varies in fineness number from 30 to 83 and is considered a high-grade core sand.

In choosing a core sand the foundryman considers grain size, distribution and shape, clay content, and mineralogical composition. If the object is high permeability, he chooses a large, round-grained sand of uniform distribution. Rounded grains have less contact with one another, the sand requires less bond, and the cores bake more easily. They possess lower green strength than other grain shapes. They may wash when exposed to a metal stream, and they separate more rapidly when heated. Large grains generally possess greater resistance to heat but produce a coarser surface. Because of less grain surface area in a given volume of large-grained sand, less bond is necessary to coat the grains properly. In sand with a wide distribution in grain size, the small grains occupy the spaces between the large ones, producing a stronger core with smoother surfaces but lower permeability. The chemical composition of sand is not a reliable criterion in the selection of core sand, but a mineralogical examination is more helpful. A high percentage of quartz is desirable because quartz does not fracture when exposed to heat. Other minerals may be less desirable because of cleavage planes which cause the grains to be more brittle.

Sand Reclamation. Large foundries that use core sand at a rate of 5 to 15 tons per hour may find that the cost of transporting new sand to the foundry and used sand to dumping area far exceeds the cost of reclaiming sand. By reclaiming old sand, the problem of storing large supplies of sand through the winter months is eliminated. About 85 per cent of the sand may be reclaimed by an efficient system. There are three known methods of sand reclamation: the dry system, the thermal system, and the wet system.

In the dry system, the cores are crushed, screened, and passed through a column of moving air, the velocity of which is adjusted to remove the fines. This method is less efficient than the wet system because of considerable loss of sand removed by the air blast.

In the thermal method, the used sand is heated to a temperature of 1000° F to burn off all the combustible material. The residue is removed by a method similar to that used in the dry system.

The wet method of reclaiming sand consists of washing the sand free of binder and other soluble substances. This process not only eliminates dust but provides an economical method of transporting sands by pumping the sand and water mixture through pipes.

The used core, removed from the casting at the core shake-out station, drops through an opening in the floor to a vibrating screen which is sprayed with water. The portion of the core that washes down through the screen falls into a *sump* and is pumped into a dewatering tank. The remaining lumps that roll off the end of the screen are conveyed to a crusher unit where a similar process of screening is repeated after crushing. Gaggers, reinforcements, and scrap metal that do not pass through the screen are deposited at the end of the screen.

As the mixture of sand and water enters the dewatering tank, it passes over a fine screen to remove small foreign material such as nails and iron shot. The sand grains settle to the bottom and are removed by a conveyor which slowly scrapes the sand up an incline, out of the tank, and into a reservoir. The wet sand is then conveyed to a muller in desired quantities by means of a crane and grab bucket. Scrubbing action of the muller frees the grains of all adhering soluble substances.

After the mulling process, a belt conveyor carries the discharged sand to a classifier where it is again picked up by a stream of water and passed over a series of openings called classifier cells. The sand grains settle in the cells, and the unwanted fines and dissolved impurities pass on with the stream. The sand is then pumped into a drier where it is centrifuged to remove water. It is then conveyed to a final drier consisting of a steam-heated drum rotating on a horizontal axis where the sand is dried to the desired degree of dampness. Because of the large volume of water needed in this process, it is customary to reclaim the water by pumping it into a reservoir where the sludge is permitted to settle. Sludge is removed from the bottom of the reservoir, and system water is taken from the top.

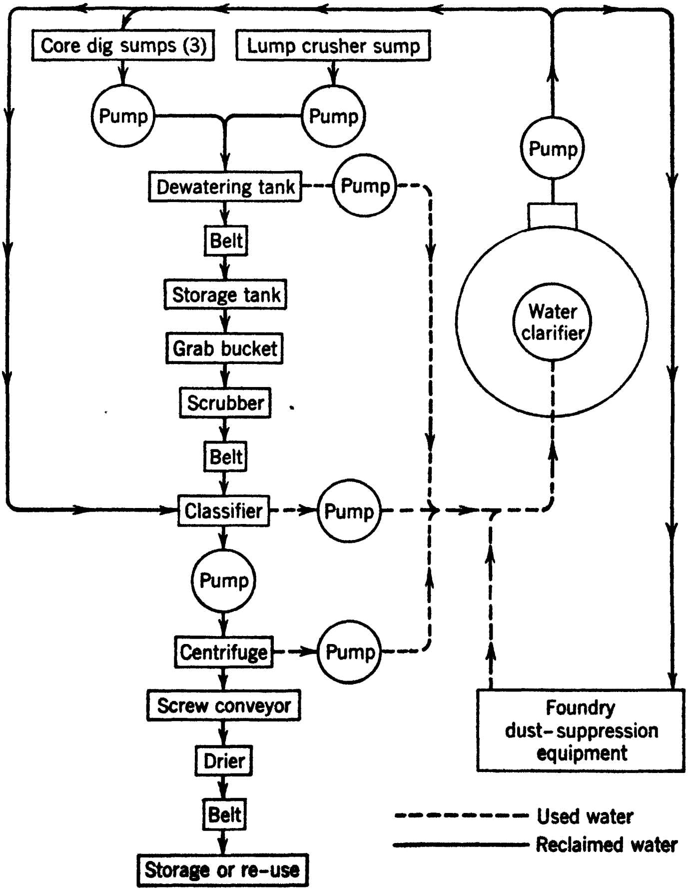


FIG. 1. Sand-water flow chart of a sand reclamation system. (Courtesy of *The Iron Age*, and Cincinnati Milling Machine Co., Cincinnati, Ohio.)

Core Binders. The function of core binders is to cement the grains of sand into desired forms and to impart sufficient strength to cores to prevent breakage, distortion, or erosion in the core making, molding, and casting process. The binder should have good dispersing properties to avoid excessive mixing and should form a mixture which does not stick to core boxes. The resulting core should be sufficiently permeable, should produce the minimum amount of gas when in contact with molten metal, and should disintegrate after the metal solidifies. To acquire all these properties in a single bonding material has been, and still is, the object of considerable research.

The cementing action of core bonds is chemical or physical, depending on the characteristics of the bond. Frozen green sand cores (depending on water for bond) have been used with success in some rare cases. Bonding action of commercial binders is generally attained by heating the core in an oven. This class of binders consists of oils, cereals, rosins, sulfite liquor, molasses, and proteins.

Oil bond depends on the drying action of heat for core strength and hardness. Like varnish, the oil coating remains gummy in the dried condition. Before manufactured core oils were available, linseed, marine, and corn oil were used. Commercial core oils are more economical and produce better cores. Although vegetable oils are the principal ingredients in core oils, specially processed mineral oils are not uncommon. A small quantity of highly refined sardine oil is often used to prevent the sand from sticking to the core box. The solidification of vegetable oils depends on a chemical reaction with the oxygen of air at a temperature ranging from 350° to 450° F. Mineral oils composed of unsaturated hydrocarbons are partially polymerized by a process of passing the oil vapors over a catalyst at elevated temperatures. The chemical reaction called polymerization is the union of two or more molecules of the same compound to form a new compound whose molecular weight is a multiple of the original molecular weight. The partially polymerized oil is still in a liquid state when mixed in the core sand and formed into cores, but upon further heating polymerization is completed and the oil changes to a solid state, thus binding the core to form a solid structure.

Thermoplastic binders such as rosin and pitch depend on heat to liquefy and disperse the binder in the sand. The powdered binder is mixed with sand and formed into cores; when heated, the binder liquefies and coats the grains of sand. When cooled, the dispersed liquid solidifies to form a united mass. Rosin is the most abundant of resins and is obtained by distillation of pine sap or by extractions from pine wood. Petroleum and coal-tar resins are available as by-products in the petroleum and coal tar industry. Synthetic resins are also available, but, in general, they are too costly for core binders.

Resin binders produce moderately strong cores at a low cost. The cores bake rapidly at a low temperature, resist moisture when in the mold, and collapse rapidly when the mold is poured. The cores are somewhat plastic and tend to distort if stacked too high or exposed to heat in storage. Rosin is often added to core oils to speed up drying and to reduce the volume of core gas. Pitch, obtained as a by-product of coke, is a thermoplastic core bond used in large cores. It is generally compounded with dextrin and sea coal.

Thermosetting plastic core binders are gaining popularity because of their high hot strength, rapid hardening, collapsibility, low gas formation, and resistance to moisture absorption. In the green state the plastic solution fuses to the sand grains. When heated, it is transformed to an insoluble infusable form. Unlike thermoplastic core binders, these binders will not revert to the liquid state. Phenol and urea-formaldehyde plastics are customarily used in this class of binders.

The function of heat in setting cores that are bonded with cereal, molasses, protein, and sulfite liquor is principally to drive off water moisture. This class of binders has a tendency to reabsorb moisture when stored in a humid atmosphere or if left in a green sand mold too long before pouring. Present-day cereal binders, such as dextrin, are the product of corn, processed in various ways to produce a variety of bonding properties. Cores bonded with cereal dry quickly and collapse rapidly upon pouring. Because cereal produces green as well as dry bond, small quantities may be added to oil-bonded core sand to improve the green strength of cores. Molasses lacks the strength of core oils and therefore is used only as a supplement to give cores an added surface hardness. Molasses water may be sprayed on the core, or it may be added to the core mixture. In the process of evaporation, molasses tends to migrate to the surface, forming a hard crust. Organic compounds known commercially as glue, gelatin, and casein are classed as *protein* *binders* and used in foundries where collapsible cores are desired. Sulfite liquor is a by-product of the pulp industry. It consists of lignin and the chemicals used in the separation of lignin from cellulose of wood. It is sold to foundries as a concentrated liquid or a dry powder. It does not ferment like molasses, stands up under high temperature, and dries rapidly.

The binders that become firm on setting at room temperatures are sodium silicate, Portland cement, and rubber cement. Sodium silicate, commonly called water glass, is a high-temperature bond. Cores of sodium silicate have low permeability and are difficult to remove from the casting. Sodium silicate is used in special cases to resist erosion. Portland cement is occasionally used as a core bond in the production of large steel, gray iron, and nonferrous castings. Rubber latex, treated with a preservative, may be employed as a core bond to produce cores of quick collapsibility and easy shake-out properties.

Core Mixtures. Because of the large number of variables existing in foundry practices, the compounding of core mixtures is usually based on past experiences and experimentation and on the available material. A core mixture may produce excellent cores for one type of casting but fail in another. For that reason, there are many formulas consisting of various combinations of ingredients in various proportions. Following are a few examples of core sand formulas:

CORE FOR MEDIUM-SIZED STEEL CASTINGS

Sand	1200 lb
Bentonite	5 qt
Cereal	4 qt
Rosin	26 qt
Silica flour	75 lb

CORES FOR GRAY IRON CYLINDERS

Sand	1000 lb
Core oil	4 qt
Cereal	2 qt
Casein binder	4 qt

CORES FOR BRASS AND BRONZE CASTINGS

Sand	900 lb
Oil	4 qt

CORES FOR ALUMINUM CASTINGS

Sand	100 qt
Oil	1 qt
Dextrine	1 qt

Water is added to almost all core mixtures to dissolve dry binders and to help disperse liquid binders. The amount of moisture usually varies from 2 to 5 per cent by weight.

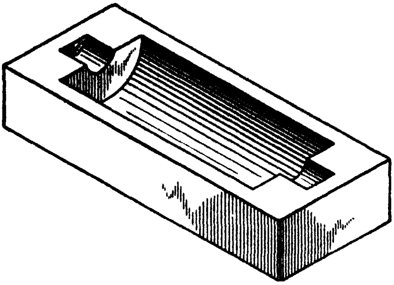


FIG. 2A. One-piece core box.

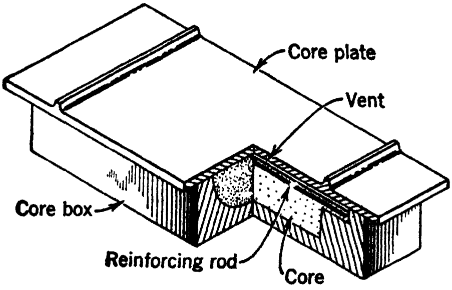


FIG. 2B. Core plate in position, just before rolling-over.

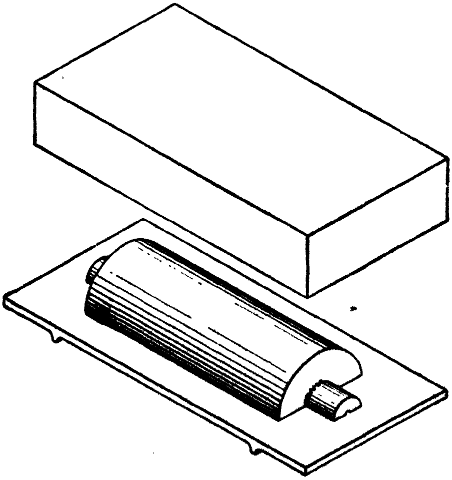


FIG. 2C. Core box drawn from core.

Core Boxes. Core boxes may be made of wood or metal, depending on the number of cores to be produced. A metal box is generally preceded by a wood master core box which is molded and cast to form the metal box. The added cost of making and finishing a metal box is justified when a wood box would not outlast the job. Metal core boxes are usually made of aluminum. Steel strips are inserted in the parts of the box which are exposed to excessive wear.

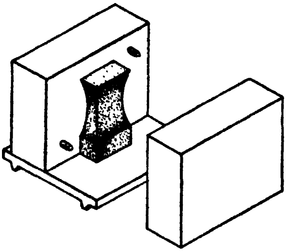


Fig. 3. Two-piece core box.

The simplest type of core box is a one-piece box, as illustrated in Fig. 2. In the core-making procedure, the box is dusted with parting compound to keep it dry. It is then filled with sand. A wire extending across the length of the core is inserted in the sand to reinforce the core, more sand is added to the box, and the sand is rammed down. Excess sand is struck off the box, and a vent channel is cut across the length of the core. A plate is placed on the box, as illustrated in Fig. 2*B*, the assembly is rolled over, and the box is rapped and drawn. Figure 2*C* shows the green core ready to be placed in an oven to be dried.

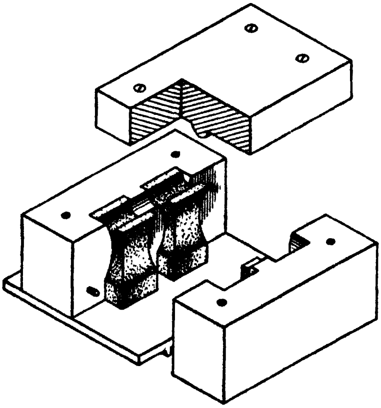


Fig. 4. Three-piece gang core box.

More complicated designs require multiple-part core boxes. The most common multiple core box is a two-piece or *split type*, illustrated in Fig. 3. The pieces are equipped with dowel pins for proper alignment and held together or clamped to avoid spreading of the box when the core is made. The two halves of the box are then drawn in opposite directions, leaving the core resting on the plate.

Small cores are sometimes made in a gang core box containing more than one cavity. Figure 4 shows a three-piece gang core box. To remove the box from the core, the top part is drawn vertically and the two remaining parts are then separated horizontally.

Loose core box pieces may be employed to avoid a complicated core box. The function of the loose pieces, as illustrated in Fig. 5, is to provide an undercut or a slope on the core which would obstruct withdrawal if it were incorporated as a part of the core box. After the core box is drawn, the loose pieces remaining in the core are drawn in the proper direction to avoid damage to the core.

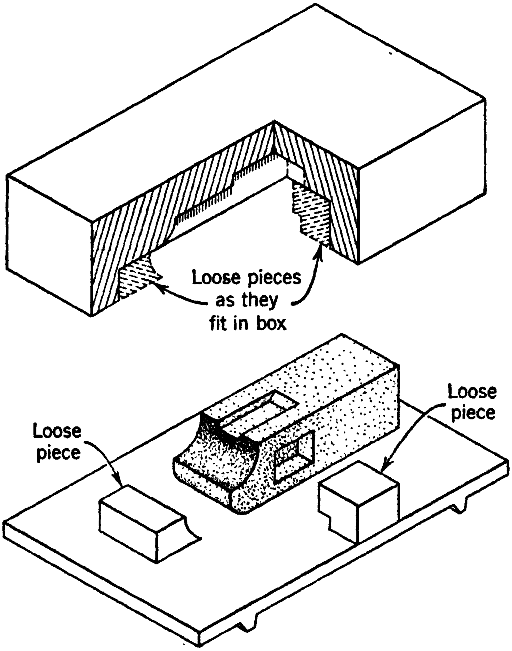


Fig. 5. Core box containing two loose pieces.

Core Drying. The oven temperature and the time required to bake a core depend largely on the size of the core, the type of bond in the sand mixture, and the physical properties desired in the core. The baking process of many oil-bonded cores involves three phases: evaporation, oxidation, and polymerization. If baking continues beyond the polymerization stage the binder will burn up and the core will crumble. The last cycle, namely that of core disintegration, should take place when molten metal surrounds the core in the mold. The length of time that a core can withstand this intense heat may be controlled somewhat by the baking cycle. If an insufficiently baked core is used, baking will continue when the mold is poured, and the core may not reach the point of disintegration. In an incompletely baked core, more gas will be generated on pouring and it will be difficult to remove the core from the casting. A properly baked core should have sufficient heat resistance to maintain its form as long as the metal is molten, but it should collapse after solidification takes place.

Slow baking causes the various phases or cycles to occur consecutively, and each reaction will be completed uniformly throughout the depth of the core. Fast baking causes the reactions to overlap, producing a variation in physical properties in various parts of the core. It is not uncommon to find improperly baked cores with green centers.

Although moisture is necessary in sand mixtures to disperse the bond uniformly and to produce sufficient plasticity for green strength, it becomes an objectionable ingredient in baking because it increases baking time. The temperature of a core rises rapidly to the boiling point of water and remains at that temperature until all the moisture is evaporated. This may take an hour or more, depending on the size of the core and the percentage of moisture. When the vaporization cycle is completed, the temperature then rises to the baking temperature at which oxidation and polymerization take place. Once the moisture is removed, the core is baked in 15 min or less.

Core ovens should be equipped with adequate controls to maintain the most effective baking temperature. It is also very important that the oven be sufficiently ventilated to reduce the humidity without too great a heat loss.

Core Ovens. Core ovens may be heated with gas, coal, coke, oil, or electricity. The choice of fuel depends on its availability, cost, and the quality of core desired. There are many types of ovens designed for various sizes of cores and production methods. Convenience in handling cores from core maker to oven and from oven to core assembly is an important consideration in choosing core-baking equipment.

The drawer-type oven, illustrated in Fig. 6, is designed to withdraw any one of the drawers for loading or unloading without disturbing the remainder of the cores in the oven. The drawers are removed from the oven by an overhead drawer-puller, which engages any one or all of the drawers at one time. A limitation in this type of oven is that the cores must be handled twice, once to place them on the drawer and again to remove them from the drawer. The drawer-type oven is used in foundries not requiring large quantities of cores.

Fig. 6. Rolling-drawer-type core oven with floor-mounted gas-fired recirculating heating system. (Courtesy of Foundry Equipment Co., Cleveland, Ohio.)

With the rack-type oven, portable racks are conveyed to the core makers who place the cores directly on the racks at the core-making stations. When the racks are loaded with cores, various methods such as lift trucks or monorail conveyors transport them back to the oven. Racks containing large cores are moved directly into the oven by rail. This type of oven is referred to as a car-type oven. The racks are admitted into the oven through two doors which swing open on hinges, or a single counterbalanced door that slides upward.

In high-production systems, the core racks move through the oven on a continuous chain or rail. The temperatures of the various parts of the oven and the speed of the conveyor are so coordinated that the core emerges from the oven not only baked but cooled. In order to conserve floor space, the vertical-type continuous oven bakes the cores as they move up through the oven and cools them on their return trip down.

Core Driers. The surface of a core plate must conform to the bottom side of the core in order to prevent the green core from being distorted. Such plates with irregular surfaces are called driers. Driers are ordinarily made of aluminum because they are easily finished, are light in weight, and absorb less heat when placed in the oven. Driers are designed with thin uniform sections to reduce heat absorption and are reinforced sufficiently with ribs to avoid warpage when exposed to sudden changes in temperature. Small-sized flat core plates are often made of steel or cast iron. Steel is lighter and absorbs less heat than cast iron because of thinner sections.

Core Assembly. When a small number of castings is required, the need for a core drier may often be avoided by making the core in two halves and pasting the halves together after they are baked. Figure 2*A* illustrates a core box in which the halves of a cylindrical core are made. When a core is not symmetrical, two boxes are necessary.

When core driers are available, a one-piece green core is made by *booking*. The two core boxes are rammed up separately, assembled, and drawn. The assembled core is then placed on a drier. Alignment of the two boxes may be attained with hinges or merely with pins as illustrated in Fig. 7*A*. Before booking, it is often necessary to make a groove along the flat surface to provide a vent through the center of the core. This may be done by hand, or with a special vent plate illustrated in Fig. 7*B*. Figure 7*C* shows the vent plate being removed after making the impression in the core. The two core boxes labeled A and B are then booked as illustrated in Fig. 7*D*. Core box B is then

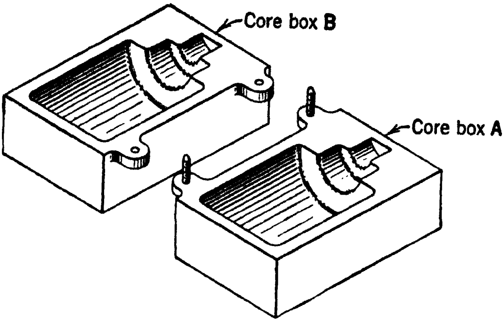


FIG. 7*A*. Book core box.

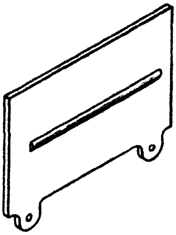


FIG. 7*B*. Vent plate.

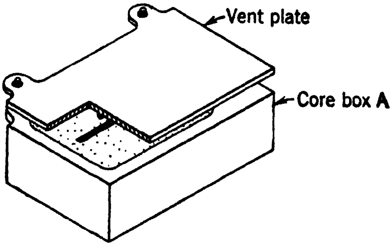


FIG. 7*C*. Vent plate being removed from box.

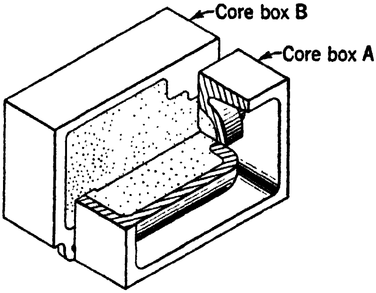


FIG. 7*D*. Booking the cores.

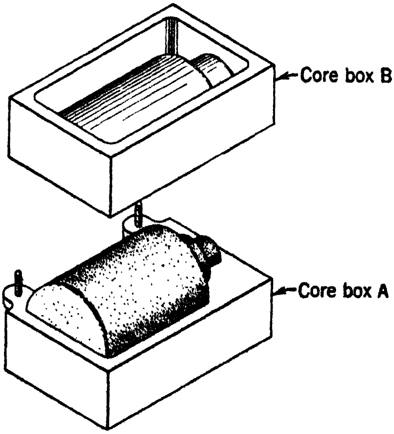


FIG. 7*E*. Removing core box B.

removed, as illustrated in Fig. 7*E*, and the drier is placed over the core, as in Fig. 7*F*. The assembly is then inverted, and core box A is removed, as in Fig. 7*G*. The green core, resting in the drier, is placed in an oven to bake. The dry sand core is shown in Fig. 7*H*.

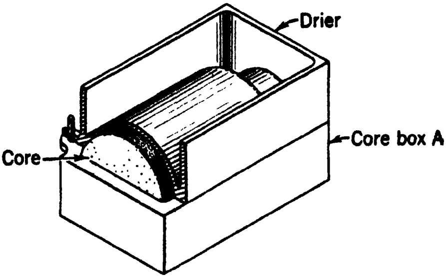


Fig. 7*F*. Drier placed over core.

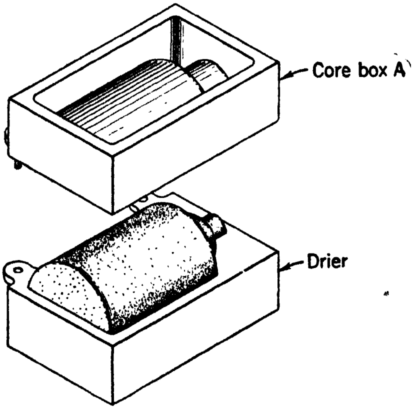


Fig. 7*G*. Core box A being drawn from drier.

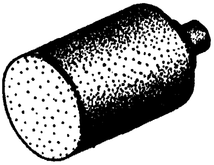


Fig. 7*H*. Core after it is baked and removed from drier.

Complicated core assemblies involve many cores made in individual core boxes. The customary way of fastening cores together is by pasting, but where greater strength is required bolts are used. Before assembly, each core is trimmed with a file or emery cloth to remove fins or other irregularities. Vent holes are cleared, and additional vents may be filed in the core prior to assembly. If dimensional tolerances are close, the individual cores may be checked with templets. After assembly, another check may be necessary to insure proper alignment. The joints and rough spots of the assembly are *mudded* to prevent fins and rough spots on the casting. The mudding material consists of red talc or graphite, moistened with water to the consistency of mud and applied to the core with fingers. The assembly may then be coated with core wash by dipping or spraying the core, or by brushing. Core wash prevents metal from penetrating the core, thus producing a smoother casting which is easier to clean. The refractory ingredient of core wash is generally a finely divided graphite or silica flour. The basic material is dispersed in a liquid binder consisting of water and bentonite, water and cereal, core oil, or just plain water. Unless the core is hot, it must be dried after it is coated. This may be done with a torch or by placing the core in an oven.

Stock Cores. Cylindrical cores are used in foundry work more frequently than cores of any other shape. For this reason it is desirable to have in stock a supply of cylindrical cores ranging from 3/8 to 3 in. in diameter and 20 in. long. When a core of a certain diameter is desired, it is taken out of stock and cut to the desired length; the ends are tapered down to the proper angle on a coning and cut-off machine. The coning and cut-off machine is similar to a bench grinder, having a cut-off wheel on one side and a grinder equipped with guides on the other side.

Stock cores are made on a continuous core machine, Fig. 8, which resembles a sausage machine in that the material is fed into a reservoir from above and forced into a tube by means of a tapered screw. A rod extending through the center of the screw forms a vent through the center of the core as it is extruded from the tube on a grooved tray. Other shapes, less common than the cylindrical type, may also be made on a continuous core machine.

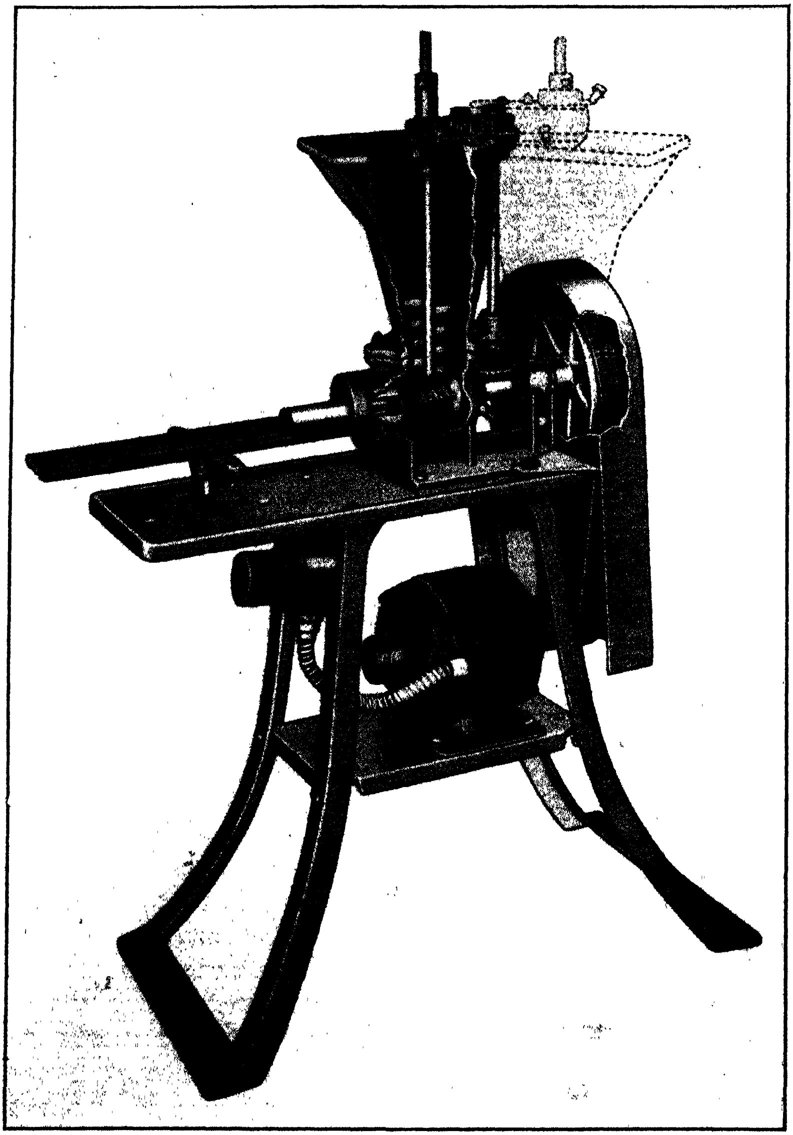


FIG. 8. Stock core-making machine. (Courtesy of Wadsworth Equipment Co., Akron, Ohio.)

Kiss Core. If a core has no core prints and depends on contact pressure to hold it in position, it is called a *kiss core.* It may be used in places where dimensional accuracy is unimportant. The core projects slightly above the parting plane and is held in position by the pressure of the cope, as shown in Fig. 9.

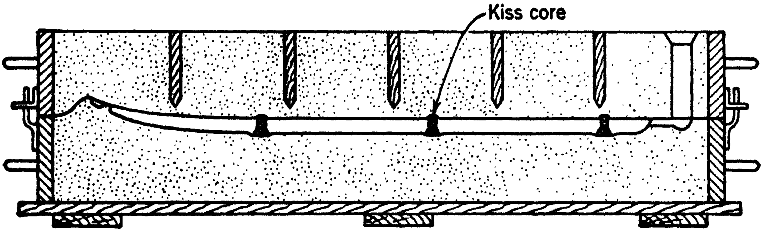


Fig. 9. Kiss core.

A core may be partially anchored with core prints and may depend on other parts of the core to kiss the mold for further support. A core that is properly supported with prints but has a surface touching the mold cavity for the purpose of making an opening in the casting at that point is said to be *kissed through.*

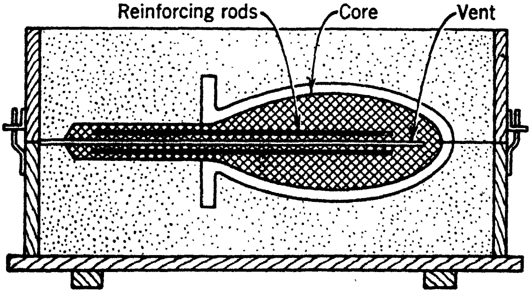


Fig. 10. Balance core.

Balance Core. Unlike a core having prints on opposite ends, a balance core, as shown in Fig. 10, has a single print and produces a single opening in a casting. The print should not only be large enough to support the weight of the core which extends into the mold cavity, but it must withstand the force of buoyancy of the molten metal surrounding it.

Chaplets. If a core print is too small to support a core, or if the buoyant force of molten metal causes the core to shift, it is necessary to support the core with metal chaplets. Chaplets of various standard designs and sizes may be purchased to fill the needs of any situation. They may be placed between two cores or between the mold face and the core, as shown in Fig. 11. If the weight of the core tends to force the chaplet into the mold, a flat core may be embedded in the mold to support the chaplet. Another type of chaplet may extend down through the drag and rest against the bottom board, as illustrated in Fig. 12. A chaplet extending through the cope is held down by a bar extending across the top of the mold.

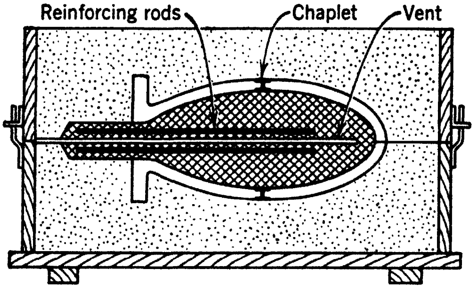


FIG. 11. Core held in position by double-head chaplets.

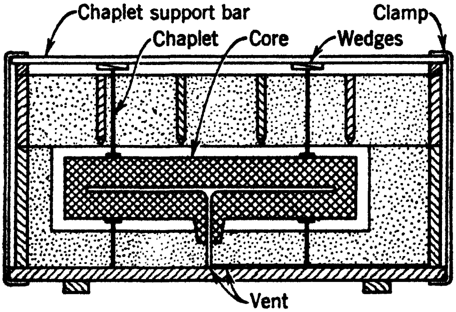


FIG. 12. Core held in position with single-head chaplets.

Proper selection of the type and size of chaplets is necessary to get fusion between the casting and chaplet. Although with good judgment and proper care a sound casting can be obtained with chaplets, they are not recommended for castings that are subjected to high pressures.

Stop-Off Cores. A core placed in a mold cavity to prevent metal from flowing into a portion of the cavity is referred to as a *stop-off core.* A cavity formed by a pattern reinforcement (pattern stop-off) may be filled in by a stop-off core to eliminate the reinforcement on the casting. Frequently a core is necessary to form a hole in a casting when the hole is located in a position inaccessible to the customary core print. A condition of that nature exists in the casting of Fig. 13*A*. The two slotted holes in the vertical leg of the casting are made with a dry sand core. The print not only supports the two slot-forming projec-

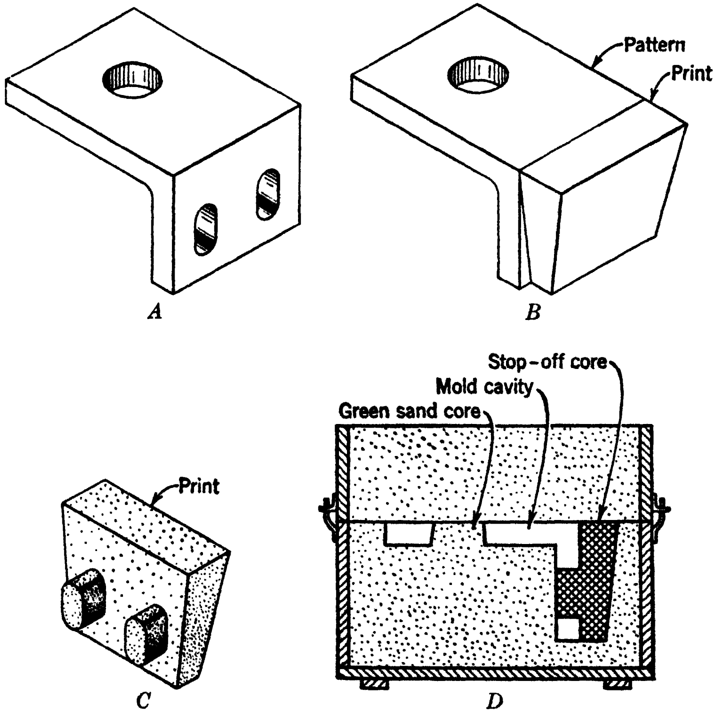


Fig. 13. *A*. Casting requiring a stop-off core to make slotted holes. *B*. Pattern illustrating core print for stop-off core. *C*. Stop-off core. *D*. Mold section illustrating stop-off core.

tions of the core but forms a part of the vertical face of the leg. Such a core is also referred to as a tail-print core, by virtue of the function of its core print. The pattern, core, and mold section are illustrated in Fig. 13, *B*, *C*, and *D*.

Cover Core. The purpose of a *cover core* is similar to that of a balance core, except that the cover core extends down in the mold cavity and the balance core extends horizontally in the mold cavity. With the cover core, no extensive print is necessary to counteract the fluid pressure because pressure is applied upward against the print. The print of the cover core is usually formed in the drag at the parting plane, and it covers the entire mold cavity except for the gate entrance. When the mold is closed, the cope holds the core down in position. The foundryman sometimes finds it economical to substitute a cover core for a cope. The core then contains the necessary sprue openings for pouring and feeding. In order to avoid a thick core and yet provide sufficient head pressure, a pouring cup is often pasted on top of the core.

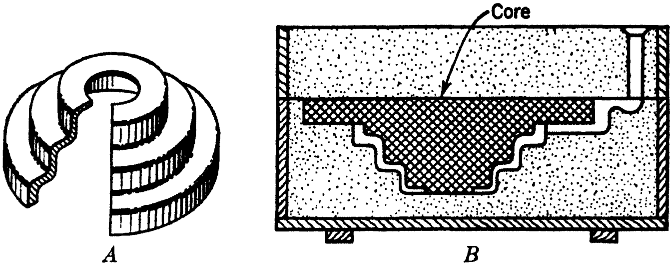


FIG. 14. *A*. Lamp-base casting. *B*. Cover core used to form interior of lamp-base casting.

A core that hangs from the cope is referred to as a hanging core. If paste is not strong enough to hold the core in the hanging position, it is necessary to fasten the core with a wire or rod which extends through the cope to a fastening on the top side of the cope.

Examples of the cover core and hanging core are shown in Figs. 14*A* and 14*B* and Fig. 15. Both the lamp base and annealing box were molded as illustrated to avoid slag impurities on surfaces most important to the casting.

Ram-Up Core. Instead of being inserted in the mold after the pattern is drawn, the ram-up core is set in the mold with the pattern before the mold is rammed. The simplest application is a slab core rammed in the bottom of a mold cavity to furnish a seat for a chaplet. This is done by placing the core slab on the pattern and ramming sand over the core and pattern. When the pattern is drawn, the core remains embedded in the sand mold.

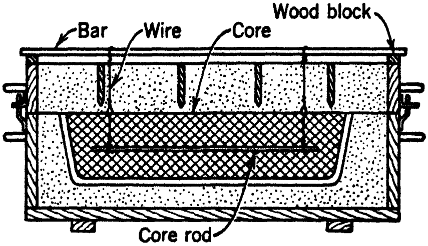


FIG. 15. Hanging core.

Ram-up cores may also be used to form exterior and interior portions of a casting that would be too difficult to form with a pattern in green sand. It is used only when the cored detail is located in a position inaccessible to other types of cores.

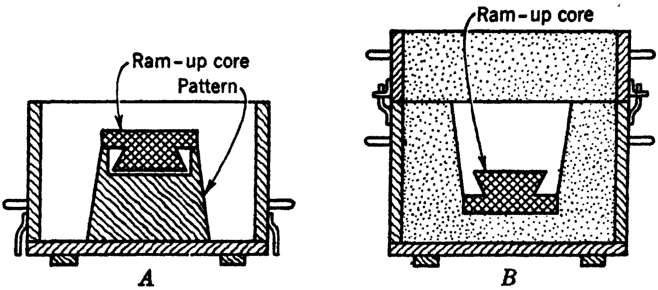


FIG. 16. *A*. Ram-up core set in pattern in preparation for molding. *B*. Completed mold with ram-up core embedded in mold.

For interior designs where a single print is located in the bottom of the mold, a ram-up core may be preferable to chaplets or to paste to hold the core in position. The pattern for the ram-up core in Fig. 16*A* is hollowed out enough to allow the part of the core forming the interior design to extend down into

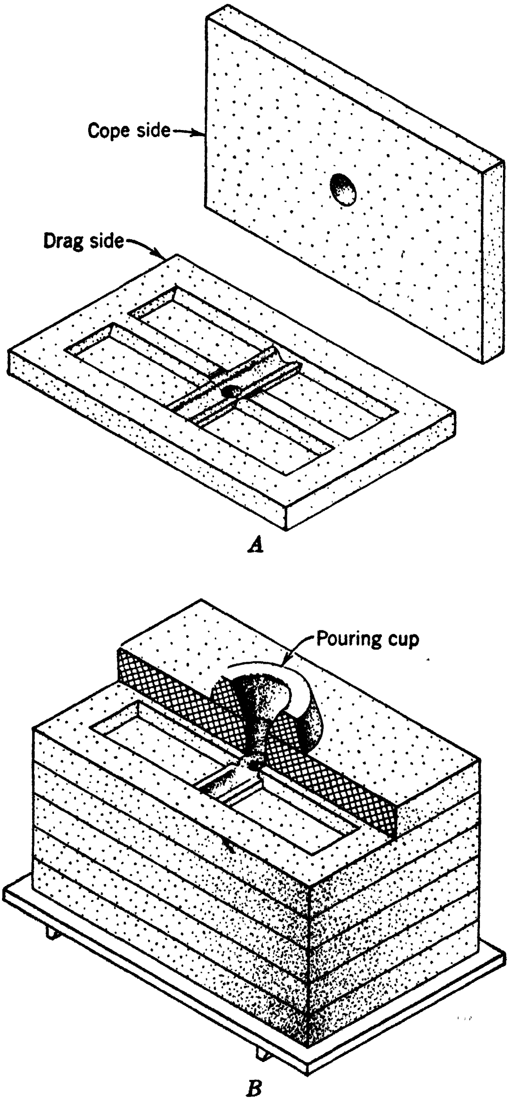


FIG. 17. *A*. Slab core for stack mold. *B*. Stack mold.

the pattern. The print of the core covers the opening in the pattern to keep out sand. The pattern and core assembly are molded, and, when the pattern is drawn, it leaves the embedded core, as shown in Fig. 16*B*, in its proper location in the mold.

Set-Up Core. A mold core print is customarily formed in green sand by a pattern print. If a small print on a heavy core provides an inadequate bearing surface in the green mold, it may be necessary to substitute a dry sand core for that portion of the mold containing the print. Such a core, designed to form a seat for other cores, is called a *set-up core.* If a large number of core prints project from the end of a core assembly, a single core may be designed to incorporate seats for all the prints. This set-up core may be pasted to the core assembly before the core is placed in the mold. When the core is placed in the mold, the set-up core rests in a mold print designed to the exterior shape of the set-up core. For an illustration of a set-up core, see Fig. 19 of Chapter 13.

Dry Sand Stack Mold. Figure 17*A* illustrates a slab core used in the construction of a stack mold. One side of each core contains the drag cavity of the casting. For a flat back parting, the other side of the core is a flat surface. Through the center of each core is a sprue hole which is connected to the cavities with gates. When the cores are pasted together, a continuous sprue hole extends down to the bottom core, and at each parting is a set of gates leading to the cavities contained in the parting. The cores may be stacked as high as desired. Figure 17*B* illustrates a dry sand stack mold. With such a mold the yield ratio (ratio of weight of castings to total weight of metal poured into the mold) may be over 90 per cent.

PROBLEMS

1. Discuss the properties of various core sands and the effect they have on cores.
2. List the various types of core binders, and give their characteristic properties.
3. What is the function of water in core mixtures?
4. How are core boxes protected against excessive wear?
5. Explain how control in core baking can influence core disintegration when the mold is poured.

6. Describe the function of a core drier. Why is aluminum the most desirable material for driers?
7. List the steps in making a core in two pieces and then assembling the core. List the steps in making the same core in a book core box.
8. What is the advantage of a stock core compared with a core made in a core box? What type of stock core is most common?
9. Give the function of a chaplet, and explain why chaplets are avoided whenever possible.
10. Describe the following types of cores, and give a situation in which each type would be used:

    (*a*) Balance core.
    (*b*) Kiss core.
    (*c*) Stop-off core.
    (*d*) Cover core.
    (*e*) Ram-up core.
    (*f*) Set-up core.

11. State some of the advantages obtained in a dry sand stack mold.
12. Why are loose pieces often used in a core box?

6

Foundry Production Equipment

Molding Machines. The principal functions of molding machines are to pack sand in the mold, remove the pattern, and manipulate the mold into closing position. Molding machines are named after their principal functions. For example, a jolt roll-over, pattern-draw machine is one that packs the sand by jolting, inverts the mold, and draws the pattern. If any other characteristic molding function is incorporated in the mechanism of the machine, it may be included in the name.

Mold Packing. Sand may be packed in a mold in three principal ways: by squeezing, by jolting, or by slinging. In the squeezing method, the flask is filled level with molding sand and squeezed until the sand has the desired density. Packing sand in molds by squeezing is limited to small snap molds not more than 6 in. in depth. Molds containing green sand cores are not satisfactorily squeezed because of the inability of sand to flow into the core cavities of the pattern. In the jolting method, the table supporting the flask is raised mechanically and dropped in rapid succession. The sudden change in inertia at the end of each fall packs the sand in the flask. A popular molding machine for small- and medium-sized molds first jolts and then squeezes the sand. The Sandslinger packs molds by hurling sand into the flask at a high velocity. The sudden change in inertia of the sand causes it to pack.

Machine-rammed molds are more desirable than hand-rammed molds because of greater uniformity in mold structure. Uniform density improves permeability and mold stability. With improved permeability, the flow of gases is less likely to be restricted; consequently, blow holes are less likely to occur. With improved mold stability, the weight of the molten metal is less likely to distort the mold and cause dimensional instability.

Squeezing packs sand more densely at the top of the mold where the squeeze board presses against the sand. The density of a squeezed mold decreases uniformly with depth, the lowest density being at the parting plane. The opposite is true in jolting, the density being greatest at the parting plane. Being dependent on inertia, the density of a jolted mold is varied by the height of the stroke, the amount of sand heaped on top of the mold, and the number of strokes. In packing a mold, an equilibrium is reached beyond which further jarring will do no good. If greater density is desired, the height of the stroke may be increased or sand may be heaped higher above the flask. A weight may be placed on top of the mold to increase inertia and to produce a more uniformly packed mold. This method is frequently employed on jolt machines without squeezers to

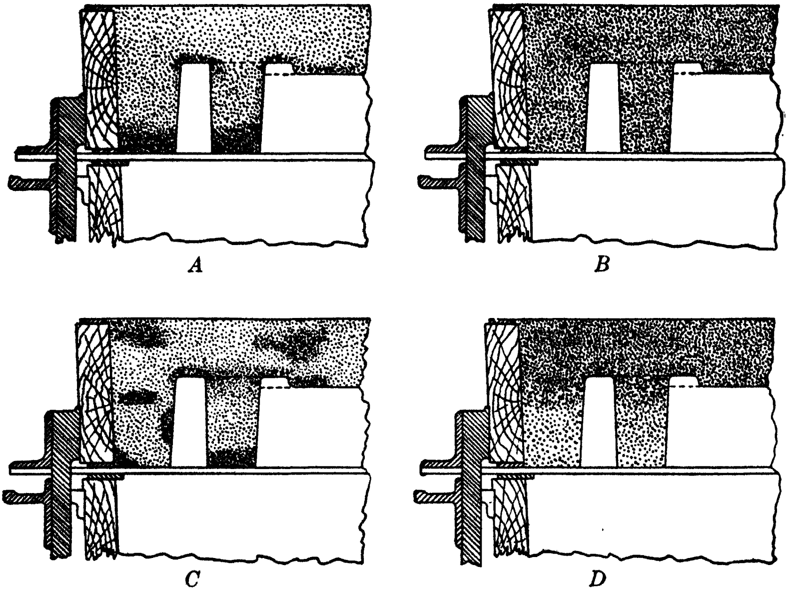


Fig. 1. *A*. Jolt ramming. Sand rammed harder against pattern. *B*. Jolt and squeeze ramming. Uniform ramming throughout. *C*. Hand ramming. Hard and soft spots unavoidable. *D*. Squeeze ramming. Sand rammed harder near top. (Courtesy of Osborn Manufacturing Co., Cleveland, Ohio.)

eliminate butt ramming after jolting. Sand characteristics may often be varied to improve flowability and to increase mold density. Excessive mold density is undesirable because it lowers permeability. Large-grained sands may be rammed harder than fine-grained sands without affecting permeability. Figure 1 illustrates density variations resulting from hand ramming, jolting, and squeezing.

Making a Mold on a Jolt-Squeeze Molding Machine. In assembling the flask and match plate for machine molding, the cope half of the flask is placed on the machine table with the joint side up, as illustrated in Fig. 2*A*. The match plate is placed over this with the drag side of the pattern up, and finally the drag half of the flask is placed over the assembly with its joint side down. The flask pins on the drag pass through the guides of the match plate and cope.

Sand is then riddled over the drag side of the pattern, and the flask is filled with heap sand. If all the sand is screened, the flask is merely filled with molding sand. The perimeter of the mold is peened, and excess sand is struck off with the edge of the bottom board. The board is then placed over the sand (care being taken that it fit inside the flask as illustrated in Fig. 2*B*), and the mold is jolted by pressing the right knee against the pad of the jolt knee valve. The added momentum of the board helps to pack the sand more densely in the top of the mold. Also, if the board is rammed down into the flask, it is less likely to slip when rolling over. The assembly is then rolled over, and the cope half of the flask is filled with sand in the same manner as described for the drag. After the sand is struck off, a squeeze board is placed over the sand surface and the mold is squeezed. This is done by pulling the squeeze head to full forward position with the left hand, and pushing down on the squeeze valve handle with the right hand. Air enters the squeeze cylinder, raises the table, and squeezes both the cope and drag halves of the mold until an automatic release valve pops open at a predetermined pressure. The lever and the squeeze head are then released, each returning to its original position.

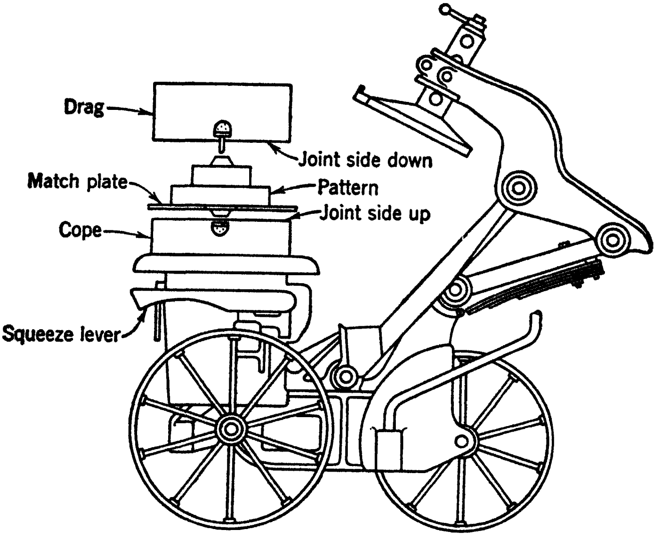


FIG. 2*A*. Cope, match plate, and drag being assembled in preparation for making a mold. (Reproduced from print belonging to Osborn Manufacturing Co., Cleveland, Ohio.)

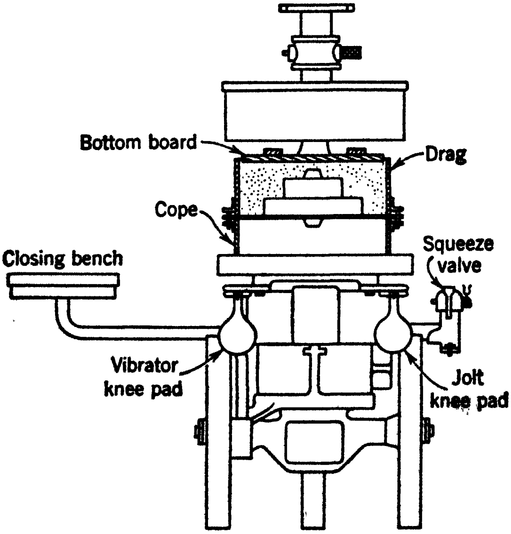


FIG. 2*B*. Position of mold on machine when jolting the drag. (Reproduced from print belonging to Osborn Manufacturing Co., Cleveland, Ohio.)

A sprue hole is then cut through the cope in the position indicated by an impression left in the sand by the squeeze board. A sprue cutter is similar to a thin tapered pipe. With a twisting action it is forced down vertically in the cope until it reaches the match plate.

The vibrator is then set into action by pressing the left knee against the vibrator knee valve pad, and the cope is lifted and placed on a closing bench at the left of the machine. The match plate is drawn in a similar manner and placed on a hook located on the machine head.

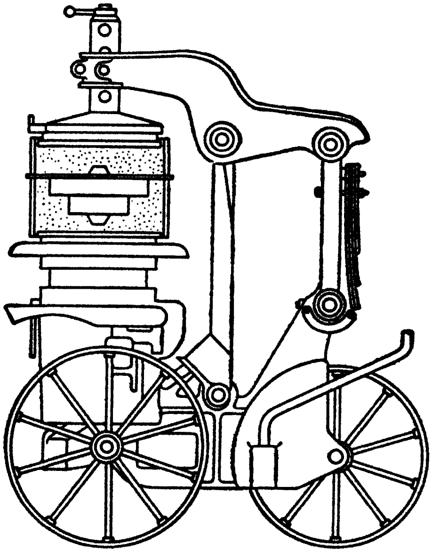


FIG. 2*C*. Mold in squeezing position. (Reproduced from print belonging to Osborn Manufacturing Co., Cleveland, Ohio.)

Cores are set, the sprue hole is cleaned out, and the mold is dusted with refractory and closed. Figure 2*C* illustrates the mold in the squeeze position.

Figure 3 illustrates the production of drags on a drag plate. The cope half is made on another machine located on the other side of the bin. When the two halves are completed, they are assembled on a roller conveyor which moves the molds to the pouring area.

The Jolt-Squeeze Mechanism. A sectional view of a jolt-squeeze mechanism is illustrated in Fig. 4. When a mold is being squeezed, the jolt piston and cylinder ride along with the squeeze piston, the jolt cylinder being an integral part of the squeeze piston. The jolt piston and table is a one-piece casting, and, during squeezing, the table rests on the squeeze piston.

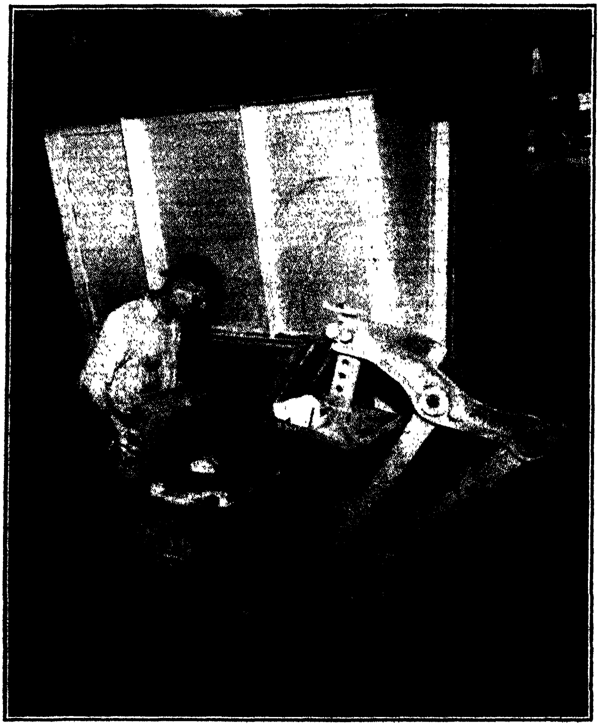


Fig. 3. Jolt-squeeze molding machine making drags on a drag plate. Copes are made on a machine on the other side of the bin. The two halves are assembled on a conveyor in front of the bin. (Courtesy of Osborn Manufacturing Co., Cleveland, Ohio.)

During jolting, the squeeze piston lies solidly on the base of its cylinder. When the jolt valve is opened, air enters the jolt cylinder via the jolt inlet and the piston rises; but when the piston passes the exhaust port, pressure drops and the table falls, striking the top of the squeeze piston. When the jolt piston reaches the bottom of its stroke, sufficient pressure is built up to cause the piston to rise again, the cycle being repeated two to three times per second.

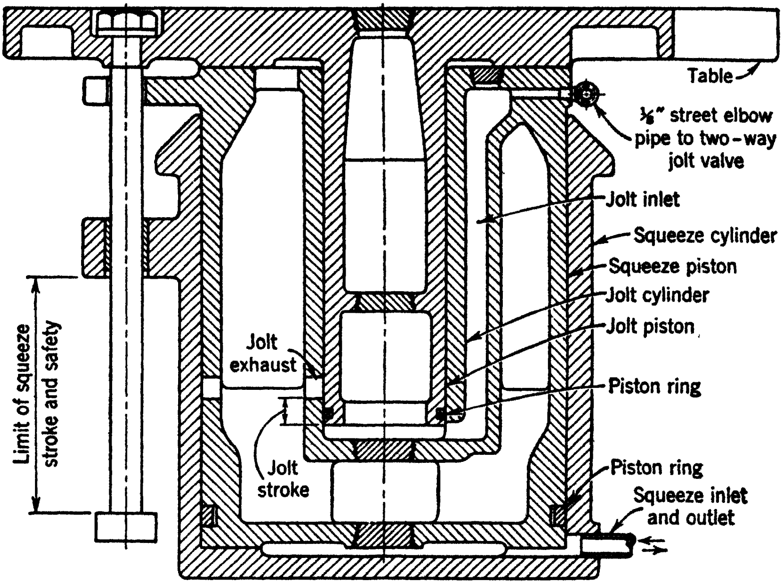


FIG. 4. Sectional view of jolt-squeeze cylinders, illustrating their function. (Courtesy of Milwaukee Foundry Equipment Co., Milwaukee, Wis.)

Jolt Rock-Over Foot-Draw Molding Machine. A molding machine that swings the mold over its top and places it in a rolled-over position on the opposite side is sometimes referred to as a rock-over machine. This operation is performed manually on small molding and core-making machines of the rock-over type. Figure 5 shows a rock-over machine operated by two air-powered pistons. When air is admitted in the cylinder, the piston moves downward until dead center is reached on the crank arm. At this point, pressure is released, and the crank pin swings over center to the other side. This action swings the mold table through 180 degrees to the other side, placing the inverted mold on the arms of the flask rest. The arms of the flask rest are self-adjusting to insure a four-point contact on

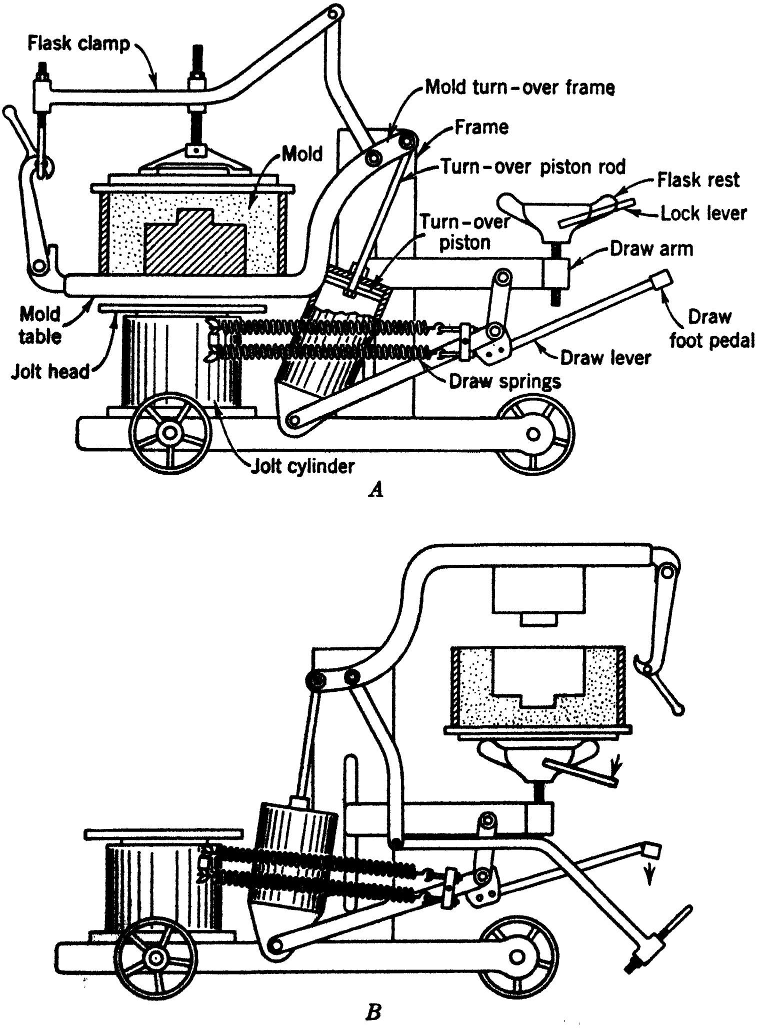


FIG. 5. *A*. Jolt rock-over foot-drawn molding machine. Mold is rammed, clamped, and about to be rolled over. *B*. Mold being drawn from stationary pattern. (Reproduced from print belonging to International Molding Machine Co., La Grange, Ill.)

the bottom board of the flask. The lock levers are then pushed down to lock all arms in position, after which the flask clamp is released. The vibrator is turned on, and the mold is drawn downward by stepping down on the draw lever. After the mold is drawn from the pattern, the table is swung back into its original position by turning on the cylinder air pressure and releasing it as dead center is reached.

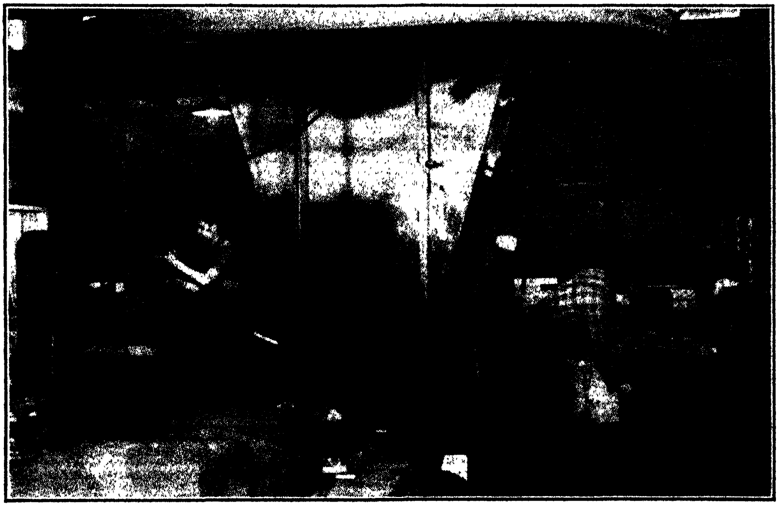


FIG. 6. Two jolt-squeeze stripping machines. One makes copes and the other makes drags. The molds are assembled on roller conveyors. (Courtesy of International Molding Machine Co., La Grange, Ill.)

Jolt-Squeeze Pin Stripper. The pin-stripper machine may be used in the production of copes and drags, provided the flasks have lifting trunnions, as illustrated in Fig. 6. Completed molds are removed from the machine with a hoist. Drags are rotated 180 degrees on their trunnions to bring the parting plane face up. A cope may be rotated 90 degrees for inspection and finishing and then rotated back to the closing position. If the cope and drag cavity are identical and the patterns are properly located on the pattern plate, both halves of the mold may be made on the same machine. This, however, is not the usual case, and a separate machine is usually employed to construct each half of the mold.

The mold is separated from the pattern by lifting it off a stationary pattern. This is done by the action of four pins that contact the four flask corners and raise the mold free of the pattern. The pins are fastened at their base to a yoke that surrounds the jolt-squeeze cylinder. The drawing operation is performed by two air-operated pistons, one on each side of the yoke.

The pin stripper is efficient in that it eliminates the roll-over operation, making it unnecessary to clamp the mold. If, however, a large body of sand is contained within the confines of the flask walls, special flasks with crossbars may be necessary in both copes and drags.

Stripping Plate. The possibilities of damaging a mold are not so great on a roll-over pattern-draw machine as on a stripper machine. With a stripper, a slight fracture may cause the damaged section to drop out of the mold. Defects of this type may be avoided by increasing the amount of draft; but, if the pattern has thin sections or if a satisfactory draft is objectionable, a stripping plate may be employed to support the sand around the pattern.

A stripping plate covers the entire parting plane (bottom of mold) except where the pattern projects through. When a mold is stripped, the pins contact the plate instead of the flask. In other words, the operation is exactly the same as that described for the plain stripper, except that a plate is employed to support the sand.

As a result of modern advances in sand preparation and control, there is little demand for stripping plates. In present-day practices, a stripping plate is used only where no draft is permissible, as in cast gears.

Jolt Roll-Over Pattern-Draw Molding Machines. In a mechanized foundry, drags of medium- and large-sized molds are made on jolt roll-over pattern-draw machines. The molding machine in Fig. 7 illustrates the principal steps in the operation of the machine.

After the mold is jolted, it is butt rammed and struck off. Although butt ramming is done manually on this machine, some machines include a power squeeze that eliminates butt ramming.

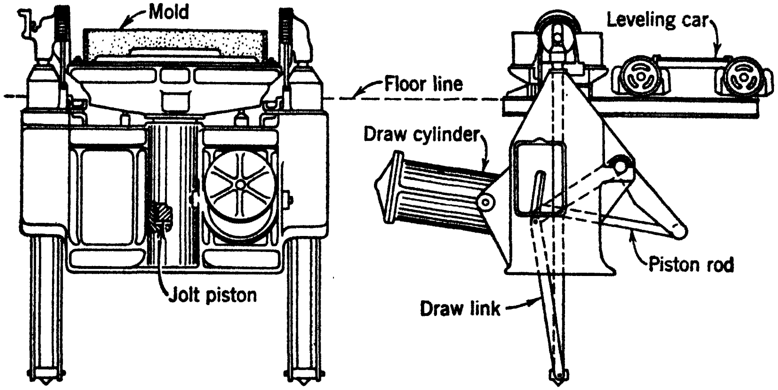


FIG. 7*A*. Mold has been jolted and struck off. The next step is to clamp the bottom board to the roll-over table, and the mold is rolled over. (Reproduced from print belonging to Osborn Manufacturing Co., Cleveland, Ohio.)

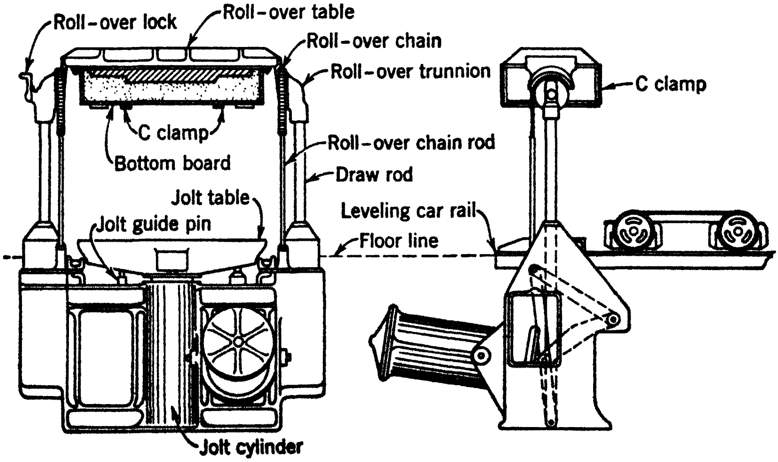


FIG. 7*B*. Mold has been rolled over and locked in position. The next step is to push leveling car in position, lower mold to car, remove clamps, and draw the pattern. (Reproduced from print belonging to Osborn Manufacturing Co., Cleveland, Ohio.)

Likewise, a molding machine may include a strike-off bar that eliminates the hand operation.

After striking off, a bottom board is placed on the mold and clamped to the roll-over table with C clamps. The mold is then ready to roll over. This is done by opening the draw valve which admits air in the draw cylinder. The piston moves in to the opposite end of the cylinder and raises the roll-over table by means of a series of links. When the table reaches a certain height, the roll-over chain rod comes to a stop as it is drawn out to its maximum length. As the table rises beyond that height, it is rotated about its trunnions by the roll-over chain. When it reaches its maximum height, it is locked in the inverted position by a roll-over lock, as illustrated in Fig. 7*B*.

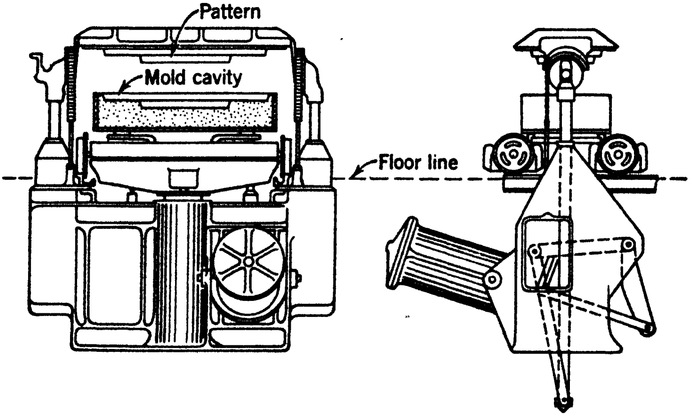


FIG. 7*C*. Pattern has been drawn. The next step is to remove mold and return roll-over table to proper position for another mold. (Reproduced from print belonging to Osborn Manufacturing Co., Cleveland, Ohio.)

The leveling car which straddles the jolt table is then rolled into position, and the roll-over table is lowered until the mold rests on the leveling bars of the car. The leveling bars are then locked in position, the clamps are removed, and the roll-over table is again raised as shown in Fig. 7*C*. The mold, being free of the roll-over table, remains on the leveling car; thus, the pattern is drawn.

The leveling car is then rolled out of position, and the mold is transferred to a conveyor which takes it past the cope machine and finally to the pouring area. The machine is made ready for another mold by releasing the lock and lowering the table. As the table drops, it rolls back through 180 degrees to its original position.

Sandslinger. The density of a sand mold rammed by a Sandslinger is controlled by the speed at which sand is hurled into the mold and the speed of the head as it is moved over the mold area. The slinging action is produced by an electrically driven impeller head, located at the end of a ramming unit arm. Figure 8 illustrates the various operational features of a Sandslinger. A storage hopper built into the machine contains the molding sand that is to be rammed. An apron feeder conveys the sand from the storage hopper to a screen where it is screened and conveyed into the boot of an elevator. This elevator delivers the sand to the top of the machine and discharges it onto a belt. The belt conveys the sand to a belt on the ramming unit which is timed to deliver the proper amount to be discharged into the path of the impeller tip or blade. The blade throws the sand into the mold.

Sandslingers may be stationary or motive. The motive type illustrated is a self-propelled unit and travels on a 4-ft 8½-in. gage track. It is equipped with a long ramming arm (up to 26 ft in the large machine) which is actuated hydraulically both for movement over the mold area and for raising or lowering to accommodate flasks or molds of varying heights. All ramming operations are carried on with equal facility on either side of the track. A double-jointed ramming arm is attached to the front of the Sandslinger and operates very much like a human arm. The joint at the machine functions as the shoulder, and the joint some distance from the machine functions as the elbow. Where one's hand would be, at the extreme end of the traveling arm, is the slinger head. The entire machine is operated by hydraulic controls located on the head. With the large machine, the operator is seated on the slinger head; with the other types, he stands either on the floor or on the flask. To get a clear picture of its operation, imagine the operator

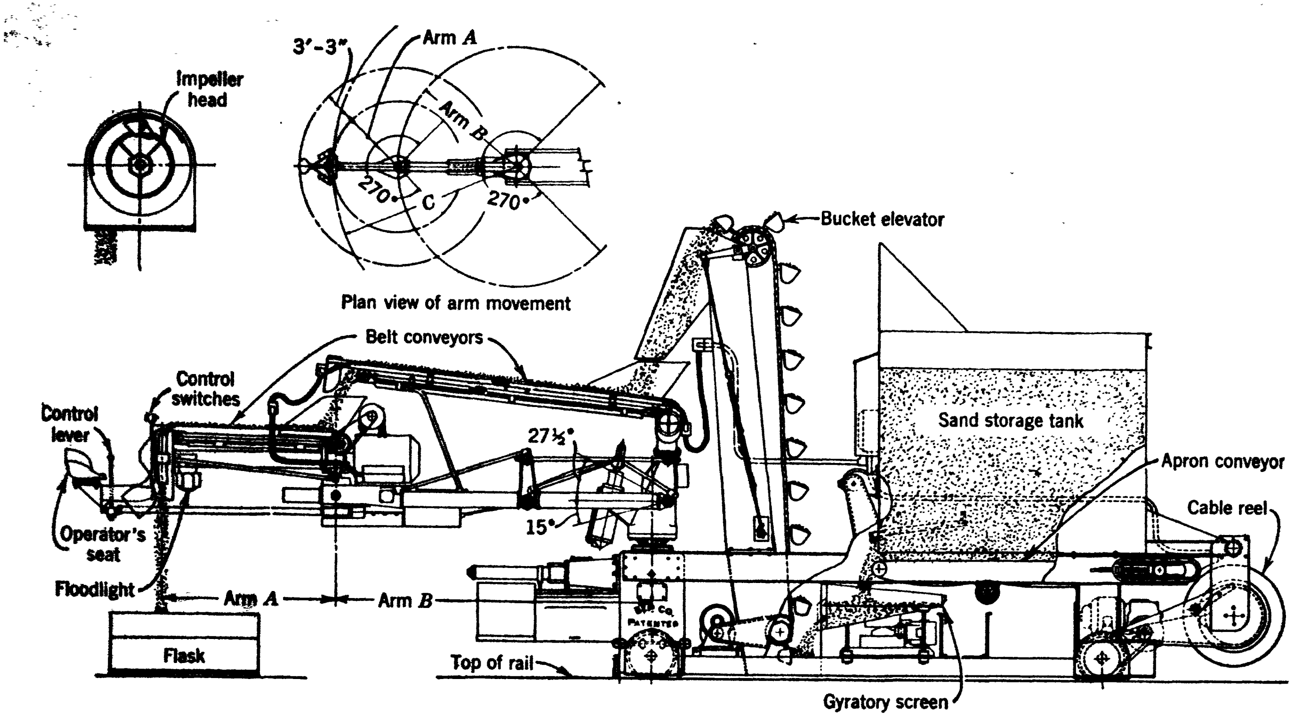


FIG. 8. Schematic view of a motive Speedslinger, illustrating the movement of sand from storage bin to flask. (Courtesy of Beardsley & Piper Co., Chicago, Ill.)

seated in the palm of your hand with your arm extended, with controls to move the arm so as to ram sand in the entire area where molds are located, irrespective of flask size or contour. Thus, the operator of a large slinger can cover a ramming area up to 24 ft in radius from the center of the track and at elevations from 4 ft to 7 ft 5 in.

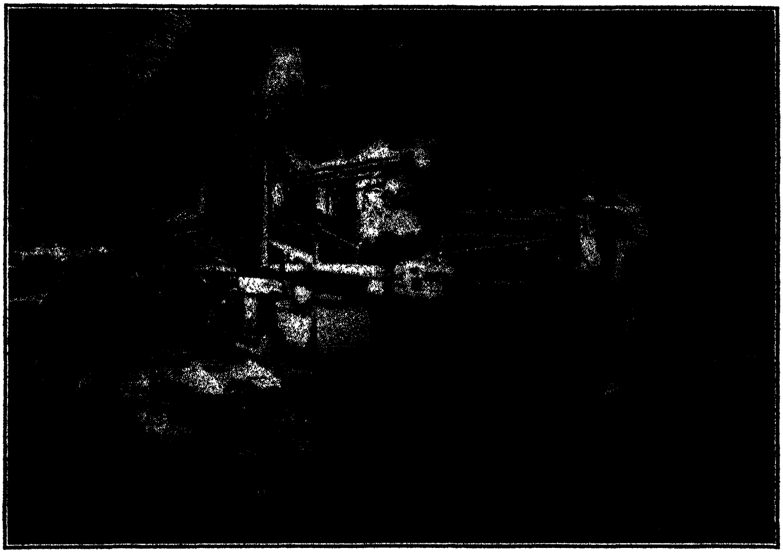


Fig. 9. Motive Speedslinger in operation of ramming a mold. (Courtesy of Beardsley & Piper Co., Chicago, Ill.)

Sand may be rammed with velocities up to 10,000 ft per minute and in volumes of 7 to 20 cu ft per minute. In hand ramming, a molder with his helper can ram the maximum of 1 cu ft per minute. The large Sandslinger, known as the Speedslinger, can ram all kinds of molds but is best adapted to large molds 6 ft square or more. Other types of manually operated Sandslingers are used for ramming molds of smaller sizes.

The sand supply may be delivered to the machine hopper with a crane and grab bucket, or it may be supplied in portable tanks which are an auxiliary part of the Sandslinger, handled by an overhead crane. Figure 9 shows a medium-sized mold being rammed with a Sandslinger.

Sand Preparation. When mechanical equipment is not used, sand molds are shaken out on the floor where they are poured. The flasks, boards, and castings are removed, and new sand or bond is added to reinstate losses due to the effects of heat. The sand is then wet down and shoveled into a triangular heap, extending the length of the molding bay. The hot sand converts moisture to steam which permeates through the sand heap and improves moisture uniformity. Just before molding time, more moisture is added if necessary and the entire heap is *cut* to produce a more homogeneous sand mixture. Beginning at one end of the sand row, the worker shovels through the entire row, forming a similar sand row behind him. At the end of each stroke, he flips his shovel to disperse the sand over the newly formed heap.

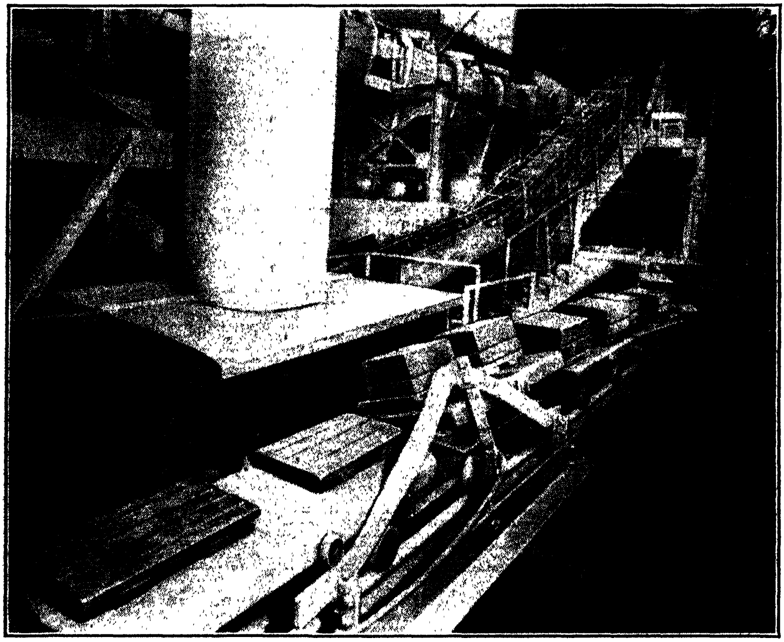


Fig. 10. Tilting top, mold conveyor at shake-out, showing a snap mold being dumped on the shake-out. (Courtesy of Link-Belt Co., Chicago, Ill.)

One of the earliest labor-saving devices in sand preparation was the sand cutter, a portable motor-driven machine which collected the sand off the floor and hurled it into a heap of desired shape. Various improved designs are manufactured for jobbing foundries that are not equipped with sand conveyors.

FIG. 11. Shake-out, illustrating properly designed dust-collecting hood. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

✓**Shake-Out.** Modern foundries prefer not to destroy the molds on the pouring floor but rather to transfer the mold by crane or conveyor to a shake-out machine. A stationary grating, mounted at a slight incline, may be satisfactory for molds that will break up when dropped. Castings, bottom boards, flasks, and jackets remain on top, and sand drops through the grate into the pit. Some shake-outs have a screen below the grate to separate core butts and foreign material from the sand.

A common type of shake-out for destruction of small- and medium-sized molds consists of a perforated plate or heavy mesh screen, fastened to a vibrating frame. Figure 10 shows a vibrating shake-out alongside a mold conveyor. As the mold approaches the shake-out position, the table of the conveyor is tipped sufficiently to cause the mold to slide off the bottom board and fall into the shake-out. Figure 11, in another installation, shows the castings as they roll off the end of a shake-out. The hot castings are then placed on hooks, suspended from a conveyor, and carried to the cleaning room.

FIG. 12. Bumper-type shake-out handling large molds. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

Large molds are often destroyed on a bumper-type shake-out, as shown in Fig. 12. The flask support consists of two beams which are hinged at one end and rest on a motor-driven cam at the other end. Sand drops down through the grating in the floor into a hopper below the grate.

Sand Screening. Mechanical riddles are operated by air or electric motors. The action of a pneumatic riddle is produced by a reciprocating piston, the reversal of strokes being performed automatically by an intake and exhaust port located in the air cylinder.

A gyratory-type riddle, shown in Fig. 13, is suspended above the floor and operated by a motor fastened to the top of the riddle frame. Below is an unbalanced wheel which is connected to the motor by a shaft and flexible coupling. A lead weight in the wheel throws the machine completely out of balance, giving it the gyratory or wobbly motion.

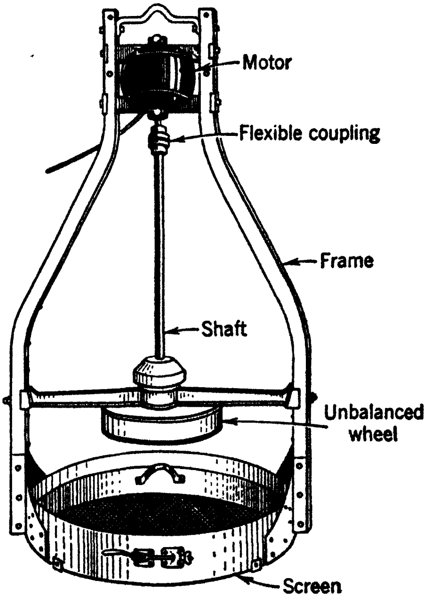


FIG. 13. Gyratory-type riddle. (Reproduced from photograph of Great Western Manufacturing Co., Leavenworth, Kans.)

In production foundries where sand is conveyed and processed mechanically, the sand is screened either by a vibrating deck screen or by a revolving ~~screen.~~ If the screen is to be located on top of a storage bin, a vibrating deck screen is often preferred to conserve headroom. When the sand is relatively free of lumps, except for unburned cores and other foreign matter, the deck screen is most advantageous in sorting and classifying. As sand is discharged at the top of the inclined screen, it rolls down and drops through the vibrating deck, leaving core butts, scrap, gaggers, and other foreign material to roll off the end into a suitable receiver. For an illustration of a deck screen, see Fig. 18 of Chapter 7.

A rotary screen may be cylindrical or hexagonal. The center line, representing the axis of rotation of the screen, is tipped downward slightly so that the material rolls through. If it is not broken up by the time it reaches the lower end, it is discharged as refuse. To avoid loss of sand in the discarded tailings, a hexagonal design is often preferred to the cylindrical type. Breaker-type screens have interior baffles which pick up and drop the sand to break up the lumps. The rotary screen is illustrated in Figs. 17 and 19 of Chapter 7. Auxiliary equipment, such as crushers and hammer mills, are sometimes employed for breaking up dry sand molds in steel foundries.

Deterioration of sand, caused by mixing, molding, and exposure to heat, results in an accumulation of fine particles, called *fines,* which dilute the sand mixture and reduce permeability and mold strength. Mold strength may be restored by adding bond to the sand. Permeability may be improved by the addition of new sand, possibly of a larger grain size. An efficient dust collector surrounding the sand screen is a very effective means of reducing fines in molding sand. The most effective way to eliminate sand dilution is by means of the sand reclamation method described in Chapter 5.

Sand-Preparation Machines. Machines designed for economical preparation of foundry sands are very important in the casting process. A great many of the subsequent molding difficulties, casting imperfections, and waste in material and labor may be traced directly to improper treatment of sand. Among the principal machines for sand preparation are paddle mixers, pug mills, and mullers. Paddle mixers are occasionally used in mixing core sands. The machine consists of a number of paddles mounted on a horizontal shaft which rotates inside a cylindrical container. The batch ingredients are put in from above, and, when mixing is completed, a bottom door is opened to remove the mixture. The sand cutter previously described may be classed as a special type of a paddle mixer to mix molding sand.

The principle of the pug mill is similar to that of the paddle mixer, except that it has two horizontal shafts turning in opposite directions. Sand and ingredients are fed into the mill at one end and discharged at the other end. The pitch of the blades on the shafts is designed to move the sand toward the discharge end. The action of the blades on one shaft, arranged to pass in opposite directions alongside the blades on the other shaft, produces the mixing or plugging action. Sand and ingredients are fed into the mill by a conveyor; water is sprayed over the mixture at the head end. It should be noted that this is a continuous process, as compared with the batch-type process described in the succeeding paragraph. For an illustration of the pug mill, see Fig. 17 of Chapter 7.

Mullers. The process of mulling is generally acknowledged throughout the foundry industry as one of the most efficient and economical methods of sand preparation. The term "mulling" implies the process of squeezing or kneading of sand for the purpose of distributing the ingredients into a homogeneous mixture. One type of muller, shown in Fig. 14, consists of one or two heavy wheels which roll in a circular path over the sand batch. The wheels are set slightly off the true radius to produce a smearing action as they pass over the sand. They are mounted on rocker arms to permit them to move up and down, depending on the amount of sand being mulled, but the lowest position is restricted to about ¼ in. above the base to prevent crushing of sand grains. A plow preceding each wheel loosens the packed sand from the bottom and directs it into the path of the rotating wheels. One of the plows scrapes all the loose sand from the outer edges of the pan, and the other plow performs the same function on the sand in the center of the muller. After mulling is completed, the sand is discharged through one or more doors in the bed plate of the mixer.

Screened sand may appear to be well dispersed; but if it is observed through a lens, it can be seen that the grains are coated with dry bond and are stuck to one another in small clusters. The function of mulling is to disperse these clusters, mix the necessary moisture with bond to form a plastic solution, and recoat each and every grain of sand. The greater the mulling efficiency, the less bond is necessary; and, with less bond, the sand is more permeable. It also follows that a reduction in bond requires less moisture, and less moisture reduces the possibility of such defects as blow holes resulting from excess steam.

In another type of muller, called the Speedmuller, rubber-tired wheels roll along the side walls of a cylindrical pan. The wheels, being fastened to jointed arms, are forced outward by centrifugal force and bear against the pan. Plows which rotate with the wheels are located at the bottom of the pan and are designed to throw the sand up into the path of the wheels. In this machine, sand is mulled between two rubber surfaces, the side walls of the pan being rubber covered.

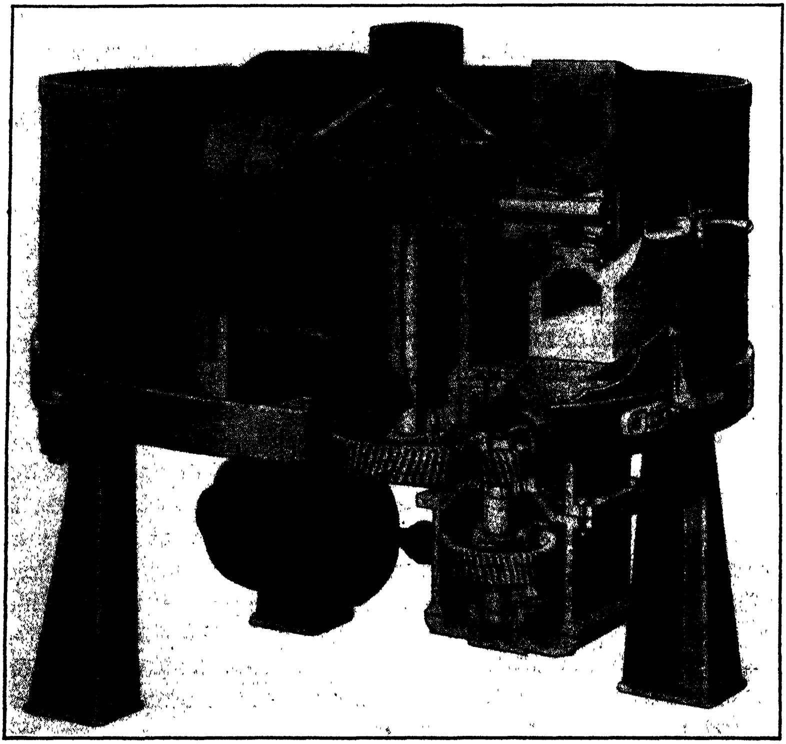


Fig. 14. Sectional view of a muller, illustrating the drive mechanism, wheels, and plows. (Courtesy of National Engineering Co., Chicago, Ill.)

Aerators. The property of sand to pack in and around a pattern is referred to as flowability. Flowability is generally improved by aerating or "fluffing up" the sand. Before mechanical aerators were manufactured, molders discovered that spraying the sand over the sand heap by flipping their shovels (as previously described) improved flowability. This action as well as that of mechanical aerators separates the sand grains and leaves each grain free to flow in the direction of ramming force with

FIG. 15. Aerator attached to the outlet of a muller. The section illustrates the action of the combing fingers in separating the sand grains. (Courtesy of National Engineering Co., Chicago, Ill.)

least friction or adhesive obstruction. One of the earliest designs in aerators consisted of a number of rotating paddles which threw the sand against a curtain of suspended rods. The rods were staggered to create a dispersal of sand.

Figure 15 illustrates one type of aerator. It consists of a rotating wheel to which is attached a number of rows of combing bars that resemble a tooth structure. The sand is picked up by the combing bars and whirled about the housing through the rotating teeth. The action separates the grains and aerates the sand.

Magnetic Pulley Separators. Magnetic separators are used to separate nails, iron shot, and other ferrous particles which pass through the screening process. Separators are sometimes used to remove iron particles from other materials, such as scrap brass, cupola cinders, cleaning-room refuse, and foundry sweepings. Separation is performed by a strongly magnetized pulley at the end of a belt conveyor. As the belt rolls over the pulley, sand and nonmagnetic particles fall freely off the end of the belt; iron particles adhere to the belt and drop off at a point where the belt leaves the magnetized pulley. In the earlier types of separators, direct current was transmitted to magnetizing coils in the pulley by means of contact rings and brushes, the design being similar to that of an electric motor. Modern pulleys, as illustrated in Fig. 16, are equipped with permanent magnets.

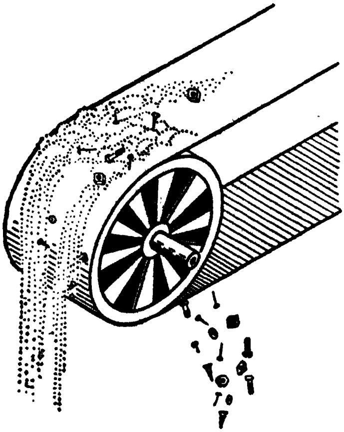


FIG. 16. Magnetic pulley separating ferrous materials from sand.

Core-Making Machines and Equipment. In addition to stock core machines and the coning and cut-off machines already described in Chapter 5, there is a large variety of labor-saving machines, many of them similar to those used in molding. As in molding, cores may be packed by jolting, squeezing, or slinging. Another method not employed in molding is blowing.

The type of machine and equipment needed in the production of cores is dependent, to a large degree, on the number of cores required, the complexity of design, the size of the core, and the ramming characteristics of the core mixture. Mixtures containing air-drying bond, such as Portland cement, must be rammed hard in order to bring the sand grains in proper contact with one another; oil-bonded sands do not require hard ramming because of the free flowing characteristics of the mixture.

Air Ramming. A portable air rammer, consisting of an air-operated reciprocating piston, a rammer rod, and a head, is equally suitable for molding and for core making. The molder or core maker merely holds the rammer and moves it over the area to be rammed. It is light in weight so that it can be easily handled and can be used on both large and shallow core boxes.

Vibrating Stripping Plate. Small oil-bonded cores are usually drawn without the aid of mechanical equipment, but, if the core has slender sections or a deep draw which creates difficulty in drawing the box, a vibrating stripping machine is frequently employed. After the core is rammed and rolled over, it is placed on the table of the machine, positioned so that the box rests against the vibrating guide plate, and drawn as the plate is vibrated. Figure 17 illustrates the core-drawing operation.

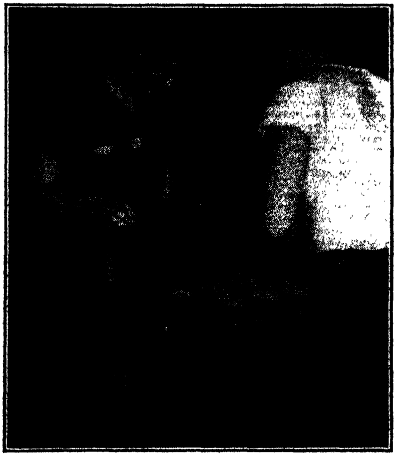


FIG. 17. Core boxes being drawn on a core drawer. (Courtesy of Freeman Supply Co., Toledo, Ohio.)

Ram Roll-Over Draw Core Machines. Many small- and medium-sized cores that require careful stripping are made in gang boxes on core-making machines. Small cores are often made on hand-powered core-making machines, as illustrated in Fig. 18. Core-making machines are essential for large cores because of the difficulty of handling heavy core boxes. Any or all machine operations may be performed mechanically, depending on what is most economical in the production of the core.

One type of machine often employed in core making is the jolt hand roll-over hand-draw machine illustrated in Fig. 19. Operation of the machine is similar to that of the jolt rock-over pattern-draw type previously described, except that the roll-over operation is performed manually and the core is drawn by a hand lever instead of a foot lever.

Core-Blowing Equipment. The use of core-blowing machines for rapid production of uniform and high-quality cores is becoming indispensable in the foundry industry. By this method, sand is introduced into the core box with a stream of high-velocity air. Located at appropriate places in the core box are vent openings which contain special screens, called *vent plugs*, for the purpose of permitting the air to blow through. The sand that accompanies the air will pack as it comes to an abrupt stop in the box.

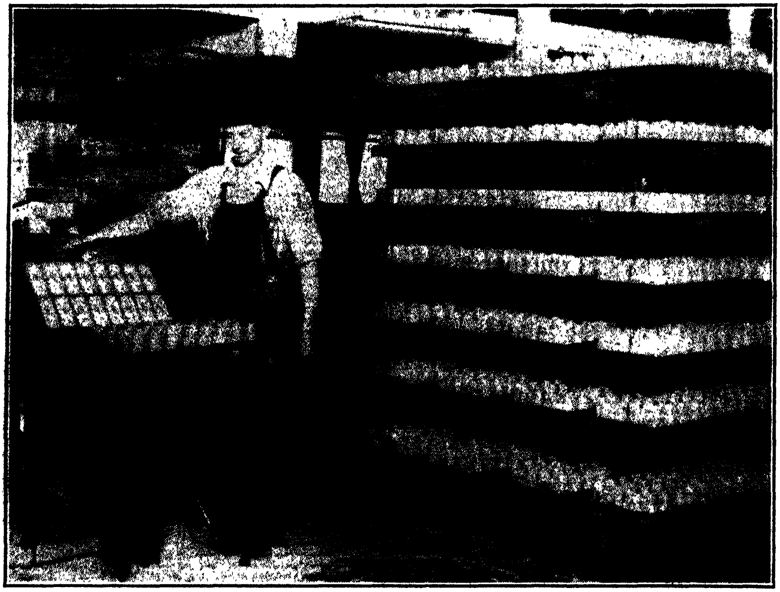


Fig. 18. Sixteen cores produced in a gang core box on a hand-ram, hand-turnover, hand-draw machine. (Courtesy of International Molding Machine Co., La Grange, Ill.)

The core-blowing machine, Fig. 20, contains a sand reservoir to supply core sand to the magazine as it is needed. The magazine is filled by shifting the carriage to the right. When the magazine is filled, the carriage is rolled back to the blow position. In the machine illustrated, this operation is performed manually. In some designs the operation is automatic. Another type of machine, designed for small cores, has a stationary magazine which is supplied by a handful of sand for each blow.

When the magazine is refilled and shifted back and the core box is placed in position, the blowing operation is performed by moving the control lever to the blow position. This sets off a series of operations which clamp the box horizontally, raise the box vertically, and set off the air which blows sand in the box.

Fig. 19. Production of a core on an air-jolt, hand roll-over, hand-draw machine. (Courtesy of International Molding Machine Co., La Grange, Ill.)

When the chuck table rises, the core box makes contact with the blow plate and forces the sand magazine up against the rubber seal of the machine head. This provides a continuous air passage from the air reservoir through the magazine where the

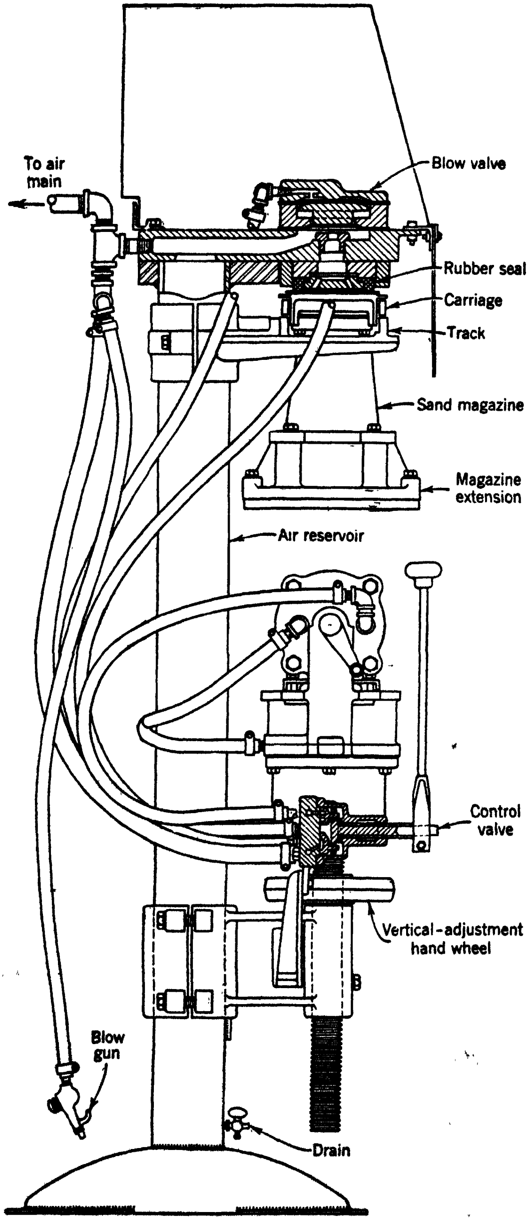


FIG. 20A Core blower. Side view. (Courtesy of Wm. Demmler & Bros., Kewanee, Ill.)

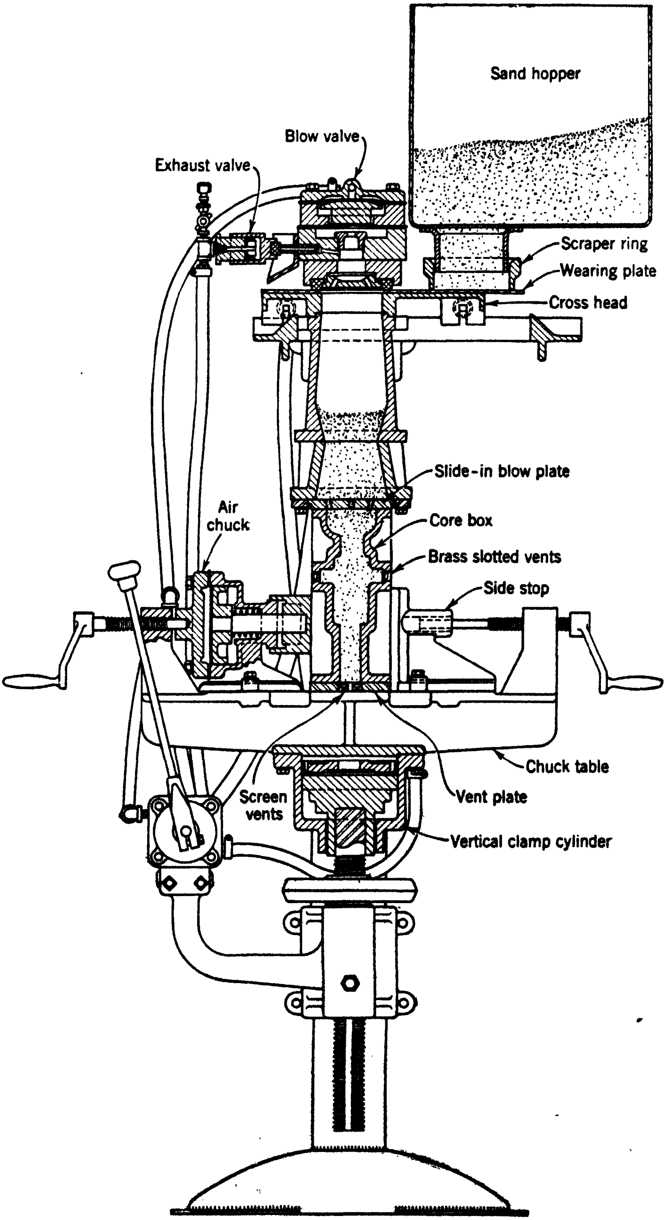


FIG. 20*B*. Core blower. Front view. (Courtesy of Wm. Demmler & Bros., Kewanee, Ill.)

air picks up sand, carries it on through the blow plate, and deposits it in the box. Air passes out through the vents.

When the lever is released, the air is turned off and the horizontal and vertical clamps retreat, releasing the core box. About 3 sec is required for the clamping, blowing, and releasing operations.

Only a portion of the sand in the magazine can be blown into the box. If small cores are being made, several cores may be blown before the magazine is refilled, depending on the machine capacity and core size. Machines are built to produce cores up to 200 lb in weight.

The blow plate is 1 in. thick, shaped to cover the base of the sand magazine, and designed with the necessary blow holes to feed the core box properly. Vent holes in the core box must not only be properly located to deposit sand uniformly and with proper impact, but their total area must be equal to, or greater than, the total area of the blow holes in the blow plate, in order that air flow is not restricted.

Sandslingers for Cores. The Sandslinger is frequently used in the production of large cores. Sandslinging differs from core blowing in that the sand is set in motion by impellers. Venting of the box is unnecessary. In recent years a small slinger called the Swingslinger, illustrated in Fig. 29 of Chapter 7, has been designed for the production of medium-sized cores. It is a stationary slinger. The slinger head is mounted on an overhead beam, and a spout to contain the flying sand leads from the head down to the core box. The machine is moored to the beam by a swivel joint, so that the spout may be maneuvered over the core box.

PROBLEMS

1. State the various methods of packing sand in molds, and describe the advantages of each.
2. List the steps in making a mold with the pattern and match plate of Fig. 12*B* of Chapter 4 on a jolt-squeeze molding machine. Use a tapered flask and slip jacket in the production method.
3. List the steps in making drags on a jolt-squeeze roll-over molding machine, using the pattern in Fig. 16 of Chapter 2. Assume that the pattern for the drag is mounted on a drag plate.
4. What are the advantages of a stripper machine?
5. How are castings separated from molds in modern production processes?

6. List the various methods of screening sand. Explain how each method operates, and give reasons why one might be preferred to another.
7. How are *fines* removed from used molding sand?
8. Explain the action of a muller.
9. Why is sand aerated?
10. Explain the action and function of an aerator.
11. What is the function of a vibrating stripping plate?
12. What is the difference in the principle of operation between a core blower and a Sandslinger?

7

Production Planning

Materials Handling. No other improvement in the modern production of castings has brought greater returns than that of mechanized materials handling. In the process of making molds and melting and alloying metals, and in the preparation of castings for shipment, large quantities of materials must be handled. Realizing that the customary practice in the past—of considering materials handling a necessary evil to be buried in overhead—can no longer be tolerated, industry has gone to great length in determining handling costs and in improving methods of reducing costs.

Improvement in materials handling is made in two ways: (1) by proper arrangement of storage space, production equipment, and work stations; and (2) by the use of efficient mechanical equipment for transporting materials.

Flow Chart. The first step in designing or redesigning a production process is to set up a flow chart to trace the successive steps through which a product is processed. The flow chart of Fig. 1 consists of three principal circuits. One circuit traces the flow of metal from raw material in storage to the finished casting. Other circuits show the flow of materials into molds and cores. Feeders, gates, and scrap are returned to material storage; flasks and gaggers go to the mold-production area; and sand is returned to the sand-conditioning system. Sand and bond flow to both the mold-production and core-making circuits. The core-making process depends entirely on new materials from storage. If it is decided to re-use the core sand, the core-making diagram would be a closed circuit and would receive only part of its supply from storage, as shown for molding sand.

In addition to a general flow chart which depicts the complete manufacturing process, specific flow charts may be made wherever the process involves cooperative activities.

The next step in production planning is to make a large-scale drawing of a floor plan on which scaled cut-outs of production equipment are shifted about experimentally to find the most suitable and economical arrangement. For further analysis and study, a scaled model of the layout is constructed and experimented with.

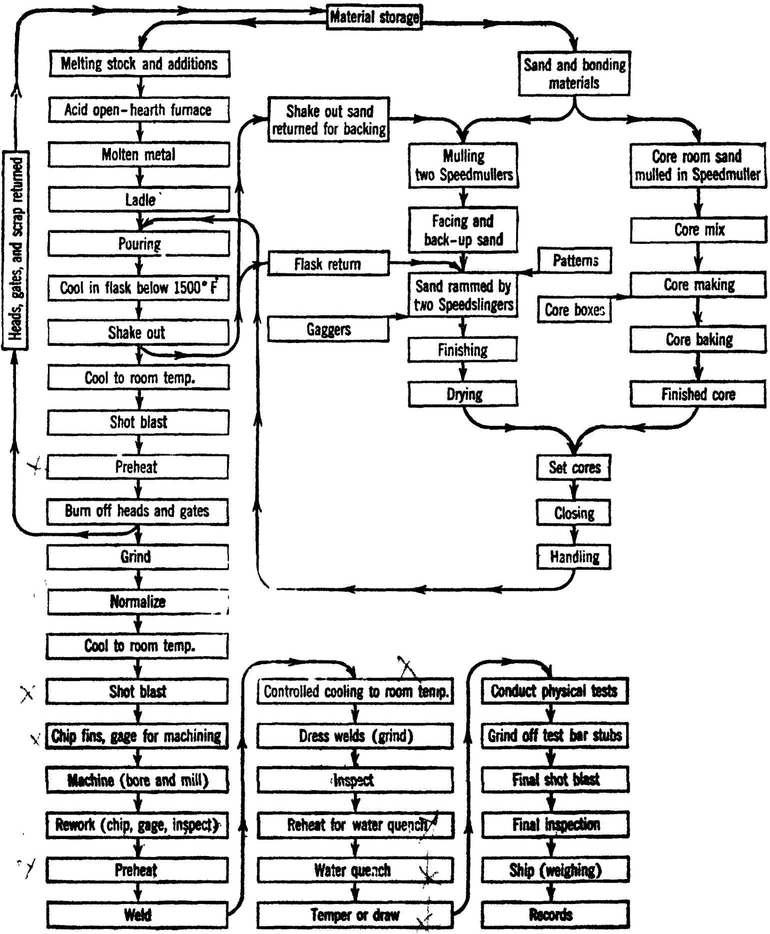


FIG. 1. Breech ring flow chart. (Courtesy of Beardsley & Piper Co., Chicago, Ill.)

When the project has reached the stage where all concerned are satisfied with the proposed plan, it is advisable to check back to see that all operations planned can be performed in a satisfactory and economical way. Much experience can be gained by visits to foundries which operate a system similar to the proposed plan.

Elements of Mechanization. Mechanization of a foundry involves the selection of production equipment and suitable conveyances. The elements of mechanization common to production foundries are as follows:

1. Molding machines.
2. Mold conveyors.
3. Sand conveyors.
4. Sand-preparation equipment.
5. Melting and pouring equipment.
6. Conveyances for molten metal.
7. Mold shake-out.
8. Cleaning, grinding, and inspection equipment.
9. Casting conveyors.
10. Miscellaneous conveyors.

Mold Conveyors. Molds must be removed from the mold-production area as soon as they are completed. This may be done in two ways. The molds may be conveyed to a storage area, where they remain until they are poured and cooled; or they may be conveyed past a central pouring station where they are poured while in motion. In the former method, molten metal is brought to the molds; in the latter, the molds are brought to the molten metal.

Roller Conveyors. Roller conveyors on which molds and other objects move by gravity are often referred to as gravity conveyors. Straight sections of gravity conveyors are customarily manufactured in 10-ft lengths and in widths of 12, 18, and 24 in. The rollers are raised about 3/8 in. above the frame so that objects wider than the conveyor may be handled. They are equipped with sealed bearings that require no oiling. Curved sections have guard rails to prevent objects from being thrown off by excessive momentum. The rollers are arranged radially on curved sections and are split, as shown in Fig. 2, to provide for differential action. Abrupt 90-degree changes in direction are made on special turntables. Roller conveyors may be installed on the floor, or they may be elevated on trestles to any desired height. They are economical and are very easily altered, should production demands be changed.

Overhead Carriers. Overhead carriers are flexible in operation and economical to install. The manually operated monorail type of mold carrier may be operated in small foundries engaged in miscellaneous production. By this method, completed molds are placed on the platform of the carrier and moved by monorail to the melting area where they are poured. After solidification, the carrier is moved to the shake-out and then returned to the molding area with empty flasks, boards, etc.

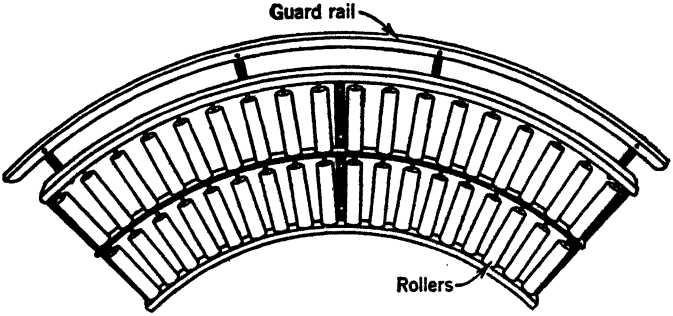


Fig. 2. Curved section of roller conveyor. Split rollers are provided to increase differential action. Guard rails prevent objects from being thrown off by excessive momentum.

An overhead monorail carrier is often employed in transferring medium-sized molds from molding machines to a mold conveyor. A tandem control, consisting of pushbuttons extending from the hoist at a convenient operating height, is used to raise or lower the mold. Horizontal travel requires little effort and is usually manual. This method is frequently employed where molding is performed by several work groups; one makes copes, another drags, and a third sets cores.

Monorail carriers are commonly used to convey molten metal from the melting furnace to molds. Figure 3 shows a mold being poured with a large ladle suspended by a hoist from a monorail conveyor. The monorail conveyor may be synchronized with the motion of the mold conveyor so that the ladle will travel along with the mold while it is being poured. When the mold is poured, the carrier is released from the chain drive and moved manually to the next pouring position.

In a production system where continuous motion is desired, monorail overhead carriers are motivated by a power-driven, continuous chain. Figure 11 of Chapter 6 shows a continuous monorail conveyor carrying castings from shake-out to the cleaning room.

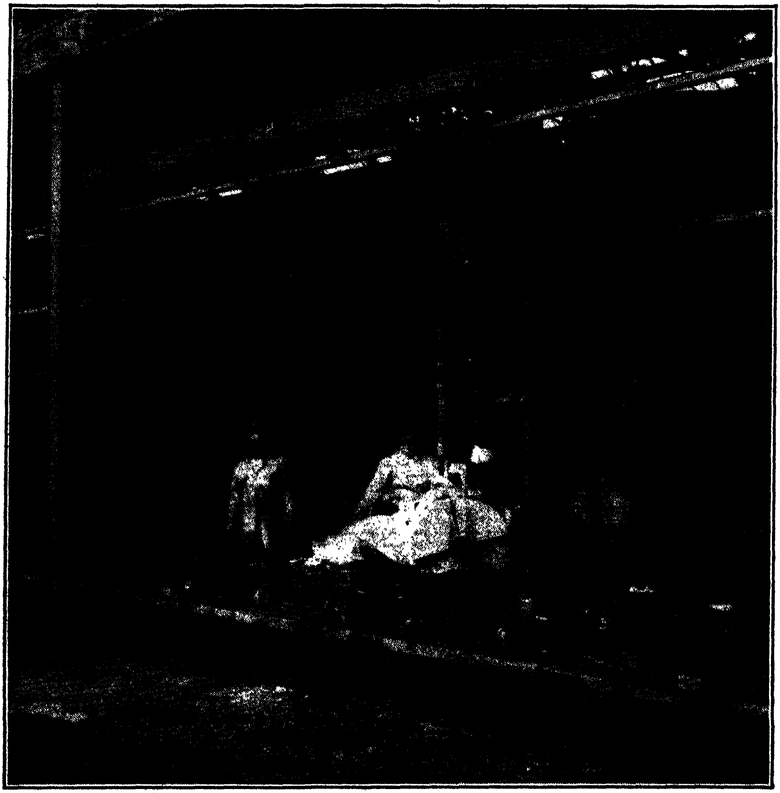


FIG. 3. Molten metal is conveyed to pouring station by monorail conveyor. When pouring, the conveyor is synchronized with the motion of the molds to aid pouring. (Courtesy of Cleveland Crane & Engineering Co., Wickliffe, Ohio.)

Large molds are transferred from molding to pouring areas by overhead traveling cranes. Traveling cranes are standard equipment in all foundries that produce heavy castings. The crane not only assists in transferring molds but performs other lifting operations in the molding process. The crane trolley travels back and forth on a bridge which spans the molding area. The bridge is supported at its ends on wheels which travel on rails through the length of the foundry. This makes it possible to maneuver the hoist anywhere in the area between the rails of the crane. Figure 4 shows a small crane used in the production of molds. Unlike the large electrically operated heavy cranes, these small production cranes are maneuvered by man power. The hoist may be powered by air or electricity. Stationary cranes of the cantilever type, called jib cranes, are sometimes employed.

FIG. 4. Small-type crane, used in the production of molds. (Courtesy of Cleveland Crane & Engineering Co., Wickliffe, Ohio.)

Car-Type (Pallet) Conveyors. Although the pallet conveyor is more expensive initially and more costly to maintain than roller and overhead equipment, it is the most efficient mold-carrying method in high-production systems. It brings the molds to centralized pouring and shake-out areas, where the work can be done by specialized work groups. It simplifies ventilation problems, occupies a minimum of space, and contributes to cleanliness. It is considered an excellent yardstick for controlling and accurately measuring productivity, and it provides better standardization of work throughout the foundry.

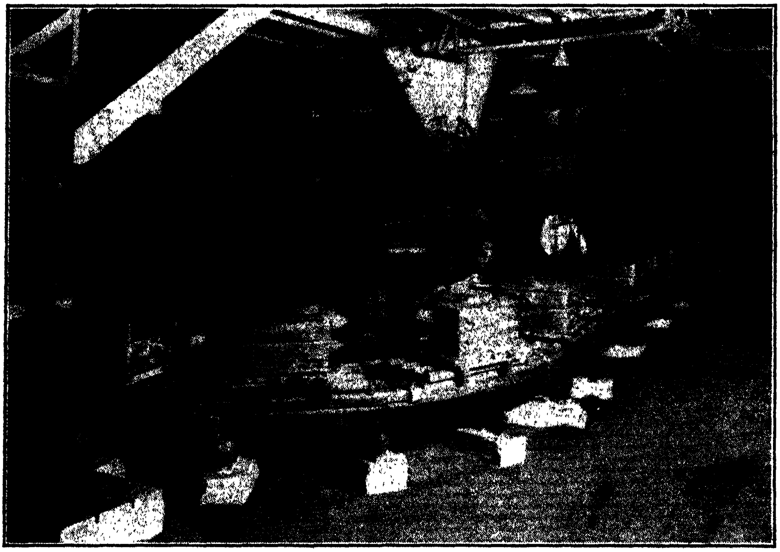


FIG. 5. Continuous car-type mold conveyor with gravity rollers for car tops. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

The pallet conveyor is a car-type conveyor that rolls along a narrow-gage track. The car tops, called pallets, may be made of cast iron, heavy steel plates, or gravity rollers. With gravity-roller tops, as in Fig. 5, molds may be transferred from molding machines to cars by means of rollers, thus avoiding any further handling. The length of a car is determined by the size and number of molds to be placed on each car top and on the radius of curvature desired in the track. Although one type of conveyor runs on two wheels, being supported by side rails, the conventional car runs on a four-wheeled truck. In some special designs, the pallet moves over the rollers without the use of wheels.

When the cars of a conveyor train are joined with a universal chain, as in Fig. 6, it is possible to flex the conveyor in the vertical as well as in the horizontal plane. After passing the drag machine, the cars roll down a decline ① and approach the cope machine at an elevation more convenient ② for mold closing. ③ From there, the mold may be lowered to near floor level for pouring convenience. After pouring, it may pass down into a tunnel below the floor, or it may rise overhead. ④ This provides more floor space which can be utilized for other operations.

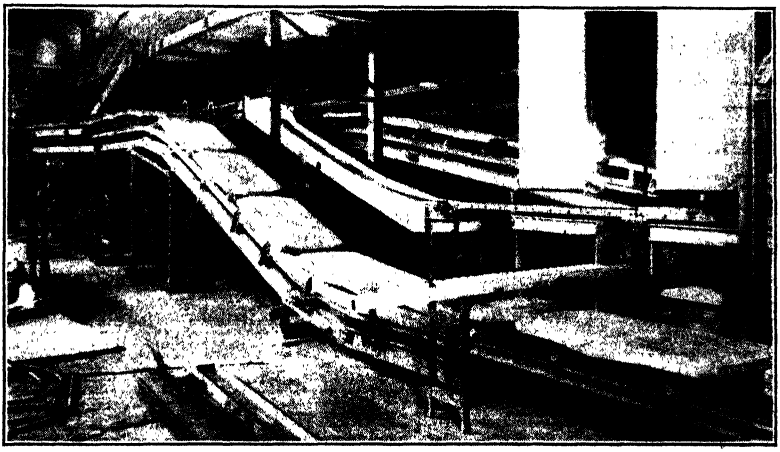


FIG. 6. Conveyor train is joined with a universal chain. The conveyor may be flexed vertically or horizontally. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

All continuous drives are provided with variable speeds in order that mold conveyance may be coordinated with mold production. Slow-speed conveyors with intermittent motion are powered with hydraulic or air-operated long-stroke pistons which move the train a distance of one or more car lengths at each stroke.

Sand Conveyors. Some of the functions of sand conveyors, employed in most production foundries, are as follows:

1. Convey hot sand from shake-out to screen.
2. Convey screened sand to storage bin.
3. Convey sand to reconditioning equipment.
4. Convey conditioned sand to distributing system.
5. Distribute sand to work stations.
6. Convey conditioned sand from hoppers to molds.
7. Convey new sand from railroad cars or trucks to storage.
8. Convey new sand from storage to production.

Belt Conveyors. Conventional types of sand conveyors are belt conveyors for horizontal and inclined travel and bucket elevators for vertical travel. The elements of a belt conveyor are the endless belt, head and tail pulleys, carrying and return idlers, belt take-up, and belt cleaners. The belt is built up of cotton duck plies, which are bonded together with rubber to form a carcass of desired strength. The rubber coating on the under side of the belt transmits driving traction, protects the belt from impregnation of dirt, and cushions the impact against idlers. The top or carrying side of the belt is covered with a heavier coating of rubber to protect it against load impact. The maximum temperature that a rubber belt will withstand is 300° F, if it is made of synthetic heat-resistant rubber; otherwise, 250° F is the accepted limit. One or more layers of asbestos insulating material on special heat-resistant belts may withstand temperatures up to 400° F. For higher temperatures it is necessary to resort to all-metal conveyors, described later in this chapter. The use of water spray to cool sand on belt conveyors is not always satisfactory because of the difficulty in controlling the moisture content of the sand.

Belt conveyors for sand are seldom under 24 in. in width. The head pulley should be large enough in diameter to provide traction and to avoid flexing strains on the belt. To keep the belt centered, the drive pulley may be crowned, its center diameter being slightly greater than that of the sides. However, if heavy loads are to be maintained on a long belt, crowning may be undesirable because of excess strain due to center stretch. A rubber-covered fabric lagging may be riveted on the pulley, or a rubber lagging may be vulcanized on the face of the pulley, to increase traction and to reduce abrasive wear between the pulley and belt.

Carrying idlers of the three-pulley, troughing type (Fig. 7) help to center the load and prevent sand spillage. They should be properly spaced to prevent excessive sagging of the belt, and large enough in diameter to prevent undue curvature on the belt. The function of the belt take-up apparatus is to keep a constant tension on the belt. With the gravity-type apparatus, the head or tail pulley is mounted on a movable carriage which, by means of a cable and weights, produces the necessary tension on the belt. Various types of belt cleaners are used to prevent sand from building up on the idlers, belt, and other parts of the system. Scrapers, rubber brushes, or water spray may be applied to the belt as it leaves the drive pulley.

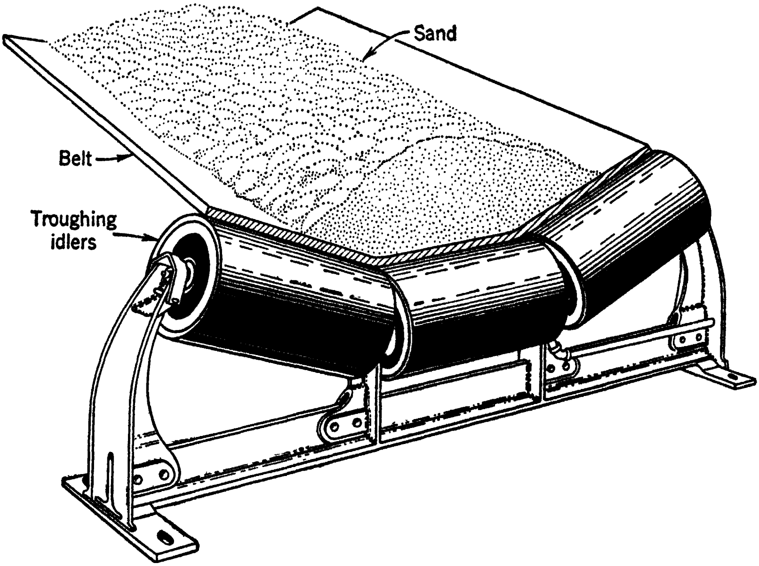


FIG. 7. Belt conveyor carrying a sand load over three-pulley, troughing-type idlers.

Although horizontal belt travel is preferred, a maximum incline of 24 degrees for tempered sand and 15 degrees for silica sand is permissible. Beyond these limits, the sand has a tendency to roll back, or it may slip along the belt and cause wear.

Because of the increased tension on an inclined belt, a decrease in belt speed is generally recommended. If the maximum slope is exceeded, the belt speed must be decreased and the load must be lessened. Belt speeds for various materials and operating conditions may be obtained from belt manufacturers. For example, a maximum of 450 ft per minute is recommended for a 24-in. belt carrying heavy abrasive material.

FIG. 8. Belt conveyor with V plows for distribution of sand to molder's hoppers. (Courtesy of Link-Belt Co., Chicago, Ill.)

When distributing sand to the molder's hoppers, the belt must be flat. It is supported by straight idlers between the discharge plows and by a flat plate under each plow. The part of the flat plate that rides the belt is edged with rubber to prevent belt injury. Single-blade plows are employed in removing sand to one side of the belt, and V-shaped plows, illustrated in Fig. 8, are used to remove sand to both sides. The V-plow may be raised or lowered to inactive or active positions by a lever operated manually or by air.

Bucket Elevators. The use of bucket elevators for vertical transportation of foundry sand is a well-established practice. Of the various types of bucket elevators, the centrifugal discharge type, shown in Fig. 9, is the most satisfactory for sand conveyance. The elements of a bucket elevator are the head assembly, foot assembly, belt and buckets, receiving hopper and boot, discharge, and casing for enclosing the assembly.

When sand is discharged into the receiving hopper, it flows to the floor of the boot, and there it is scooped up by the buckets as they round the foot wheel. Conveyor speeds from 225 to 270 ft per minute are maintained to produce the necessary centrifugal force in discharging sand. The capacity of the conveyor depends on its speed, the spacing of buckets on the belt, and the bucket size.

Inclined elevators are not satisfactory because additional support is required for the carrying load and because of the awkward catenary curve on the return run. Vertical elevators are often preferred to inclined belt conveyors because they occupy less space and are less expensive at first cost.

Flight Conveyors. A flight conveyor, illustrated in Fig. 10, may be used in distributing conditioned sand to the molder's hoppers. It has the advantage of keeping the hoppers automatically filled with sand. When one hopper is filled, the scraper drags its load of sand across the top of the filled hopper on the next one, and so on.

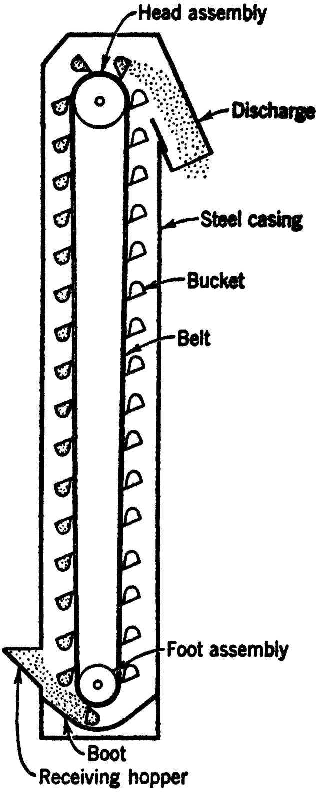


FIG. 9. Centrifugal discharge elevator.

The elements of a flight conveyor are two endless roller chains, sprockets at the drive end and foot end, trough, flights, and driving mechanism. The trough is built up of two steel channels and a steel bottom plate. As sand is fed into the conveyor, the flights scrape the sand through the trough to openings in the hopper. A hopper may be provided with a slide gate which may be closed to prevent the hopper from being filled. The steel or malleable scrapers of the conveyor are supported by two chains which roll along the top of the beams.

An incline of more than 25 degrees is not recommended because of the tendency of the sand to build up at the scraper and avalanche backwards. Flight conveyors are not so efficient as belt conveyors and serve only for specific purposes such as transportation of hot sand and filling of the molder's hoppers.

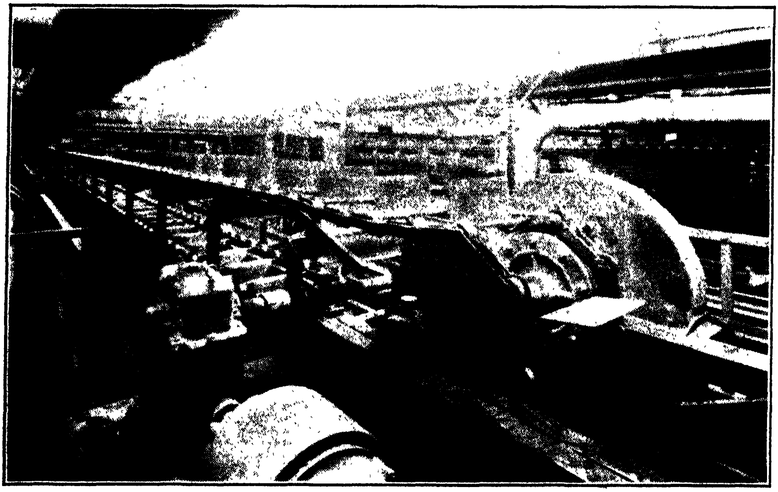


FIG. 10. Top side view of a flight conveyor showing return flights, sprockets, and drive. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

Apron Conveyors. An apron conveyor is the best means of transporting materials that are too hot to be handled by belt. It consists of overlapping beaded steel pans which are supported between, or mounted on, two strands of endless roller chains. Figure 11*A* shows three links of an apron conveyor. A sectional view of the conveyor, illustrating how the aprons are linked and their relative positions with respect to each other when rounding the sprocket, is shown in Fig. 11*B*. One of the many applications of an apron conveyor is the transportation of shake-out sand. Although a belt conveyor is more economical in initial cost and in maintenance, its use is prohibited when the sand temperature exceeds the burning temperature of the belt. This depends on the size of castings being produced. If an apron conveyor is to transport sand, it should be leak-proof, with tight-fitting, enclosed, outboard rollers to prevent sand loss and bearing wear. Side plates or skirt boards are welded on the sides of the pans to prevent spillage and to increase the depth of the sand load. Although speeds of 100 ft per minute are permissible, it is more desirable to operate at slower speeds and heavier loads. The conveyor may be damaged if "tramp"

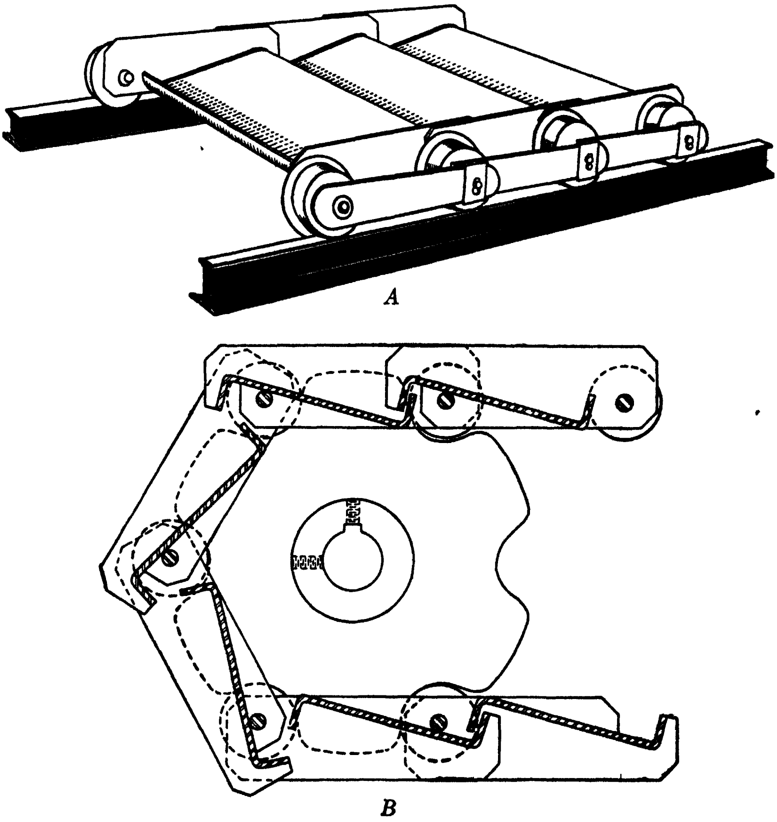
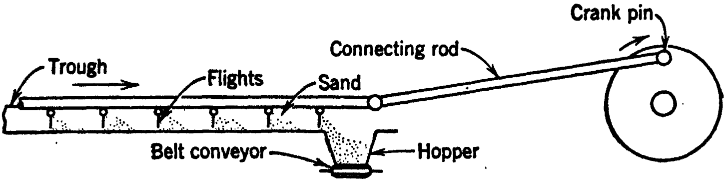


FIG. 11. *A*. Apron conveyor. *B*. Apron conveyor shows discharge action. (Courtesy of Palmer-Bee Co., Detroit, Mich.)

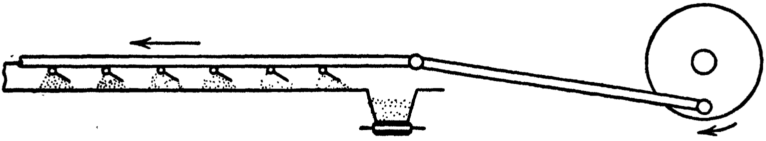
gaggers or rods get caught between the plate and overlapping head. Apron conveyors are usually protected by shear pins and automatic shut-off relays to prevent extensive damage.

Other applications for apron conveyors, such as casting conveyors and flask fillers, are discussed under specific headings in later paragraphs.

Reciprocating Conveyors. The reciprocating conveyor consists of flights, or scrapers, properly spaced and hinged on a tubular shaft which moves back and forth to produce a "hoeing action." When traveling in a forward direction, the flights move the sand a distance equal to the length of the stroke. On the return stroke, the hinged flights are free to ride over the sand heaps. The reciprocating action is produced by a crank pin and connecting rod.



A. Sand being moved toward hopper



B. Return stroke

Fig. 12. Reciprocating conveyor.

The capacity of a reciprocating conveyor is less than that of other conveyors. It is occasionally installed below the floor level if the depth of excavation is less than that necessary for the customary "return-run" type of conveyor.

Oscillating Conveyor. The oscillating conveyor, illustrated in Fig. 13, causes material to flow in a given direction as a result of an oscillating action produced by a motor-driven eccentric shaft. The trough is supported by arms which are keyed to square bars. Supported by a rubber bushing near the keyed arm and fixed to the frame at the opposite end, the square bars act as a reactor spring in absorbing the energy of the trough as it reaches the end of its oscillatory stroke.

An oscillating conveyor is ideal for transporting hot sand, castings, and other materials that are difficult to handle. Large quantities of material may be handled in tight spots where clearance is at a minimum. When distances exceed 100 ft, two units may be employed, one discharging into another. Operating and maintenance costs of oscillating conveyors are relatively low because of few moving parts.

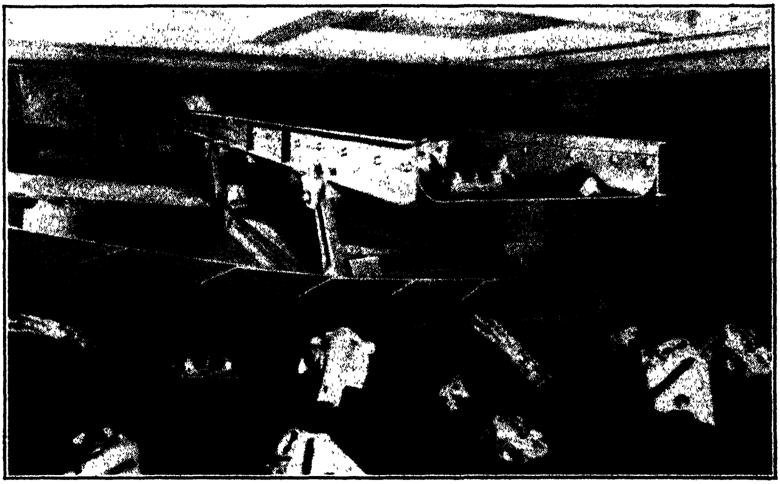


Fig. 13. Oscillating conveyor discharging sand and castings into an apron conveyor. In the background is a belt conveyor which passes under the oscillating conveyor. (Courtesy of Link-Belt Co., Chicago, Ill.)

Figure 13 shows an oscillating conveyor discharging castings into an apron conveyor. In the background is a belt conveyor carrying molding sand.

Sand Transfer by Crane and Monorail. Jobbing foundries frequently find it more convenient to transfer sand by crane and clamshell bucket. Monorail conveyors are often employed with various types of bottom-drop containers for disposing of the sand load. A motor-operated carrier is sometimes run by remote control from a central control station. Other carriers are operated from a trailer cage in which the operator travels along with the load.

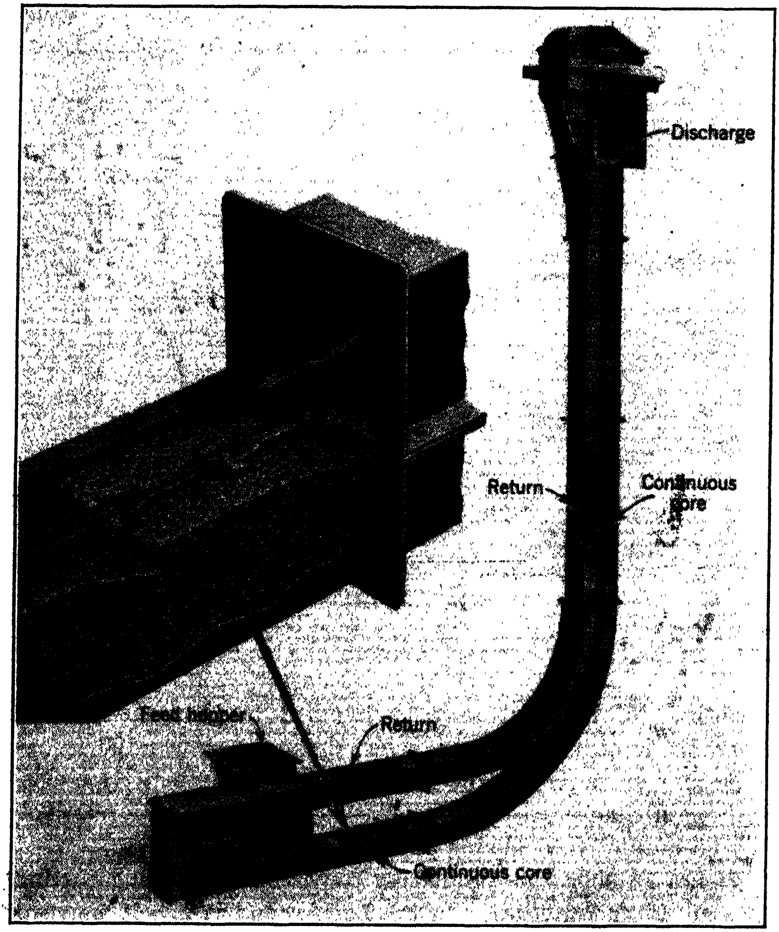


FIG. 14. Continuous-flow (en-masse) conveyor. This L-type conveyor combines a feeder, a horizontal conveyor, and an elevator, all in one unit. (Courtesy of Link-Belt Co., Chicago, Ill.)

Bulk-Handling Conveyors. Nonabrasive, pulverized materials, such as dry binders, may be conveyed by a continuous-flow (en masse) conveyor. As the material flows by gravity into the conveyor duct, it is put into motion by the action of flights which travel through the duct on an endless chain. The principle of operation differs from that of a flight conveyor in that the material flows through a closed duct as a continuous core. The L-type elevator conveyor, shown in Fig. 14, combines a feeder, a horizontal conveyor, and an elevator, all in one unit.

Screw Conveyors. Although infrequently used, screw conveyors may be employed in conveying sand from outdoor storage silos to hoppers at mixing stations. The screw conveyor consists of a long, pitched, steel helix, mounted on a shaft which rotates in a trough. As the material is fed into the trough, it is thrust forward by the rotating helicoid. Inclined travel by screw conveyors is slow, and capacity is reduced. Maintenance is simple, and replacements are relatively inexpensive.

Continuous-type paddle mixers are built on the screw-conveyor principle. The paddles, having a helical pattern, move the material forward at the same time that they churn and mix the sand.

Sand Storage. Monolithic-type concrete silos are being widely accepted for outdoor storage of new foundry sand. Steel bins of various designs to suit production needs are used for indoor storage. In general, there are two classes of bins: one to store excess sand and absorb surges which would otherwise flood the production line, and the other to supply molders with sand.

The size of main storage bins depends largely on their function in the production system. A 2-hr storage supply may be adequate in a continuous-production system, but, if operation is intermittent, as when molds are stored until a certain time when the metal is properly alloyed, the storage bin must be large enough to absorb the surge. Foundries that wish to collect all their sand in storage at the end of a day's run have storage bins of 8-hr capacity or more.

Although shake-out sand may seem to be relatively dry, it frequently retains much of its original moisture. The sand, being hot, produces steam which permeates through the heap. This improves sand strength, often enough to cause "piping" or hanging up of sand at the constricted outlet of the bin. Piping can be minimized by making the sides as nearly vertical as the design permits. A rectangular design, as illustrated in

Fig. 20, is preferred in main storage bins to reduce height. Since it has only two sloping sides, the possibility of bridging across the bottom is less likely to occur.

The capacity of hoppers and bins at molding stations should not exceed the demand by large amounts. The function of the hoppers is primarily to supply sand to the operators. The usual capacity for small-mold production is about 1½ or 2 tons. As in storage bins, bridging may be avoided by sloping two sides, the other two being vertical. A clamshell bucket, commonly referred to as a gate, is used to release sand from the hopper. The gate may be operated by a hand lever, as illustrated in Fig. 15, or it may be operated by an air cylinder.

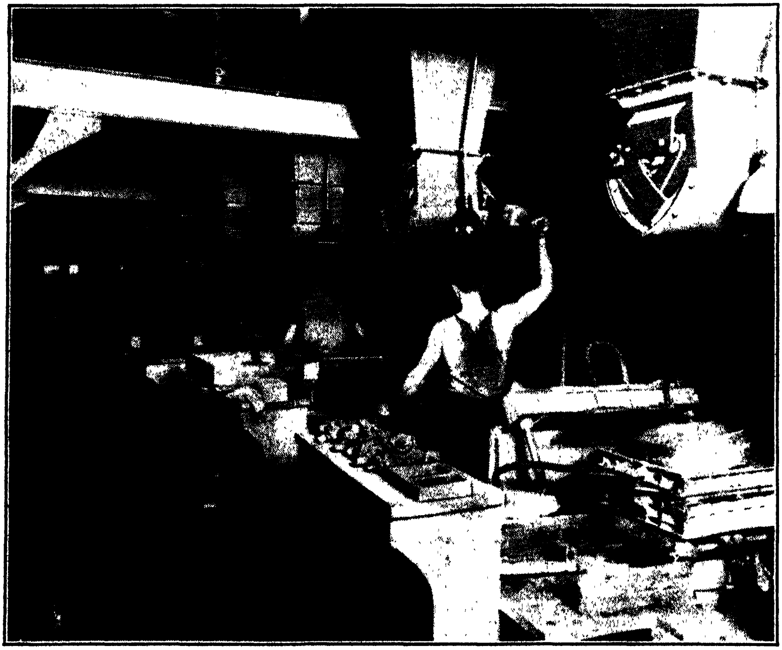


FIG. 15. By pulling down on the lever, the clamshell gates are opened, and sand falls through. Molds are produced on molding machines and placed on a continuous conveyor. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

Feeders. Short conveyors, called *feeders*, are frequently employed to transfer sand from storage bins to mixers and molds.

The wide variety of flask fillers, designed to fill the needs of a multitude of situations, may be classified as stationary or swiveling. Figure 24 shows both types of flask fillers. The swiveling type consists of a belt conveyor on a pivoting boom which can be swung through an arc to supply sand to two or three floor molds. Stationary flask fillers may be of the belt or apron variety.

Skip Hoist. Because of simplicity in construction and operation, the skip hoist is very economical, both in initial cost and in maintenance. It serves most advantageously in delivering materials to elevated locations where they are to be processed or used in batch quantities. Examples of processes requiring batch quantities are the cupola-melting furnace and the sand muller.

In the operation of a cupola, the materials of a charge (iron, coke, and limestone) are weighed and transferred to the bucket of a skip hoist. The charge is then elevated to the door of the melting furnace and discharged. Figure 8 of Chapter 11 illustrates the use of a skip hoist in cupola charging; Fig. 16 of this chapter illustrates its application with a muller.

The principal parts of a skip hoist are the bucket, the guide rails, and a hoisting machine which raises and lowers the bucket by cable. Other features, shown in Fig. 16, are the cooling hood, the aerator, and the bucket-loading unit. The bucket-loading unit operates intermittently. It consists of a vibrating screen, a belt feeder, and a magnetic separator. The bucket is loaded during the mulling period, and, as soon as the muller discharges its batch, a new batch of sand is ready to be hoisted to the muller.

To prevent sand from sticking to patterns, it is desirable to have it as cool as possible. The best place to cool sand is in the muller, where the advantage of heat absorption due to evaporation can be utilized. Some mullers have a sealed exhaust hood in which is developed a partial vacuum to increase evaporation.

Mechanized Sand-Preparation Systems. In selecting the type of equipment and the method of coordinating it into a mechanized system, it is necessary to consider the available space and headroom. Other factors, such as cost and quality of

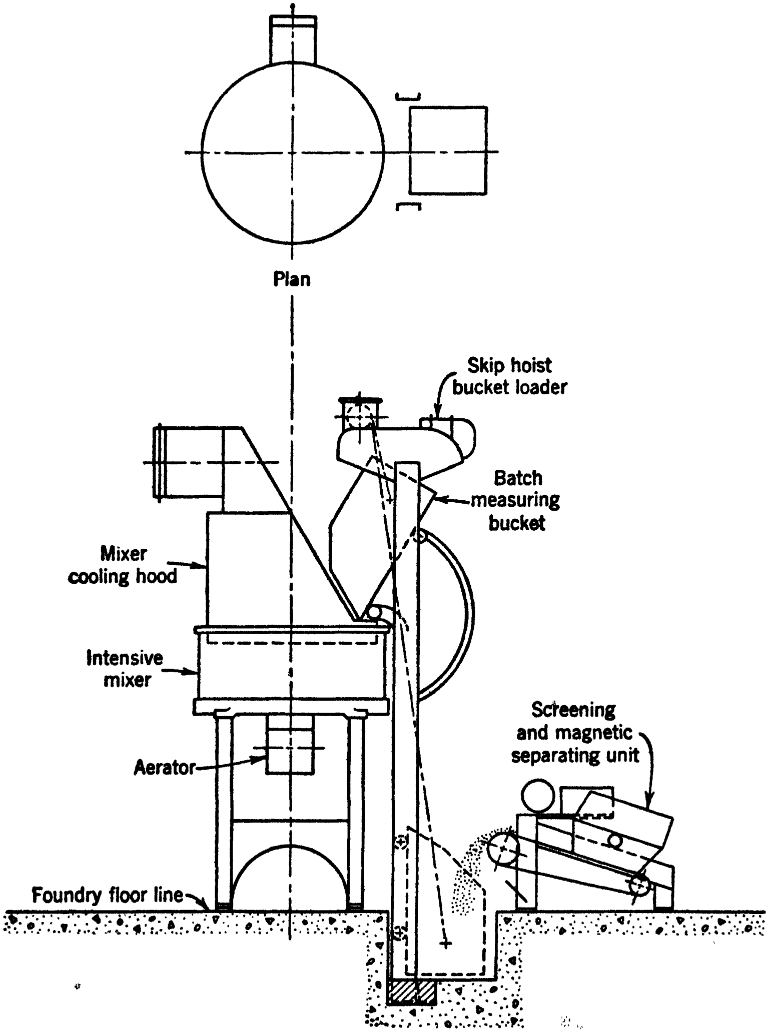


FIG. 16. Skip hoist for loading batch muller. (Courtesy of National Engineering Co., Chicago, Ill.)

equipment and various peculiarities in plant production, may influence the final plan. The following examples illustrate various types of equipment, arranged and coordinated into typical sand-conditioning units.

In *Fig. 17,* shake-out sand is discharged from an elevator into a rotary screen and deposited in a storage tank. Sand is supplied at a constant rate to the pug mill by means of an apron feeder. The rate at which sand is to be delivered to the pug mill is regulated by the speed of the feeder. As the sand reaches the exit end of the pug mill, it drops into the boot of the elevator and is carried up to the overhead distributing belts.

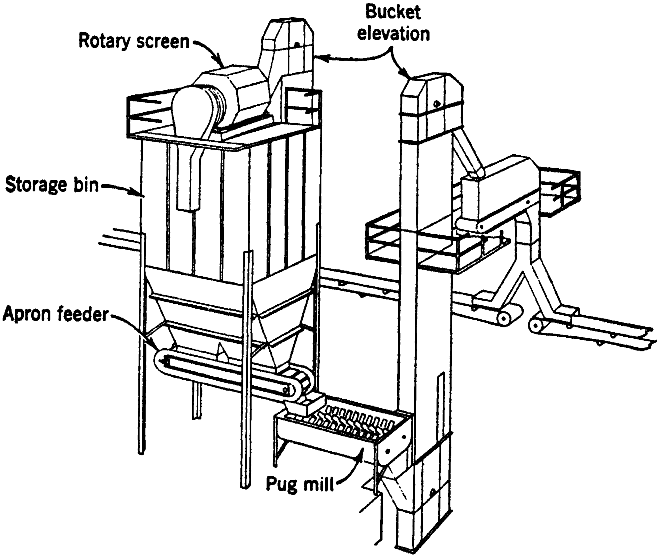


FIG. 17. Screening and conditioning plant consisting of a revolving screen, storage bins, apron feeder, pug mill, and aerator. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

In *Fig. 18,* shake-out sand is delivered to a deck screen by means of an inclined belt. An inclined belt is sometimes preferred to an elevator if the pitch of the belt is not too great and if enough space is available for the belt run. A deck screen requires less height and is often preferred to a rotary screen, especially when headroom is limited. It should be noted that in this illustration sand is stored after it is conditioned; in Fig. 17 sand is stored before conditioning. A belt feeder delivers the conditioned sand from storage to elevator.

Figure 19 illustrates a dual-purpose sand-conditioning system in which either backing or facing sand may be prepared. Facing sand is frequently used in steel foundries. Shake-out sand is transferred from the main storage bin to the bin above the muller by means of a belt feeder and elevator. The Y spout from the elevator has a gate which deflects the sand into the bin above the muller. When the sand is mulled, it is discharged to the belt below and carried back up the elevator. With the gate reversed, the discharged sand is deposited on a belt conveyor and transferred to a cross conveyor for distribution.

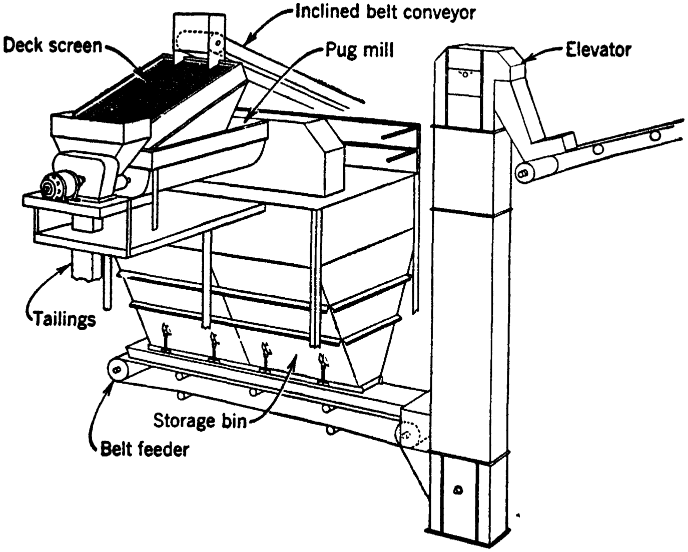


Fig. 18. Typical sand cleaning and conditioning plant showing use of vibrating screen, pug mill, and aerator, with storage after conditioning. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

In the preparation of facing sand, the two principal ingredients (new and used sand) are supplied from the partitioned bin above the muller. Other ingredients, needed in smaller quantities, are added manually by the operator. When mulling is completed, the facing sand is discharged from the muller and conveyed to the molding area in the same manner as that described for backing sand. New sand is supplied to the bin by means of a belt conveyor and elevator. The belt is fed from a hopper in the floor.

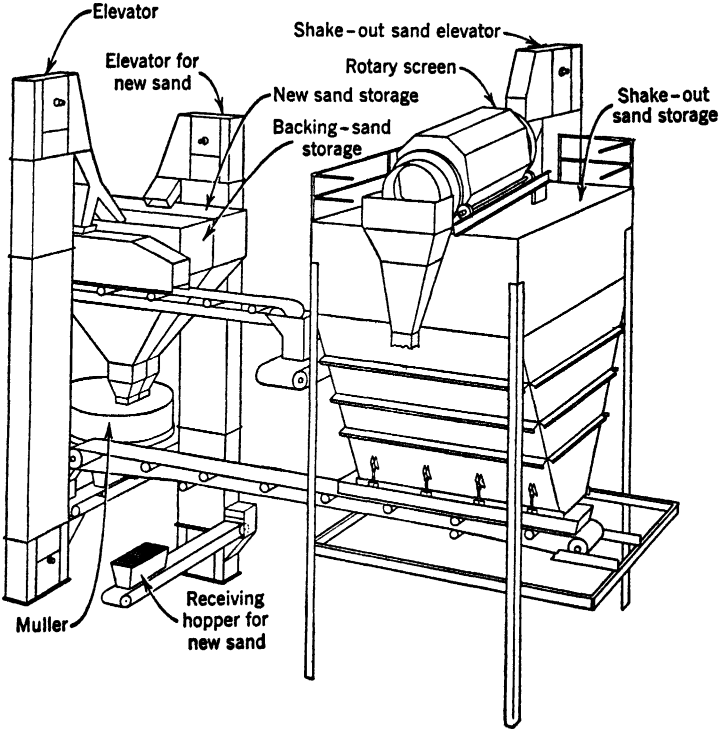


FIG. 19. Diagrammatic view of a dual-purpose sand-cleaning and conditioning plant, showing method of handling facing and backing sand in the same system, and provisions for adding new sand. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

Figure 20 illustrates a conditioning unit designed to prepare backing and facing sand simultaneously. The large bins store backing sand, and the small bins store the various ingredients for facing sand. Each large bin is equipped with a feeder, there being a muller for each bin.

Shake-out sand is screened through a rotary screen and conveyed by a series of belts and a gated duct to the main storage bins. It may also be diverted to one of the small bins by adjusting the gates in the duct to direct the sand down to the distributing belt. The other ingredients for facing sand are transferred from an inclined belt to the distributing belt by means of a straight plow, as shown in the illustration.

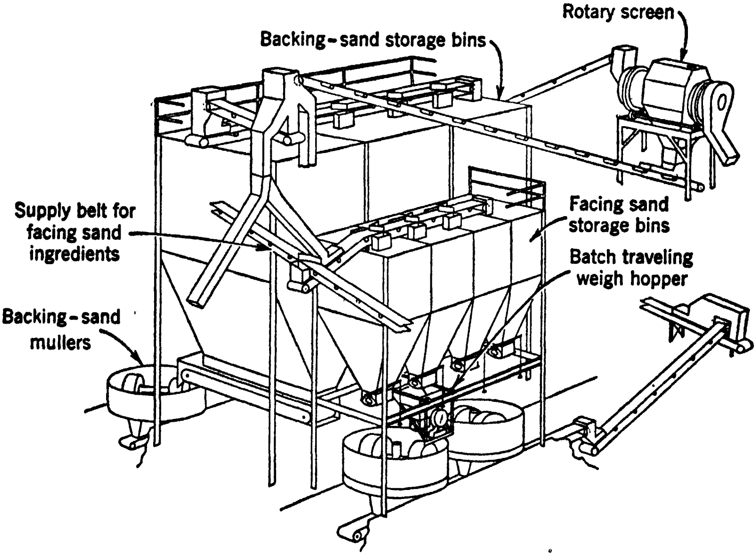


FIG. 20. Combining facing and backing sand-conditioning plant in a large steel foundry, showing use of batch traveling weigh hopper and apron feeders. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

The ingredients for a batch of facing are weighed in a traveling batch weigh hopper. Running on wheels and a track, the batch hopper is easily rolled into position under any of the supply bins where the desired amount of material is discharged and weighed. When all the ingredients are weighed, the weigh hopper is rolled into position over one of the mullers and discharged.

Typical Layouts for Casting Production Units. The following illustrations represent a number of typical layout plans for the production of castings.

Figure 21 illustrates the use of roller conveyors to carry molds away from the molding stations. This method is especially advantageous where small metal heats are prepared at various intervals of the day, or when a number of alloys are required for the various castings produced in the course of a day. The conveyors are pitched in a direction so that the molds will roll down to the opposite end of the conveyor.

After the molds are poured and the jackets are removed, the molds are dumped into a casting bucket. Elevation *B–B* shows the casting bucket in position to receive the molds. The jackets and bottom boards are placed on a return conveyor which is pitched to return the equipment to the molders. When the casting bucket is filled, it is carried by monorail to a shake-out (shown in elevation *A–A*) where the bucket is vibrated until all the sand passes through the perforated bottom. The castings remaining in the bucket are sent off to the cleaning room by monorail. Shake-out sand passes down through a hopper to a belt conveyor which delivers the sand to an elevator. A magnetic pulley collects the small ferrous particles and deposits them in a refuse box in the pit. The bucket elevator scoops up the sand and discharges it into a rotating screen above the bin. Nonmagnetic particles, such as core butts and unbroken lumps, are discharged at the lower end of the screen and deposited in a refuse box; screened sand falls into the storage bin. As sand is needed, it is discharged into a batch-measuring bucket by means of an air-operated discharge gate. The batch is then raised and dumped in a muller with a skip hoist. After mulling, the sand passes through an aerator and is then deposited into a bottom-drop delivery buggy. The buggy is wheeled into position above one of the molder's hoppers, the bottom is released, and the sand drops into the hopper.

In *Fig. 22,* a belt conveyor distributes sand to the molder's hoppers. Molds are placed on roller conveyors. When poured and sufficiently cooled, they are destroyed on a shake-out at the end of each conveyor. The shake-out sand drops through a hopper to a belt and is conveyed to the conditioning unit. There it is transported to a crossbelt and discharged over a magnetic pulley into the elevator. The sand then passes through a rotary screen and drops into a storage bin. A skip hoist is employed

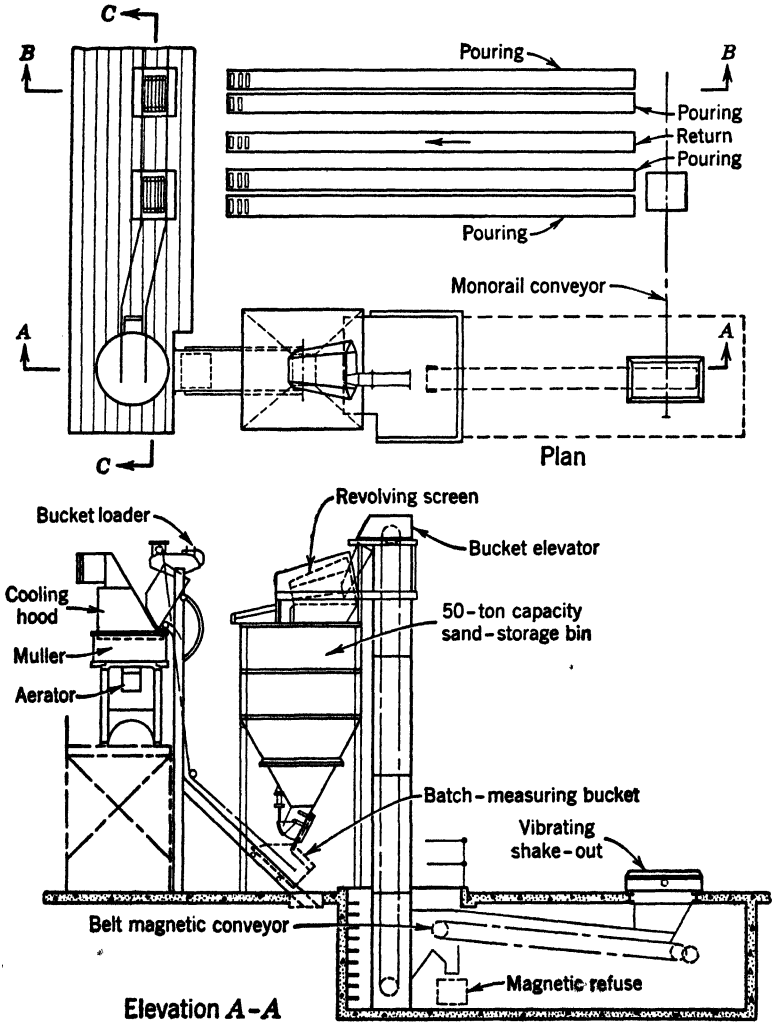


FIG. 21. Typical layout for a light jobbing foundry. (Courtesy of National Engineering Co., Chicago, Ill.)

to measure out the batch and elevate it to a muller where the sand is conditioned and discharged into an aerator. An inclined belt carries the conditioned sand to various distributing points in the foundry.

Figure 23 shows how the same conditioning system is used to supply sand to a continuous mold conveyor. Continuous mold conveyors are frequently employed in high-production foundries that produce duplicate castings in large numbers. Completed molds are placed on a continuous, power-driven (car-type) pallet conveyor which carries them through a complete cycle of pouring, cooling, and shake-out. Molten metal is brought in on a monorail and switched to the pouring station. When pouring, the operator may stand on an escalator which moves at the same rate as the molds, or the monorail conveyor may be synchronized with the mold conveyor, as illustrated in Fig. 3. As soon as the molds are poured, they enter a cooling hood where they are cooled and fumes are removed. Air is drawn through the hood and exhausted. The S curve in the design of the hood

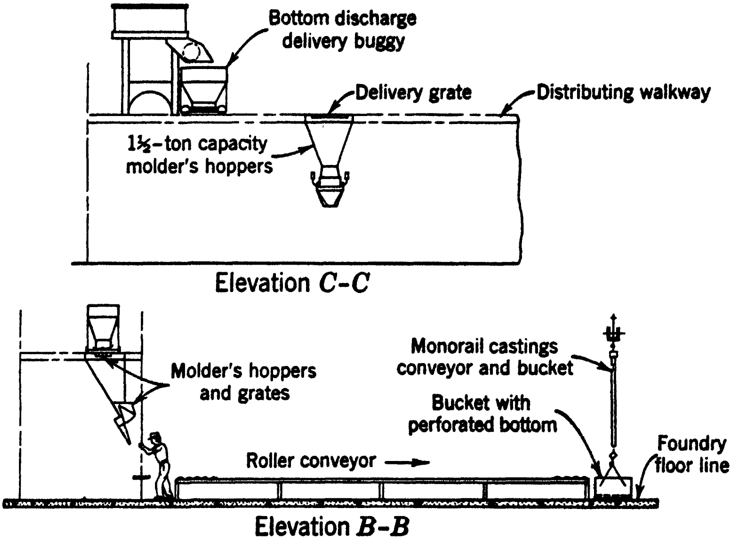


Fig. 21 (*continued*). Typical layout for a light jobbing foundry. (Courtesy of National Engineering Co., Chicago, Ill.)

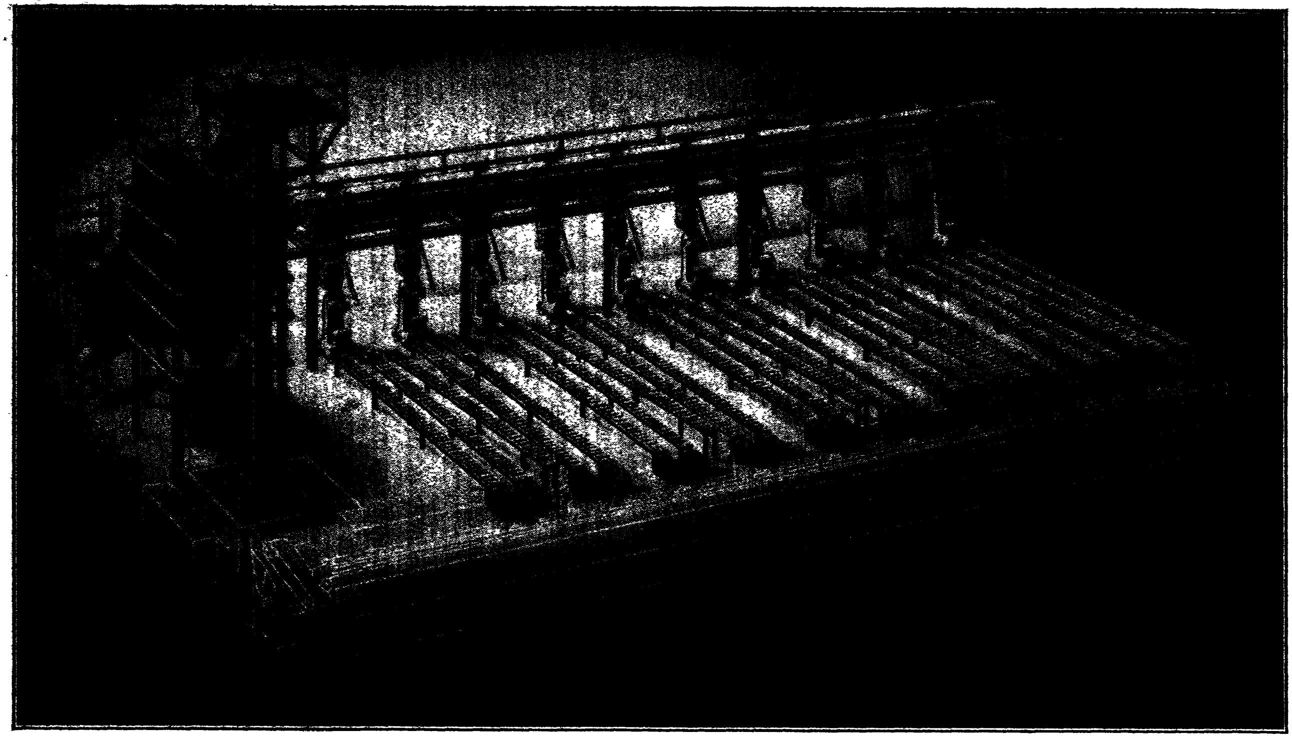


Fig. 22. Mechanized mold production system using roller conveyors for transferring molds. (Courtesy of National Engineering Co., Chicago, Ill.)

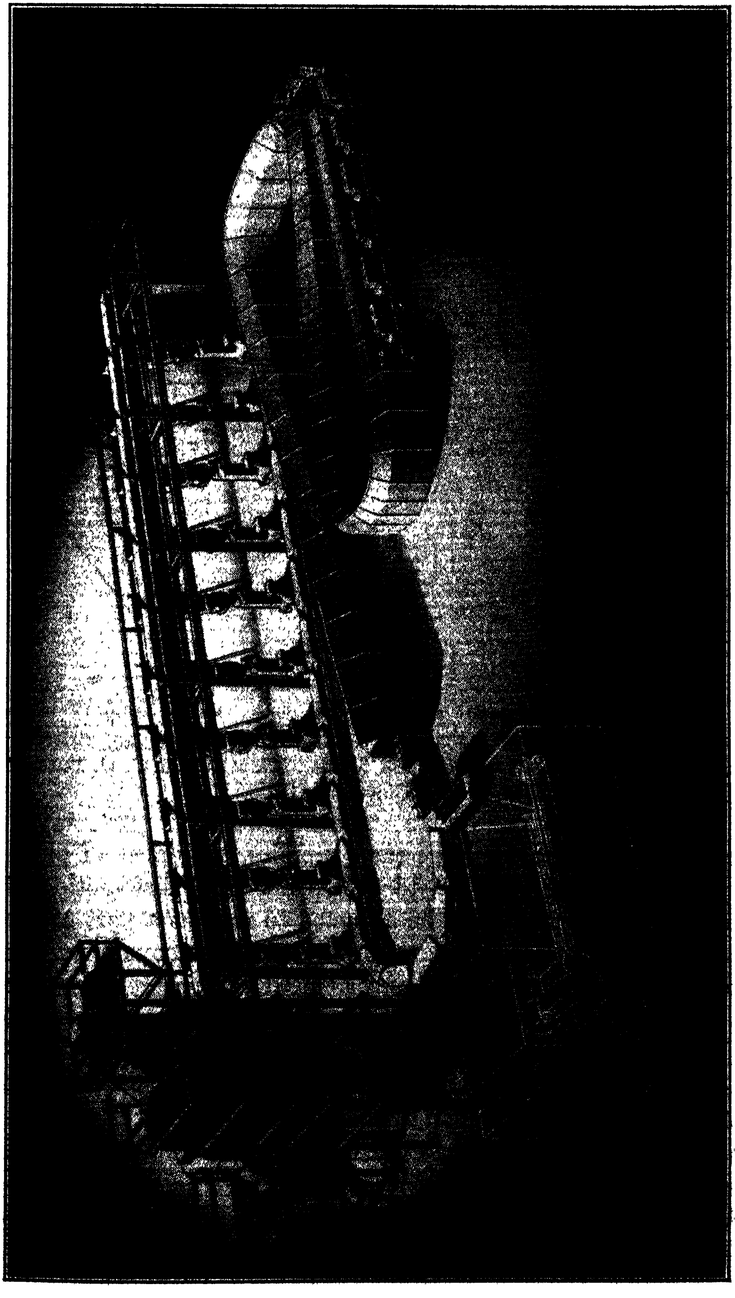


Fig. 23. Mechanized mold production system using a continuous car-type mold conveyor. (Courtesy of National Engineering Co., Chicago, Ill.)

conserves space and provides sufficient time for castings to cool before they are shaken out. A single shake-out, located near the sand-conditioning department, reduces the length of the shake-out belt and simplifies the problem of collecting dust and fumes. In some designs, a strike-off belt passes through a pit under the molder's stations to collect spilled and unused sand.

The conveyor system illustrated in *Fig. 24* was designed for jobbing foundries engaged in the production of large castings.

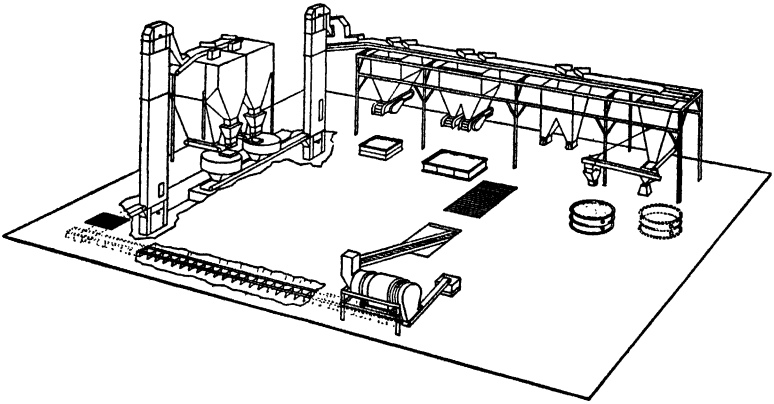


Fig. 24. Typical arrangement of equipment in a jobbing foundry making large castings, showing shake-out, screening, conditioning, distribution, and use of various types of flask fillers. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

Because of the need for large sand supplies, a number of plows are employed over each bin to obtain an equal distribution of sand. The front plow may be adjusted to remove a part of the sand, and each succeeding plow is adjusted to remove a portion of what remains; or the plows may be used alternately to remove all the sand when in the active position. In order to prevent too great a slope on the sides of a large bin, two apron feeders are often employed. Also, when used as flask fillers, the two feeders produce a better sand distribution in a mold. The swing-type flask filler illustrated in the figure may be shifted through a large arc to fill a number of flasks.

Although molding machines and Sandslingers are not shown in the illustration, they are typical of all modern foundries.

After a mold is completed, it is moved out of the molding area with a crane. The mold is then poured and, when cooled, is transferred by crane to the shake-out. The hot sand is conveyed to the screen by means of an inclined apron conveyor. The screened sand is transported to the sand-conditioning system by means of a flight conveyor. Single-blade plows transfer sand from the belt to the partitioned storage bins above the mullers. When the plow is shifted, sand is scraped to either side of the belt, depending on whether new or used sand is being delivered.

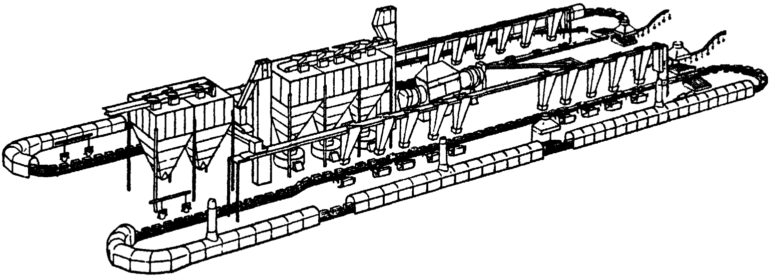


Fig. 25. Schematic view of a two-loop system in a gray iron foundry. This foundry produces 10,000 castings weighing 13 lb. each in 8 hr. Time interval from the cupola to the box car after inspection is 1¼ hr. Sand is used at a rate of 135 tons per hour. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

New sand is introduced into the conveyor system through a grate in the floor, near the elevator.

Figure 25 shows how a single sand-conditioning system may be designed to supply two production units. Among the details in the illustration, the following items should be observed.

1. Hoods for collecting dust and fumes from the shake-out stations.
2. Roller conveyors for returning flasks, boards, etc.
3. Ducts leading from the cooling hoods.
4. Monorail conveyors, showing ladles for pouring.
5. Monorail conveyors to remove castings from shake-out.

Figure 26 illustrates how various mechanized molding units can be coordinated in the production of a variety of castings, both large and small. The area contains a continuous pallet

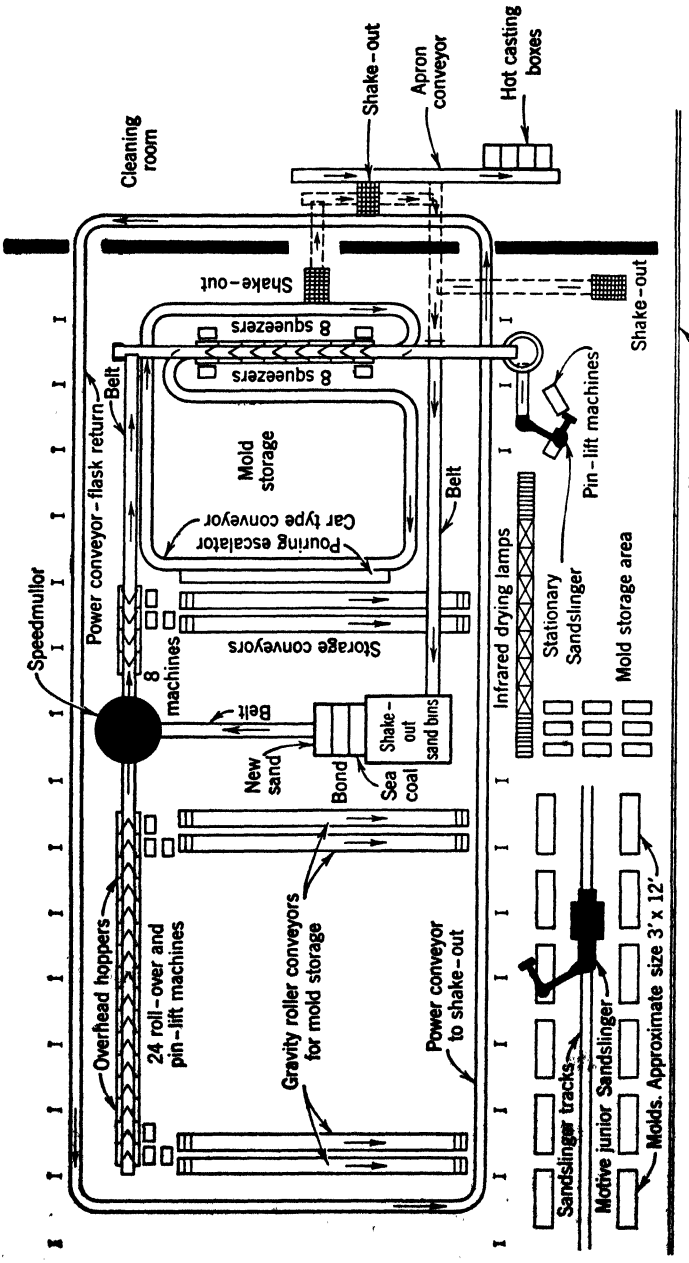


FIG. 26. Plan of a foundry producing a large variety of castings, both large and small. (Courtesy of Beardsley & Piper Co., Chicago, Ill.)

conveyor system for small molds, and a gravity roller conveyor system for medium-sized molds. The small molds are made on jolt-squeezer machines, and the medium-sized molds are made on jolt roll-over and pin-lift machines. Medium to large molds are rammed by a stationary Sandslinger and drawn on a pin-lift machine. The molds are skin dried as they are conveyed through a bank of infrared drying lamps. After skin drying, the molds are transferred to the mold storage area by crane, and there they are closed. Large molds are rammed by a motive Sandslinger. Molds of approximately 3 ft by 12 ft are rammed up on either side of the slinger track. Small- and medium-sized molds are transferred to shake-out on pallet conveyors; large molds are transferred to shake-out by crane.

Figure 27. When division of labor is desired in the production of molds or cores, a turntable may be employed. The turntable may be indexed to move the work through a given arc, each move advancing the work to the next station; or the table may be designed to move continuously while the workmen stand on the table and perform their jobs.

The turntable of Fig. 27 is a continuous-type conveyor for the production of molds. It is approximately 26 ft in diameter and has a capacity of eight stripping machines. The molds are rammed with a stationary Sandslinger. Each revolution of the table produces four copes and four drags. Completed drags are transferred to the continuous pallet conveyor by monorail where cores are set and various operations are performed in preparation for closing. The pattern for the cope and drag of each mold are so spaced on the turntable that the drag arrives at the closing station at the time the cope is completed. The cope is then transferred by monorail to the drag, and the mold is closed.

As soon as the mold is poured, it enters the cooling hood and emerges at the other end in about an hour. After shake-out, the flasks are returned to the turntable, sand is conveyed to the conditioning plant, and castings are removed for cleaning, inspection, and shipping.

Production and Handling of Cores. In many foundries the handling of core sand and cores is a greater problem than that of handling molding sand. Sand and all ingredients that make up the core must be transferred from storage to the mixing area.

In order to control the moisture content of core sand, it is customary to dry the sand before mulling. Thus, sand is handled twice: from storage to drier, and from drier to mixer. Belt conveyors and elevators are very satisfactory for transfer of silica sand. Core oils and other liquid bonds are sometimes piped in from an underground storage tank, metered, and fed directly into the mixer. Dry bond may be transferred to hoppers by bulk flow conveyors, the hoppers being located beside or above the mixer, depending on how the additions are made.

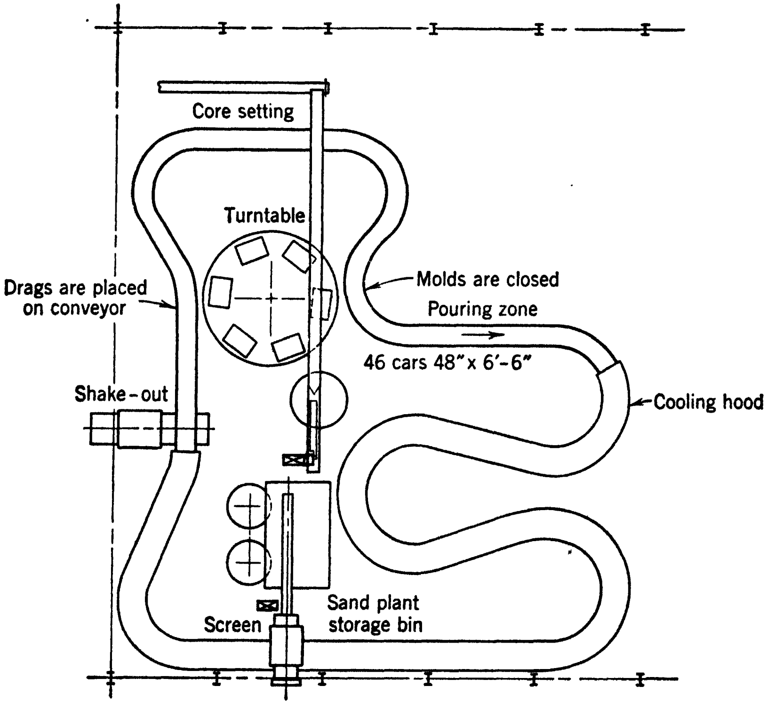


Fig. 27. Mold production with a turntable. (Courtesy of C. O. Bartlett & Snow Co., Cleveland, Ohio.)

Small quantities of core sand mixtures may be conveyed to core-making stations by wheelbarrow. If the sand is prepared on the second floor, a bottom-dump delivery buggy may be employed to deliver sand to hoppers. Monorail carriers with metal bottom-dump containers or clamshell buckets equipped

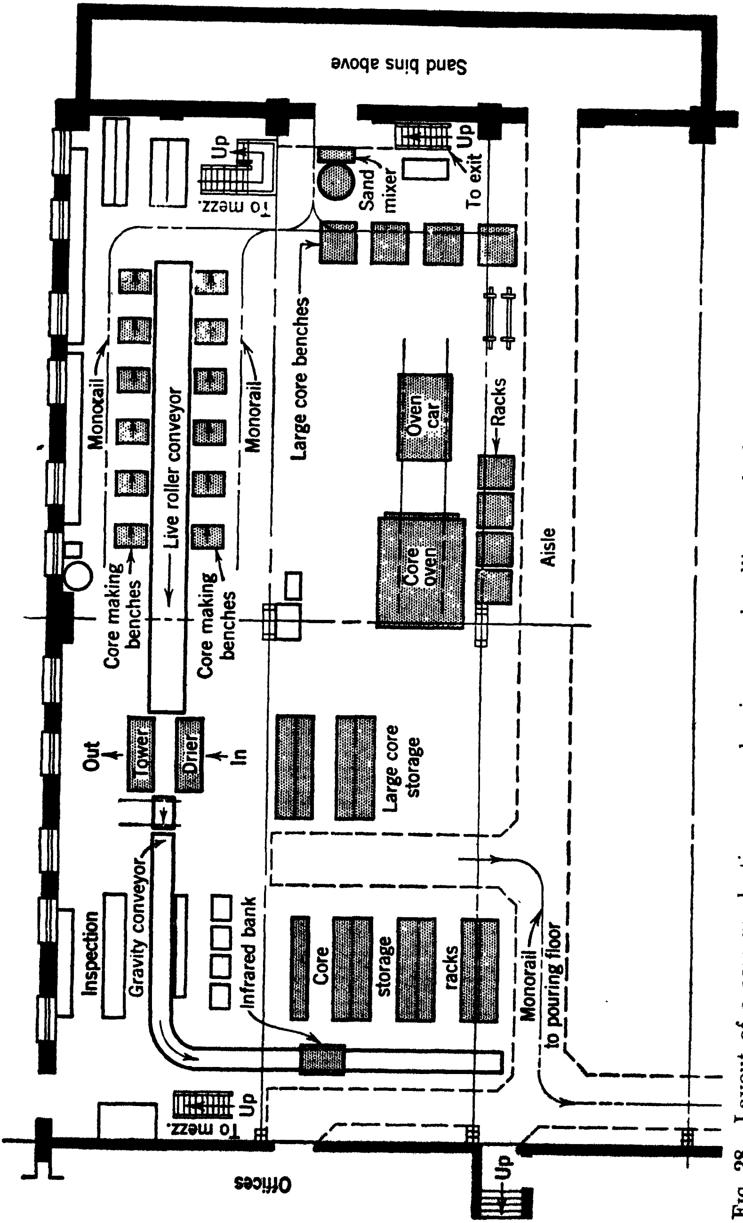


Fig. 28. Layout of a core production room showing core handling methods. (Courtesy of *Mechanical Engineering.*)

with electric hoist are often used. Bonded core sand may be elevated to the floor above the core hoppers by bucket elevator or skip hoist and then transferred to the hoppers by other conveyors.

Cores may be conveyed to the drying oven in a number of ways. A core rack may be placed beside each core maker for convenience in disposing of completed cores. The filled rack may be transferred to the oven by hand or power-lift truck, by monorail conveyor, or by rail.

The monorail may be hand-powered in small foundries or driven by a continuous chain in production foundries. With the continuous type, the racks are conveyed past the core makers, who set their cores on the racks as they move by. The racks are then conveyed through a horizontal or vertical continuous drying oven and emerge with baked cores, cool enough to handle. The conveyor continues on through the core-finishing area where the cores are removed for assembling, daubing, finishing, and final drying. Other conveyors may be employed in these latter operations, depending on the production method. Delivery to molding stations is coordinated with the rate of mold production.

Figure 28 shows a live roller conveyor for delivering small cores to the oven. As the pallets of cores reach the end of the conveyor, they are transferred to a vertical drying oven. The cores bake on their way up and cool going down. When they reach the bottom of the oven, they are transferred to a gravity conveyor which takes them through a finishing and inspection area, through an infrared drying bank, and finally to storage. The finished cores are delivered to the molders by monorail carriers.

Production of Cores by the Turntable Method. In Fig. 29, two turntables are employed in the production of motor block cores. One man operates the Swingslinger (a small Sandslinger), another strikes off the box and rolls it over on a plate, and two men draw the box. The core is then dipped in a refractory wash and placed on a conveyor. To complete the cycle, the core box is assembled and placed back on the turntable. The workmen stand on the floor (not on the table as in mold production) and turn the table manually.

Dust Control. The most important factor in the control of dust and fumes in any manufacturing process is removal at the source, where the greatest concentration exists. Once the dust and fumes are dispersed throughout the plant, the only hope of improving conditions is with an exhausting fan which merely dilutes the atmosphere. This is both inefficient and costly.

Every cubic foot of air removed from the building by an exhaust fan must be replaced by an equal volume of fresh air. In winter months it becomes a costly item to heat large volumes of cold incoming air. Properly designed hoods at shake-outs and mold cooling areas are very important. An overhead hood is more desirable than side hoods because of the natural upward draft of hot air. This is not always possible at a shake-out, especially if molds are brought to the shake-out by crane. Because of rapid decrease in air velocity with increasing distances, crossdraft hoods require much higher velocities and larger volume capacities to divert natural upward draft horizontally into a side hood. Ducts should be designed to carry dust particles at constant speed and at velocities high enough to prevent settling.

FIG. 29. Core production with turntable and Swingslinger. (Courtesy of Beardsley & Piper Co., Chicago, Ill.)

Mold cooling tunnels, shown in various illustrations of this chapter, are usually employed with continuous pallet conveyors. The hood is built up around the conveyor and extends the length of the cooling run. It has one or more exhaust stacks, the exhaust fans being built in the stacks. Removable sections may be provided in the hood for removal of weights. When gases, such as core gas and steam, are formed in large quantities, condensation traps may be installed to prevent accumulation of liquids. Clean-outs are usually installed at 10-ft intervals, for cleaning and inspection.

Gases may be exhausted to the outside atmosphere, but dust should be removed by dust collectors. Dust collectors may be of the dry or wet type. Most collectors precipitate the heavy particles in a precleaning chamber, where the air velocity is reduced sufficiently to cause precipitation. In the dry method, the precleaned air is directed through a series of dust tubes to remove a large portion of the remaining dust. In the wet-type dust collectors, the air is sprayed as it passes through a series of reversing baffles. This reduces the inertia of the moist dust particles and causes them to settle.

PROBLEMS

1. Enumerate the steps to be taken in the planning of a production unit, and give the reason for each step.
2. State the advantages of a roller conveyor.
3. Enumerate all the applications of monorail conveyors in casting production.
4. State all the advantages of a car-type conveyor.
5. State the applications in which a belt conveyor is not desirable, and give reasons.
6. State the uses in which a bucket elevator is preferred.
7. Explain the operation of a flight conveyor.
8. State the uses in which an apron conveyor is preferred.
9. Explain the operation of an oscillating conveyor.
10. How does a bulk-handling conveyor differ from a flight conveyor?
11. How is "piping" avoided in a sand bin?
12. Explain the operation of a skip hoist.
13. Plan a production unit to make the casting of Fig. P3 of Chapter 2 at a rate of 7 short tons per day for an indefinite period of time. Design the match plate, select all equipment, and draw a plan view with necessary elevations to describe the plan.

8

Physical and Metallurgical Properties of Cast Metals

With the exception of mercury, which is a liquid at room temperatures, all other metals normally exist as solids and are characterized by many distinct properties of engineering value. Being familiar with these properties, the engineer selects the most desirable material for his design, and in his specifications he often states the minimum properties of the material to perform satisfactorily the desired functions. Some of the properties by which metals are characterized are strength, ductility, hardness, heat and electrical conductivity, fatigue resistance, impact and wear resistance, and resistance to corrosion by various atmospheres and liquids. The tests in common usage for determining the strength of cast metals are tensile, compressive, and transverse tests.

Test Specimen. A test specimen may be obtained in one of three ways. The most widely adopted method is to cast the specimen in a permanent mold, using a small portion of the molten metal which remains in the ladle after the casting is poured. Other methods are to cast the specimen in the same mold with the casting, or to destroy the casting by machining the specimen from the casting. Details for test specimen standards may be found in the American Society for Testing Materials (ASTM) Standards, 1946, Parts IA and IB.

Tensile Strength. After a test specimen is machined to standard specifications, it is placed in a testing machine and pulled in tension until it breaks. The behavior of the specimen is observed, and the data are recorded. The tensile strength of a specimen represents the maximum force applied to a unit cross-sectional area and is derived by the formula P/A, where P represents force in pounds, and A, the area in square inches.

A routine foundry test may require no further investigation than that of ultimate strength. However, by plotting the recorded data on a stress-strain diagram, as illustrated in Fig. 1, a diagnosis of the physical properties of the metal in tension can be made. In this diagram, the *stress* in pounds per square inch is plotted on the ordinate, and elongation, measured in inches per inch and referred to as *strain*, is plotted on the abscissa. The part of the curve represented by a straight line indicates the elastic range in which the specimen behaves according to Hook's law. If, under these conditions, the load is released, the specimen reverts to its original dimensions. Beyond the elastic limit the specimen acquires a permanent set, and on further application of stress the specimen reaches an ultimate strength at considerable expense to elongation.

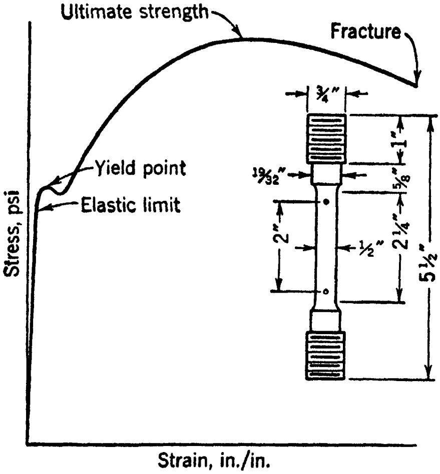


FIG. 1. Stress-strain diagram.

Compressive Strength. The principles involved in compressive testing are similar to those of tensile testing except that the specimen is squeezed instead of pulled apart. In the testing of brittle metals such as cast iron, the maximum load in pounds per square inch is often the only datum of practical value. In the testing of ductile metals, the amount of permanent set (shortening of specimen) under a given load often serves as the basis for testing specifications.

Compressive tests are applied much less than tensile tests. In most cases, a tensile test reveals the desired properties of the metal as well or better than the compressive test.

Transverse Strength. Cast-iron test bars are often subjected to a bending test as a means of foundry control. The round bar, frequently 21 in. long and 1.20 in. in diameter, is supported on two knife edges, as illustrated in Fig. 2, and the deflection is measured as the load is applied. Consideration of the load required to break the specimen and of the deflection attained under that stress gives some measure of the properties of the iron.

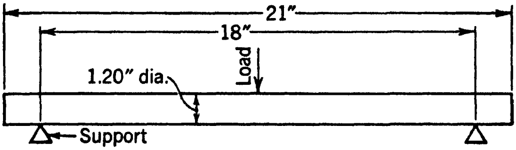


FIG. 2. Transverse strength test.

Deviation from the desired values established for a certain grade of iron gives the supervisor a warning that some objectional factor has entered into the casting process. The manufacturer and purchaser may agree upon certain values in determining acceptability of the product. Standards for minimum breaking loads for transverse tests of cast irons may be obtained from ASTM specifications. For example, a cast iron of 30,000-psi tensile strength is specified to withstand the minimum transverse breaking load of 2,200 lb when a 1.20-in. diameter test specimen is used.

Ductility. The degree of permanent deformation (elongation) before fracture is a measure of ductility. Except in brittle metals, the properties usually specified are tensile strength and elongation. Elongation is expressed as the percentage of the original gage length, as 20 per cent in 2 in. After a test specimen is broken, the pieces are fitted together again and the distance between the two punch marks representing gage length, is measured. The difference between this measurement and that of the original gage length (2 in. in this case) represents the elongation. Elongation is expressed in terms of percentage of increase of gage length. The concept of ductility is derived from comparisons of elongation properties of metals.

Hardness. The hardness of metal is generally defined as resistance to indentation. Of the five indenter-type hardness machines, the Brinell hardness tester is most frequently employed for testing of castings. It consists of a vertical press, designed to force a ball, 10 mm in diameter, into a test specimen under a load of 3000 kg for ferrous and 500 kg for nonferrous metals, the time interval for load application being specified for each indenter and load. The diameter of the indenture is then measured, and the hardness number (representing the ratio of the load in kilograms to the impressed area in square millimeters) may be obtained from a table, or it may be computed if the table is not available.

The Rockwell hardness tester uses steel ball indenters of various sizes, or a diamond point, depending on the material to be tested. This test measures the depth of indentation and is read directly from a dial on the machine. The casting is forced up against the indenter until a specified minor load is reached. A major load is then applied at a given rate and released automatically. The depth of indentation caused by the major load is read from a dial gage while the casting is still under the minor load.

Formulas and conversion tables are available to interpret results of one hardness test in terms of another, but these should be interpreted with care because each hardness test represents a different combination of physical properties, depending on the type of machine. Data obtained from different types of testers should not be converted to compare hardness of castings that differ greatly in chemical composition or heat treatment, and when comparisons are made on castings of similar metal composition the results should be considered only as approximate values.

The following table represents various metals whose hardness numbers were obtained by the Brinell method.

Impact Resistance. The Charpy machine measures impact in terms of the amount of work required to break a notched test specimen. A heavy pendulum swings through a given arc and strikes the center of the specimen, which is supported at its ends.

Table 1. Brinell Hardness Tests of Various Metals

Cast Metal	Tensile Strength (psi)	Elongation in 2 In. (%)	Brinell Hardness (3000-Kg Load on 10-Mm Ball)
Steel			
Low carbon (0.11% C) (as cast)	59,000	13.2	126
Medium carbon (0.25% C) (heat treated)	77,000	31.5	136
High carbon (0.30% C) (heat treated)	92,000	26.0	164
Low alloy (2.39% Ni) (heat treated)	145,000	20.0	288
High alloy (iron-chromium) (heat treated)	250,000	3.0	500
Cast Iron			
Gray iron	23,000		174
Chilled iron	50,000		650
			(500-Kg Load on 10-Mm Ball)
Nonferrous Metals			
Red brass	40,000	25.0	60
Nickel bronze	50,000	20.0	100
Aluminum-copper alloy	22,000	2.0	65
Magnesium-aluminum, zinc alloy	27,000	5.0	50

Impact resistance is measured in foot-pounds of energy. Another type of impact machine, called the Izod machine, is similar to the Charpy in principle except that one end of the test specimen is held rigidly in a vise, the center of the notch being coincident with the upper face of the vise jaws. With this machine, the pendulum strikes and breaks off the upper half of the specimen.

Physical Metallurgy. To the designer, manufacturer, and metal worker, it is important not only to know the physical properties of various metals but also to understand the fundamental nature of metallic structures which is responsible for the various properties and phenomena associated with the development of desired characteristics.

A brief and simplified presentation of internal metallic structure and the mechanics of solidification will be made to assist in understanding the properties of various cast metals. For detailed study, the student is referred to a text on physical metallurgy.

The Structure of Metals. In contrast to the assumption made in chemistry that all matter is composed of molecules consisting of two or more atoms, it is generally believed that metallic elements are monatomic.

When heated to a liquid state, the atoms of a metal have no relation to one another with regard to any definite position. Their random movement due to internal energy is limited only by their affinity for each other, and, the higher the temperature, the more freedom in shifting of bonds is evidenced by increased fluidity of the liquid.

As heat is removed from a molten mass of pure metal, its temperature drops at a definite ratio in proportion to the rate of heat loss, until the point of solidification is reached. At the point of solidification, the temperature remains constant until all the metal is solidified, and the state of energy is lowered from that of a liquid to a solid. The dissipated heat in this constant-temperature phase is called *latent heat of fusion.* When referred to in terms of energy, it is called latent energy.

In the stage of transformation from a liquid to solid, the motion of atoms becomes slower and slower until random motion stops, and the atoms assume a definite geometric pattern called a *space lattice.* Atomic motion changes from migratory to vibratory motion, and each atom takes a fixed position in relation to other atoms.

The orderly arrangement of atoms in their space lattices can be reduced to a simple configuration called a *cell,* which consists of a small number of atoms arranged according to some definite three-dimensional geometric pattern, much too small to be seen with the highest-powered microscope. Although there are a number of known pattern formations for metals, the majority of common metals crystallize according to three types: the *body-centered cubic,* the *face-centered cubic,* and the *close-packed hexagonal.*

The unit cell of the body-centered cubic structure is represented by nine atoms, one in each corner of a cubic pattern, and one in the center. The face-centered cubic structure has fourteen atoms, one in each corner, and one in the face of each plane of the cube. The close-packed hexagonal cell has seventeen atoms, one in each corner, three equally spaced atoms in the center of the hexagonal polyhedron, and one in the center of each of the two hexagonal planes.

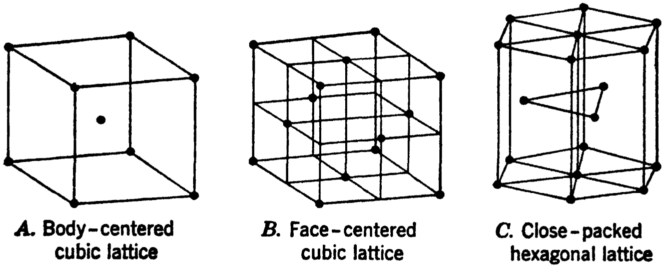

A. Body-centered cubic lattice
B. Face-centered cubic lattice
C. Close-packed hexagonal lattice

FIG. 3. Common pattern formations of cell structures.

A schematic diagram of the three structures is illustrated in Fig. 3, *A*, *B*, and *C*. A more accurate picture of the unit cell may be represented by a number of balls, as shown in Fig. 4, which illustrates the body-centered cubic structure. To carry this further, one can imagine each ball consisting of a nucleus surrounded by electrons which travel about the nucleus in their respective orbits.

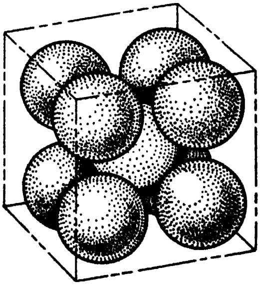


FIG. 4. Body-centered cubic lattice, illustrated with nine spheres.

The atoms that compose the unit cell may be all of the same element, as in a pure metal, or the cell may consist of two or more elements. A cell representing a compound such as cementite (Fe_3C), for example, will have some of the atomic positions occupied by iron atoms and other positions occupied by carbon atoms. Such a structure is called an *intermetallic compound* and is characterized by an invariable pattern, so that every unit cell is precisely the same as every other cell. In contrast to that is the variable arrangement, such as exists with copper and nickel. It is referred to as a *solid solution* in which all unit cells are constructed of the same number of atoms but in which the proportions of the respective elements vary. Structures representing intermetallic compounds are complicated.

Formation of Crystals. The growth of a crystal begins with the formation of a number of unit cells. As solidification proceeds, other atoms attached themselves to an original cell to build up more unit cells in an orderly manner, according to the space lattice structure. It should be noted that the atoms at the corners of unit cells are shared equally by the adjoining cells of the lattice structure. The size of crystals (more commonly referred to as grain size) depends on the rate of formation of cell nuclei. As solidification progresses, each crystal grows about its cell nucleus until it meets its neighbor. As a result, each crystal assumes a different shape, depending on the internuclear space. The orientation of the space lattice of each crystal is determined by the position of the original cells. This results in a random orientation with the space lattice of each crystal

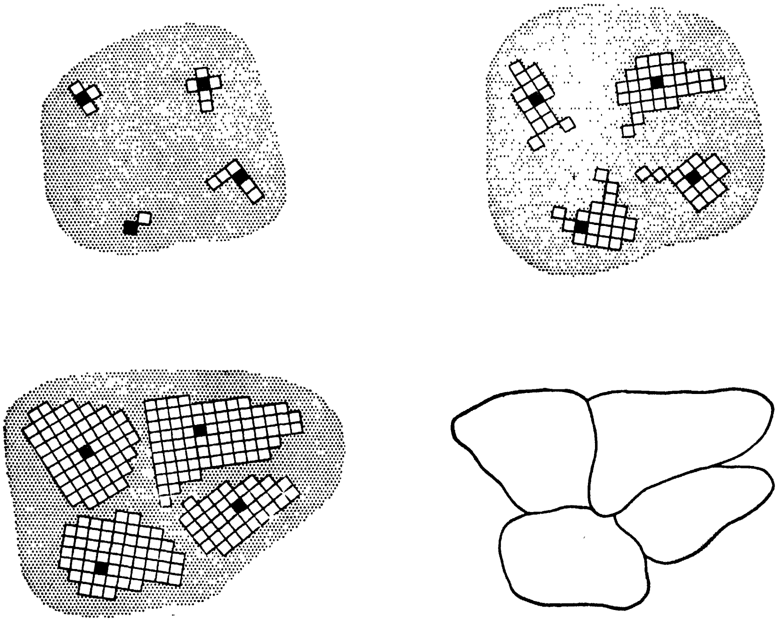


FIG. 5. Schematic illustration of crystal growth.

independent of the others. The atoms in the space between the crystals at the grain boundary are attracted equally to the adjoining crystals. Figure 5 illustrates schematically the process of crystal growth.

When a casting is stressed, resistance to deformation is increased by the number of interruptions in the continuity of the lattice planes. Lattice planes are imaginary parallel planes passed through the lattice structure in such a way that the series of planes will intersect all the atoms of the crystal. Just as it is possible to pass vertical parallel planes in a number of directions to include all the plantings of a field of corn, parallel planes may be passed through the three-dimensional structure of a crystal in certain directions to include all the atoms of the structure. When the casting is stressed, the planes slip over one another in a manner similar to that of the sliding of a deck of cards. Because each crystal is oriented differently, the continuity of slip is disrupted at the grain boundary. Smaller grains in larger numbers produce stronger and less plastic metals.

The control of grain size and its effects on the physical properties of castings will be discussed at appropriate times in connection with specific cases.

Allotropic Modifications. Some metals may change from one crystal lattice structure to another when the temperature of the metal is changed. Iron, for instance, exists as a body-centered cubic structure in a certain temperature range below freezing. As the temperature drops, the cell structure changes to a face-centered and finally to a body-centered structure. This is accompanied by a change in physical properties. Because of a change in internal energy from one crystal state to another, the temperature levels off in the same manner as described for the latent heat of fusion.

Microscopic Analysis of Grain Structure. A microscope is commonly employed in the study of grain structure. When a permanent record is desired for subsequent analysis, a photograph may be taken of the microscopic image. Such photographs are called photomicrographs.

In preparing a specimen for micrographic study it is necessary to have a flat surface so that the image may be focused into view. The specimen is ground on a flat emery or silicon carbide wheel and made as smooth as possible with emery cloth. Final polishing is done on a felt-covered rotating disk which is saturated with water and very fine polishing powder.

In order that the grain outline may be distinguished, the polished surface of the specimen is etched with a suitable reagent. Reagents attack grain structure in varying degrees, depending on the composition of the grain and its orientation. In some specimens the grain boundary is attacked more readily than the grain structure. When the etched specimen is placed under the microscope, the light source, being perpendicular to the polished surface, is reflected directly from the unetched areas, producing a white image of the unetched grains. The deeply etched grains or grain boundaries appear black. Surfaces roughened to various degrees produce various shades of gray, depending on the amount of light reflected into the microscope. The range of magnification with an optical microscope is from 100 to 2000 linear magnifications.

Photomicrographs up to 100,000 diameters are obtained with an electron microscope which makes use of an electron beam instead of a light beam. Because electrons are not reflected as light beams are, it is necessary to make a mask of the etched surface out of a material such as Formvar, which is transparent to electrons. A thin film of the material is cast over the etched specimen, and, when it solidifies, it is stripped off and placed in the path of the electron beam of the microscope. The varying thickness due to the etched impression on the transparent film produces corresponding degrees of transparency to the electrons. The distorted electronic path is further diverged by an electromagnetic field and exposed on a photographic plate.

A recent development has increased the power of the electron microscope to 200,000 diameters. With this, particles may be detected that are separated from one another by as short a distance as one fifty-millionth of an inch.

Time-Temperature Relations. If the temperature of a body of pure metal is recorded at regular intervals of time as it cools from the molten state to room temperature, a time-temperature curve may be plotted to illustrate the transformation points at which liquid begins to freeze and solidification is complete. A constant temperature is observed during transformation at solidification in spite of continued heat loss due to a cooling atmosphere, because of the evolution of internal energy in the change from a higher to a lower energy state. The horizontal line of Fig. 6 shows the time and temperature at which solidification begins and ends.

The solidification temperature of the pure metal mentioned above may be lowered if another metal is alloyed into it. The reduction in freezing temperature is proportional to the quantity of alloy added, but only up to a certain point. This can be illustrated with the more familiar example of adding salt to water in order to lower the freezing point of the solution. When the freezing temperature is reached, pure ice crystals begin to precipitate out, leaving a higher salt concentration in solution. Subsequently, the freezing temperature of the liquid drops to a lower point. This continues until a concentration is reached at which the entire solution freezes. The final liquid concentrate which freezes to form ice and salt crystals is called a *eutectic*, and the temperature at which freezing takes place is referred to as the *eutectic temperature*.

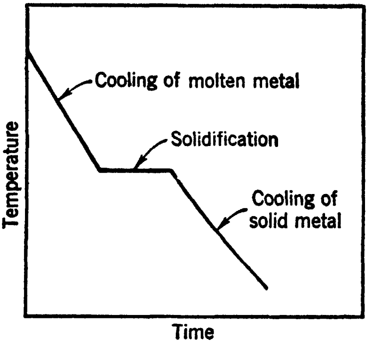


FIG. 6. Time-temperature cooling curve of pure metal.

The same phenomenon takes place with two metals such as lead and antimony which are soluble in the molten state and insoluble in the solid state. The curved line *ab* of Fig. 7 represents the phase at which lead crystals precipitate out and temperatures drop as a consequence. The horizontal line represents the eutectic temperature at which the remaining eutectic of lead and antimony freeze.

Equilibrium Diagrams. The equilibrium diagram showing temperature-composition relationship between two metals in an alloy is an aid to the engineer in the visualization and understanding of temperature-solubility and temperature-composition relationships. It should be noted that when the alloy contains more than two metals the difficulty of portraying relationship decreases enormously.

Instead of plotting temperature against time, as in the previous charts, the equilibrium diagram plots temperature against composition. Figure 8 represents an equilibrium diagram of two metals, M_1 and M_2, which are soluble as liquids but insoluble in the solid state. The abscissa represents percentage composition, and the ordinate represents temperatures. The area above the precipitation curve indicates the temperatures at which various compositions remain in a molten soluble state. The shaded area indicates the temperature through which solidification takes place. The space below the shaded area represents temperature at which the metal is solid.

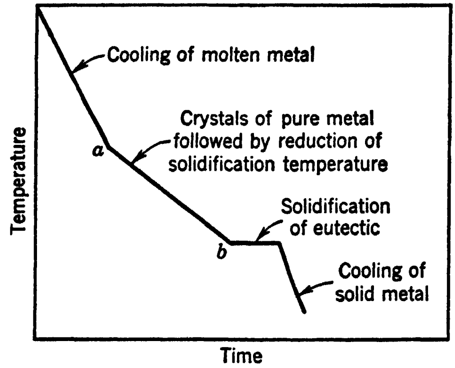


FIG. 7. Time-temperature cooling curve of two metals which are soluble in the liquid state but insoluble in the solid state.

A molten solution of 90 per cent M_1 and 10 per cent M_2 (as indicated on the diagram) begins to form pure crystals of M_1 at a temperature of T_1. The loss of M_1 crystals from the molten solution results in a higher liquid concentration of M_2, and, as previously described for salt and water, the freezing point is subsequently lowered. Finally, when the temperature drops to T_e, the remaining liquid solidifies as a eutectic consisting of 60 per cent M_1 and 40 per cent M_2.

On the other hand, if we begin with a solution consisting of 10 per cent M_1 and 90 per cent M_2, pure crystals of M_2 begin to form at a temperature of T_2, as indicated on the right-hand portion of the diagram. As higher concentrations of M_1 are accompanied with correspondingly lower freezing temperatures, the same eutectic is reached as before.

If we begin with a molten solution of eutectic composition, no preliminary crystallization occurs until the eutectic temperature is reached, and then the entire mass becomes solid. The eutectic consists of a fine grain structure of M_1 and M_2 crystals.

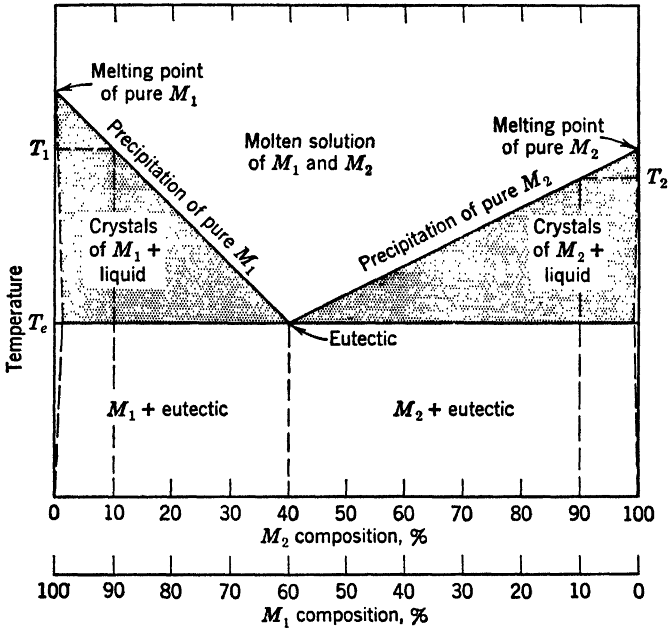


FIG. 8. Equilibrium diagram of two metals soluble in the liquid state but insoluble in the solid state.

Alloys consisting of more than 60 per cent M_1 will be composed of pure crystals of M_1 surrounded by a matrix of eutectic composition. On the other hand, alloys of a composition of less than 60 per cent M_1 will consist of pure crystals of M_2 surrounded by a matrix of eutectic composition.

The microstructure of the lead-bearing type of alloy of Fig. 9 serves to illustrate the discussion of eutectic-type structure.

Phase Diagram of Metals Completely Soluble in Solid State. The phase diagram of two metals such as copper and nickel which are soluble in both liquid state and solid state is illustrated in Fig. 10. As previously mentioned, all cells of a solid solution have the same number of atoms, but they may differ from each other in the ratio of the atoms. For illustrative purposes, let it be assumed that we have a solution of 100 atoms, consisting of 50 atoms of copper and 50 atoms of nickel. One cell of this solid solution may be composed of 3 atoms of copper and 11 atoms of nickel, or 4 atoms of copper and 10 atoms of nickel, each cell being composed of 14 atoms. Other cells will have more atoms of copper and fewer of nickel so that the overall atom count of the solid solution will be 50 copper and 50 nickel.

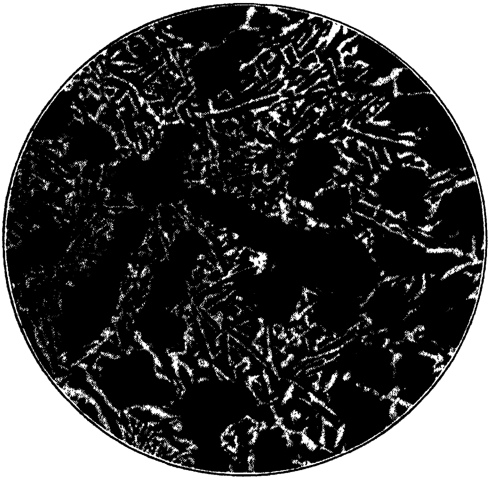


FIG. 9. Photomicrograph of lead-antimony alloy. ×200. A typical eutectic structure. The lacy structure represents the eutectic, and the black areas are lead. (Courtesy of National Lead Co., Brooklyn, N. Y.)

A solution of equal parts of copper and nickel begins to solidify at a temperature of T_1, as indicated on the phase diagram. The composition of the crystals as indicated by point S_1 is 66 per cent nickel and 34 per cent copper. Because a larger amount of nickel is extracted from the liquid, the solution becomes richer in copper. This results in a reduction in the solidification temperature. When some temperature as T_2 is reached, the liquid composition (L_2) is 40 per cent nickel and 60 per cent copper and the crystal composition (S_2) is 56 per cent nickel and 44 per cent copper. With further reduction from T_2 to T_3, the last traces of liquid will solidify at a composition (L_3) of 35 per cent nickel and 65 per cent copper.

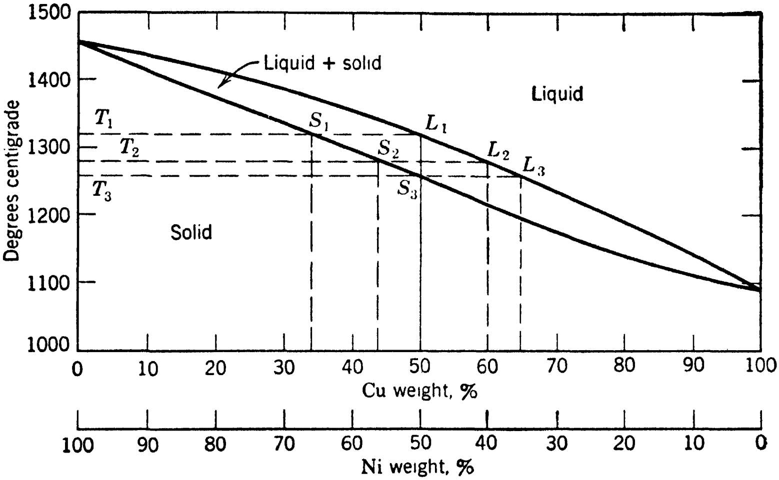


FIG. 10. Phase diagram of two metals, mutually soluble in both liquid and solid states.

Iron-Carbon Diagram. In theoretical steel where only iron and carbon are employed, carbon is alloyed with iron in the form of an intermetallic compound called cementite (Fe_3C) whose composition consists of 6.67 per cent carbon and the remainder iron. Although the commercial alloys contain silicon, manganese, phosphorus, and sulphur, the structural constituents of ferrite and cementite retain their characteristics. The percentage composition of the iron-carbon alloy is therefore based on ferrite and cementite, ranging from 0 to 100 per cent as indicated in brackets below the abscissa of the diagram, Fig. 11. The conventional iron-carbon diagram, however, is presented in terms of percentage of carbon. The maximum of 6.67 per cent carbon shown on the scale represents 100 per cent cementite. Cementite is very hard and brittle and is found in large quantities only in white and mottled cast irons. A photographic microstructure of white iron is illustrated in Fig. 14.

Solid soluble solutions of iron and carbon within the range of 0 and 2.0 per cent carbon, indicated by the area *ABHF* of the iron-carbon diagram, are called austenite or gamma (γ) iron. Gamma iron has a face-centered cubic structure and is characterized by its nonmagnetic properties.

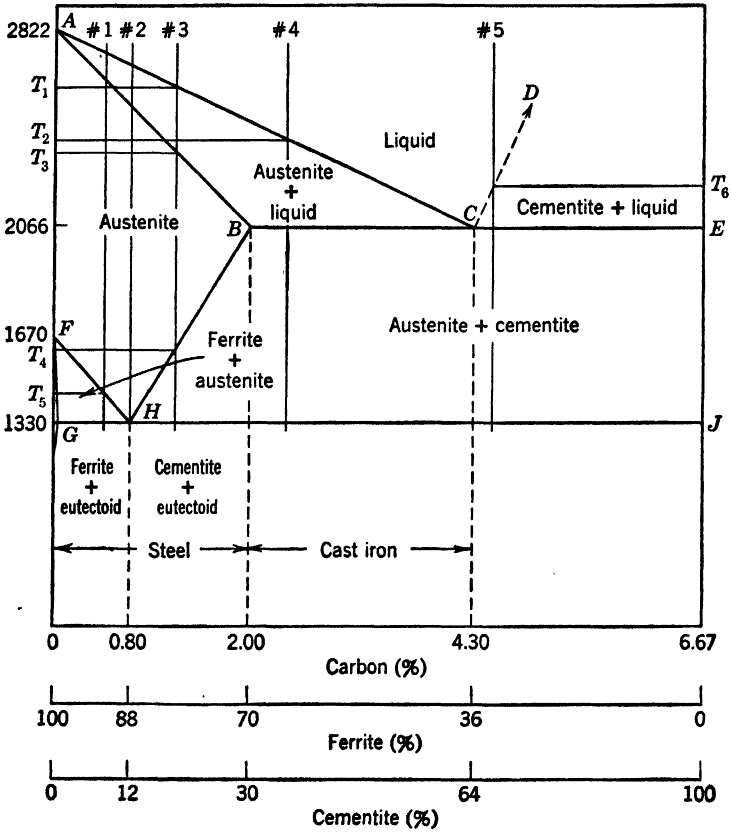


FIG. 11. Simplified form of iron-carbon diagram.

The temperature range indicated by the area *FHG* represents the transformation of gamma iron to its allotropic body-centered cubic or alpha (α) form. Alpha iron is magnetic.

Transformation of Molten Solution of Iron and Carbon to the Solid State. In the study of transformation of iron and carbon from the liquid to the solid phase, the area above the line *ABE* on the iron-carbon diagram will be considered.

The part of the diagram indicated by *ABC* represents partial solubility. The portion of the curve from *A* down to *B* is similar to the solubility curve of Fig. 10. Varying proportions of iron and carbon will crystallize in the form of austenite in a manner similar to that described for copper and nickel. For example, a molten solution of composition No. 3, containing 1.2 per cent carbon, will begin precipitating austenite of low carbon composition at a temperature of T_1, but soon the liquid becomes richer in carbon, and the solidification temperature drops. This continues until all the metal is solidified at a temperature indicated at T_3. The entire solid solution consists of austenite of varying carbon composition.

If the molten solution contains between 2.0 and 4.3 per cent carbon, solidification will proceed in the same manner as described above, except that the last remaining liquid will not solidify as austenite but as eutectic. It should be recalled that the eutectic temperature is the lowest point at which the liquid mass remains as a liquid. It also represents the composition at which both constituents will solidify together. A solution of No. 4 composition will precipitate austenite in the same manner as No. 3 until the eutectic temperature is reached. The last free austenite to precipitate will be of 2.0 per cent carbon. The remaining liquid will solidify in the form of a eutectic consisting of austenite and cementite. The resulting matrix consists of free austenite interspersed with eutectic.

If the original molten composition is 4.3 per cent carbon, no precipitation begins until the eutectic temperature of 2066° F is reached, and the resulting solid consists of all eutectic structure.

The part of the diagram represented by *CDE* is similar to that of the lead-antimony diagram. A molten solution of No. 5 composition begins precipitating free cementite at T_6. As the molten solution becomes weaker in carbon and stronger in iron, solidification temperatures lower until the eutectic point is reached. The resulting solid consists of free cementite interspersed with eutectic.

Allotropic Transformation of Crystals from One Physical State to Another. In order to facilitate a change of metallic structure from one physical state to another, sufficient time must be allowed for the transformation. By control of the rate of cooling or by addition of alloys that act as retardants, many variations in physical properties are attained. It is upon these principles that the mechanics of heat treating is based. Large steel castings made in pit molds are often cooled at a very slow rate, sometimes remaining embedded several weeks after pouring.

FIG. 12. Photomicrograph of steel consisting of 0.15 per cent carbon. ×500. White portions are ferrite, and dark portions are pearlite. (Courtesy of Professor G. M. Enos, Purdue University.)

It is not uncommon to reheat castings to a temperature above a point of allotropic transformation and then quench them at a rate that retains the physical properties of the desired phase. The process of changing the crystalline structure of castings by the practice of heating and quenching will be dealt with in Chapter 9.

It should be observed that the diagram *FGH* is similar to *ABC*. After a metal of No. 1 composition solidifies to austenite, it cools to the temperature of T_5 before any allotropic transformation occurs. At that point, ferrite begins to form, leaving a richer carbon solution of austenite. This results in lowering the transformation temperature in the same manner as described in the liquid-to-solid phase. When the temperature of 1330° F is reached, the remaining austenite of 0.80 per cent carbon is transformed to a fine-grained eutectoid structure called pearlite. The composition of pearlite is fine-grained ferrite and cementite. The final metallic structure consists of ferrite interspersed in a pearlite matrix. Figure 12 shows a micrograph of a steel specimen containing ferrite and pearlite.

Beginning with No. 2 composition, the final structure after solidification and cooling is pearlite. A solution of No. 3 composition begins its allotropic change at T_4. The transformation to cementite reduces carbon concentration in austenite and lowers the temperature of transformation until the eutectoid *H* is reached. The final structure is free cementite interspersed with pearlite.

Cast Iron. From the diagram it is clear that solid solubility exists only to the point *B*, which corresponds to a 2.0 per cent carbon. These metals in which carbon is completely soluble are classified as steels. Further classifications of steel will be discussed in Chapter 9.

Iron with a carbon content greater than 2.0 per cent is classified as cast iron. In actual practice, the carbon in cast irons ranges from 2.25 to 4.3 per cent. Commercial cast irons usually have other elements such as silicon and manganese to improve their properties, but first carbon and iron will be discussed.

As previously described, iron of composition No. 4 becomes completely solid at 2066° F in the form of free crystals of austenite interspersed with eutectic. If this solid composition is cooled to 1330° F at a rate sufficient to prevent the formation of graphite, a white cast iron is formed consisting of pearlite and cementite. White iron is very hard and brittle.

At a slow cooling rate or with the addition of a graphite former such as silicon, graphite flakes form in the matrix, producing a softer and more machinable iron. Definite changes take place in the phase diagram when a third element is added. Two per cent silicon addition, for example, will shift the eutectic from 4.3 per cent to approximately 3.6 per cent carbon.

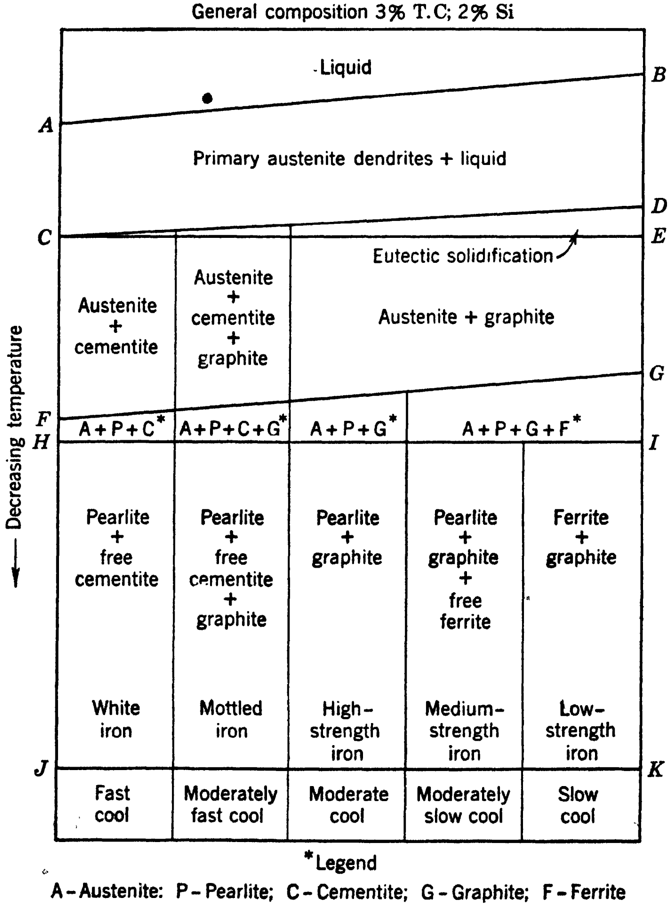


FIG. 13. Transformation occurring during solidification and cooling of cast iron. (Courtesy of American Foundrymen's Society, Chicago, Ill.)

Figure 13 illustrates the effect of cooling rate on the metallurgical properties of cast iron containing 3 per cent total carbon and 2 per cent silicon. The following statements summarize the significance of the illustration.

1. Fast cooling results in white iron consisting of pearlite and cementite. White iron is the first step in the production of malleable iron which is discussed in Chapter 9. In the photomicrograph of white iron in Fig. 14, the white formation represents cementite and the darker portion represents pearletic structure.
2. Moderate fast cooling results in a matrix of pearlite, free cementite, and sometimes graphite. The photomicrograph of Fig. 15 illustrates a mottled structure in which free cementite and pearlite are present.

FIG. 14. Photomicrograph of white iron. ×100. Dark areas are pearlite, and white areas are cementite. (Courtesy of Professor G. M. Enos, Purdue University.)

3. Moderately cooled cast iron produces a matrix of pearlite and graphite. Small carbon flakes dispersed in the fine pearlite matrix reduce hardness and consequently improve machinability with a minimum reduction in strength. This structure is referred to as a high-strength iron. Figure 16 illustrates the laminated structure of pearlite, the light portions representing cementite, and the dark, ferrite.
4. Moderately slow cooling produces a softer iron. It is readily machined, produces a fairly smooth finished surface, and is the most common type desired in economical production

FIG. 15. Photomicrograph of mottled cast iron, illustrating free cementite (white) and pearlite. ×400. (Courtesy of Professor G. M. Enos, Purdue University.)

FIG. 16. Photomicrograph of pearlitic gray cast iron, illustrating pearlite and graphite flakes. ×1000. (Courtesy of Professor G. M. Enos, Purdue University.)

where high strength is not necessary. Figure 17 illustrates a common gray iron structure of this type.

5. Slow cooling produces a matrix of ferrite and graphite which results in a soft iron possessing low strength. Its open-grained structure and large graphite flakes are apparent to the naked eye. It possesses many desirable qualities for engineering design.

FIG. 17. Photomicrograph of gray cast iron, illustrating graphite, ferrite (white), and pearlite (gray). ×300. (Courtesy of Professor G. M. Enos, Purdue University.)

PROBLEMS

1. How are test specimens obtained for the testing of the strength of cast metals?
2. What is the significance of *ultimate strength* in a tensile test?
3. In what way does a foundryman use the transverse test?
4. Describe the fundamental concept of the unit cell.
5. What is meant by the latent heat of fusion?
6. Describe the fundamental concept of the formation of crystals.
7. Describe how a metal specimen is prepared for microscopic study of crystal structure.
8. Explain the time-temperature cooling characteristics of a pure metal.
9. Explain the time-temperature cooling characteristics of a binary alloy.
10. Assuming a molten solution of 20% M_1 and 80% M_2 (Fig. 8), explain how solidification takes place.

11. Assuming a molten solution of 20% nickel and 80% copper (Fig. 10), explain how solidification takes place.
12. Using the iron-carbon diagram of Fig. 11, explain how solidification takes place for the following metal alloys:

    (*a*) Less than 0.80% carbon.
    (*b*) 0.80% carbon.
    (*c*) Between 0.80% and 2.00% carbon.
    (*d*) 3.00% carbon.

13. Explain what changes may occur by varying the rate of cooling of cast iron.

9

Properties and Uses of Ferrous Cast Metals

Classification. Cast metals are generally classified in two groups: ferrous and nonferrous. Ferrous metals are subdivided according to carbon content and classed as steel or cast iron. Each of the classifications is further subdivided according to its composition. The diagram in Fig. 1 illustrates the principal classifications and subdivisions of both ferrous and nonferrous metals.

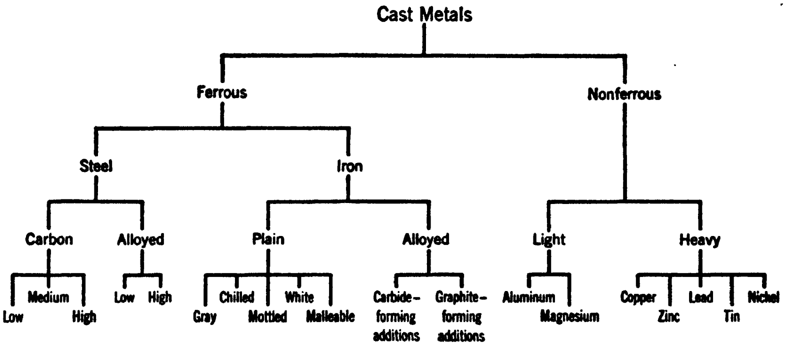


FIG. 1. Diagram showing classification of metals.

Steel. Although the carbon content of steels ranges up to 2.0 per cent, the bulk of steel castings is produced in the medium carbon class of 0.20 to 0.50 per cent carbon. Other elements normally found in unalloyed cast steel are held within limits to prevent any dominating influence on the steel. The normal percentages of these elements in carbon steel are within the following limits:

ELEMENT	PERCENTAGE COMPOSITION
Manganese	0.50–1.00
Silicon	0.20–0.75
Phosphorus	0.05 max
Sulphur	0.06 max

Heat Treating Cast Steels. Because of greatly improved engineering properties obtained through heat treatment, cast steels are seldom used in the as-cast condition. Increased strength by heat treatment is attributed to reduction of grain size and a more uniform grain distribution.

When metals solidify, the crystals frequently arrange themselves in a heterogeneous structure called *dendritic* or *pine-tree* structure which makes the casting inferior in mechanical properties. This coarse and segregated cast structure is homogenized by heating the casting to, or slightly above, a transformation temperature at which the constituents will revert to austenite. Just as droplets of oil suspended in water tend to assume a spherical shape, surface tension causes the crystals in the solid matrix to tend to separate from the dendritic pattern and form a homogeneous uniform matrix. Also, in this transformation stage, the fine-grained pearlitic crystals absorb parts of the large ferrite grains to form a structure of more uniform grain size. The time allowed in the transformation temperature range as well as the temperature in which the metal is held are very important factors in the control of crystal size. The higher the temperature and the longer the time, the greater is the tendency for crystals to grow in size and weaken the structure.

The rate at which the casting is quenched is also an important factor in the final grain structure and distribution. If a medium-carbon steel is water quenched, an exceedingly fine-grained metal of extreme hardness is produced, called *martensite.* A slower quench will produce a softer metal called *troostite* or *sorbite,* the latter being the softer of the two.

The heat-treating processes commonly employed in the steel-casting industry are annealing, normalizing, liquid quench, and tempering.

Annealing consists of heating the casting above the critical temperature at which transformation takes place, holding it at that temperature until transformation is complete, and then cooling it slowly in the furnace. The casting becomes ductile and acquires good machining properties. Castings possessing internal stresses caused by mold obstruction or by some peculiarity in design are often annealed, primarily to remove these stresses.

Normalizing is similar to annealing except that, instead of controlled cooling in the oven, the casting is cooled in still air. The finer-grained structure produced by normalizing improves strength, yield point, impact, and fatigue properties of carbon steel.

The practice of quenching steel from the transformation temperature to room temperature by means of water or oil is generally followed by a tempering operation to relieve internal stresses due to rapid cooling and also to adjust the hardness of the casting to the desired requirements. Tempering is done by reheating the casting to some temperature below the critical range and then cooling it at a specified rate.

Low-Carbon Steel. Low-carbon steels are produced only for special purposes. Electrical equipment that is subject to current reversals is often made of low-carbon steel to reduce heating effects caused by loss of energy due to hysteresis. Low-carbon steel is also used in electrical design where the part must lose its magnetism when the exciting force is zero.

Response to heat treatment to improve physical properties is not so great as for higher-carbon steels. Nevertheless, low-carbon steels are frequently annealed to improve ductility and to increase the yield point and impact values. The tensile strength of low-carbon steels under various heat treatments ranges from 55,000 to 70,000 psi.

Medium-Carbon Steel. Because medium-carbon steel responds so well to heat treatment, the castings are seldom used without some sort of treatment to enhance the properties desired in the metal. For example, a tensile strength of 130,000 psi can be obtained by heating a 0.30 per cent carbon steel to 1650° F, water quenching, tempering to 700° F, and air cooling. That same steel has a tensile strength of 76,000 psi before heat treatment.

Medium-carbon steels play an important role in a large variety of applications, and examples of their use are found in all industries where steel castings are used.

High-Carbon Steel. Cast steels containing more than 0.50 per cent carbon are applicable for services requiring considerable hardness and resistance to abrasion.

White Iron. Iron containing more than 1.75 per cent of carbon may, under certain conditions, contain most of its carbon in the combined (Fe_3C) state. Having a Brinell number in the range of 450, white iron is very hard and most difficult to machine. When machining is necessary, it is done at very slow speeds, but finishing is preferably done by grinding. White irons of lower carbon content are more easily finished than the higher-carbon irons, since the constitution of the latter contains a greater proportion of cementite.

White iron may be produced in one of two ways: (1) by cooling the casting rapidly enough to prevent the removal of carbon from chemical combination, and (2) by proper adjustment of the composition.

Castings containing thin sections have a greater tendency toward becoming white iron than those containing thick sections because of rapid loss in heat. Heat conductivity of mold material is also an influential factor. A permanent metal mold will have a greater tendency to produce a casting of white structure than a sand mold will. To produce a finer-grained structure in a certain part of a casting, a metal insert, called a *chill,* may be embedded in the mold.

Under certain conditions, the exterior portion of a casting may be completely white and the inner portion may consist of gray iron. The transitional area between these two extremes is a close-grained structure of varying portions of gray iron and white iron called mottled iron. Castings such as these, with three zone structures, are called chilled castings and are used commercially where hard, wear-resistant surfaces are necessary. The mottled structure between the hard outer surface and the soft inner core provides a backing for the chill to absorb impact stresses in service. The depth of chill varies according to the percentage of carbon, silicon, manganese, phosphorus, and sulphur present in the metal.

If the carbon content is increased to the point where some of it exists as free carbon, strength and hardness of the metal is reduced, but machinability is greatly increased. Free carbon breaks up the continuity of the metallic structure and aids in lubricating the cutting action.

Silicon is known as the graphitizer because it lowers the solvent power of iron for carbon. An increase in silicon will reduce the depth of chill, and, if it is added in sufficient quantities (depending on the composition of the metal), the white chill is completely eliminated. The composition of silicon in iron varies from 1 to 3.75 per cent, depending on the composition of the metal and the type of metal desired.

Sulphur is a carbide-stabilizing element, but it is not considered harmful in amounts up to 0.16 per cent, if the correct amounts of manganese and silicon are present. Excess sulphur is undesirable because it reduces fluidity, increases shrinkage, produces chill, and makes iron hard and brittle. It requires from ten to fifteen times as much silicon to counteract a given amount of sulphur.

Managanese is also a carbide stabilizer but only when added in quantities in excess of that required to neutralize sulphur. Sulphur, having a greater affinity for manganese than for iron, will form manganese sulphide which is insoluble in iron and exists as a relatively harmless metalloid. If given sufficient time, much of the manganese sulphide will float to the surface of the molten metal where it can be skimmed off with the slag. The bad effects of sulphur may be eliminated by adding about 0.30 per cent more manganese than what is theoretically needed for chemical combination with sulphur. The normal amount of manganese in commercial cast iron is between 0.50 to 0.80 per cent.

Phosphorus has little direct effect on the graphitizing of carbon. It unites with iron to form iron phosphide. The eutectic, consisting of iron, iron phosphide, and cementite, is called steadite. Phosphorus increases the hardness of iron and improves fluidity by reducing the melting temperature. Commercial iron contains from 0.15 to 0.90 per cent phosphorus.

Malleable Iron. The only practical importance of white iron is in the manufacture of malleable iron. The white iron casting, prior to heat treatment, must contain no free carbon, and therefore the carbon-silicon ratio must be in such proportions as to produce a matrix of ferrite and cementite. The range of analysis of white iron in the production of malleable iron is as follows:

Carbon (%)	1.75–2.30
Silicon (%)	0.85–1.20
Manganese (%)	0.40 max
Phosphorus (%)	0.20 max
Sulphur (%)	0.12 max

After the gates are removed, the white-iron castings are cleaned and ground, placed in annealing boxes, and packed with slag, sand, silicon, gravel, or mill scale. The purposes of packing are to protect the castings from excessive oxidation and to prevent warpage in the heat-treating process. The metal boxes are then placed in a furnace and heated for about 20 hr until the castings acquire a temperature of 1600° F. They are then held at that temperature for a period of 40 hr. The temperature is then lowered at a rate of 8 to 10 degrees per hour until it reaches 1275° F, at which time the doors of the furnace are opened and the castings are allowed to cool to room temperature. In this heat-treating process, the white iron, consisting of free cementite in a matrix of pearlite, is transformed to temper carbon in a matrix of ferrite. Temper carbon appears as free carbon in the form of nodules, as illustrated in Fig. 2. Temper carbon does not lessen the strength of the matrix as do the flakes in gray iron.

As the result of this slow heating and cooling process, malleable castings are relatively free of internal strains. Of all ferrous metals of comparable strength, malleable iron is the most easily machined because of the absence of cementite and because of the lubricating action of the carbon. Malleable iron is ductile like steel and has a high fatigue strength and excellent corrosion resistance. A common grade of malleable iron has a tensile strength in the neighborhood of 50,000 psi. The yield strength of malleable iron is often estimated at 65 per cent of the ultimate strength.

By varying the heat-treating process, standard malleable iron may be made harder, stronger, and more resistant to wear, at a sacrifice of ductility and resistance to shock. This is done by preventing complete transformation from combined carbon to nodular carbon. This type of iron is termed pearlitic malleable iron.

Because of the unique combination of properties, malleable castings have a wide industrial application. In spite of a disadvantage in weight, aircraft castings such as landing gear parts, brackets for wing assemblies, and engine mountings are often made of malleable iron because of its toughness and shock-resisting properties. Among the leading users of malleable iron castings are the manufacturers of farm machinery and automobiles. Other applications are conveyors, building equipment, hardware, marine and mining equipment, pipe fittings, and railroad and road machinery.

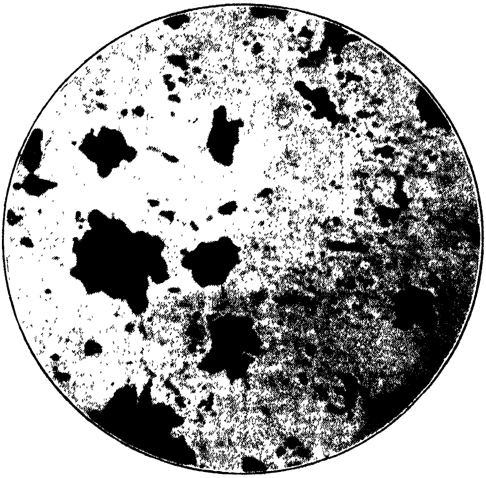


FIG. 2. Photomicrograph of malleable iron, illustrating temper (nodular) carbon (black). ×150. (Courtesy of Professor G. M. Enos, Purdue University.)

Gray Cast Iron. Gray cast iron is characterized by the presence of a large portion of its carbon in the form of graphite flakes. Although gray iron is often defined as steel containing graphite, its properties are far different from those of steel. Owing to its low specific gravity, graphite occupies over three times as much space as an equal weight of metal. From 6 to 10 per cent of the volume of a typical gray iron is occupied by graphite. Because the graphite flakes contribute no more to strength than so many voids, the tensile strength and elasticity of gray iron is considerably less than of steel. Nevertheless, gray iron is the most widely used engineering material because of the ease with which it may be cast, its excellent machinability, and its good

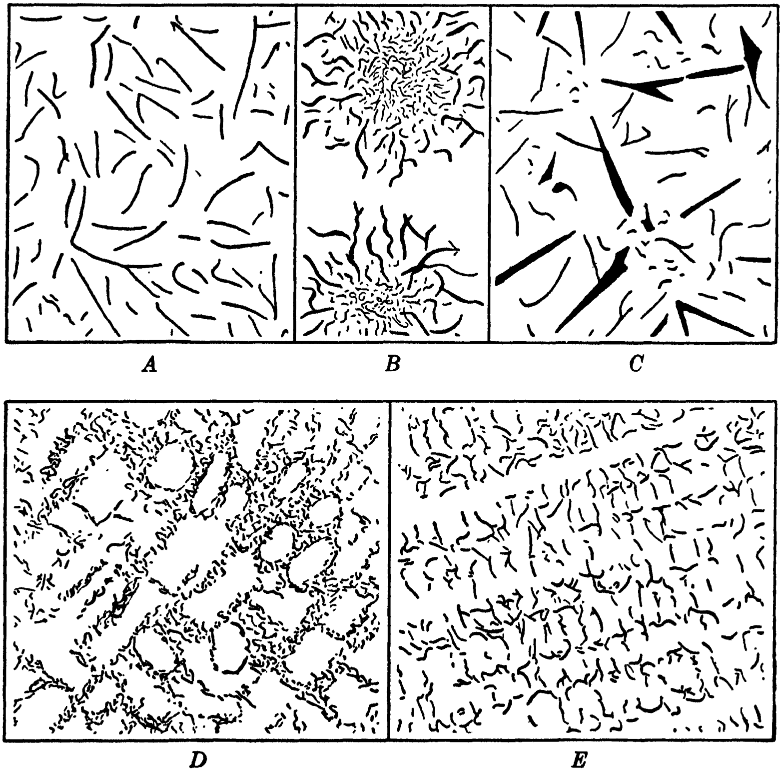


FIG. 3. Graphite flake type chart. *A*. Uniform distribution, random orientation. *B*. Rosette groupings, random orientation. *C*. Superimposed flake sizes, random orientation. *D*. Inter-dendritic segregation, random orientation. *E*. Inter-dendritic segregation, preferred orientation. (Courtesy of American Foundrymen's Society, Chicago, Ill.)

antifriction properties, vibration-damping properties, and stress-relieving properties.

Among the elements normally found in gray iron, carbon and silicon are the most effective in the control of mechanical properties. A lowering of carbon content (with the proper addition ~~of silicon~~ to prevent mottled or white iron) produces a matrix containing smaller graphite flakes. The strength properties of gray iron are improved by reducing the flake size and distributing the flakes more uniformly.

In addition to classification by flake size, graphite flakes are classified according to the way they are organized in various patterns. Figure 3 illustrates the *graphite flake-type chart,* prepared by the joint committee of the American Foundrymen's Society and the American Society for Testing Materials.

The American Society for Testing Materials classifies gray iron according to tensile strength in the following manner:

Table 1. A.S.T.M. SPECIFICATIONS (A48-41)

(Courtesy of American Society for Testing Materials)

Class	Tensile Strength (min psi)
20	20,000
25	25,000
30	30,000
35	35,000
40	40,000
50	50,000
60	60,000

Although many attempts have been made to correlate the carbon-silicon ratio to the tensile strength of cast iron, the results have not been too reliable because of many other factors involved. Most commercial irons contain between 2.50 and 3.75 per cent total carbon. The carbon may exist in the combined state as in white iron, or it may be almost completely in the free state, depending on control and composition. Following are some typical chemical analyses of cast iron in commercial usage.

Table 2. PERCENTAGE COMPOSITION OF VARIOUS CAST IRONS

Application	Total Carbon	Silicon	Phosphorus	Manganese	Sulphur
Automotive cylinders	3.25	2.25	0.15	0.70	0.09
Chilled car wheels	3.10	1.70	0.45	0.65	0.09
White-iron castings	2.90	0.60	0.70	0.60	0.20
Piston rings	3.50	2.90	0.50	0.65	0.06
Valves and Fittings	3.30	2.00	0.35	0.50	0.10
Machinery (thick sections)	3.25	1.25	0.35	0.50	0.10

Two outstanding properties of gray iron are high compressive strength and absorption of vibration, called *damping*. The compressive strength of gray iron is from three to four times its tensile strength. Much of the damping capacity in cast iron can be attributed to the carbon flakes (formerly referred to as voids in an iron matrix), which permit plastic deformation of the metal surrounding the carbon particles. These properties (compressive strength and damping) are an excellent combination in materials for machine parts and machine tools.

Machinability of gray iron is generally good, but it depends largely on the microstructural constituents of the metal. A ferritic structure consisting of a high percentage of free carbon is readily machined. Pearlitic structures consisting of pearlite and free carbon produce smoother machined surfaces but are more difficult to machine. As the combined carbon increases, machinability becomes more and more difficult.

The wear-resistant properties of cast iron are attributed to two characteristics, resistance to indentation and lubrication. The type of iron best suited depends on the service conditions under which abrasion takes place. Chilled surfaces are used where there is danger of surface indentations due to high unit pressures. Typical examples are wire-drawing dies, car wheels, and cams. A chilled surface is also advantageous under highly abrasive conditions such as those found in sandblast nozzles, pug mill knives, and plow points. Gray iron is used where the danger of surface indentation is not present. The lubricating property of free graphite is an outstanding asset in reducing friction and preventing galling and scoring on sliding surfaces. A typical example is the cylinder block of automobiles.

Ordinary gray iron is not used extensively for magnetic applications because of its poor permeability and inability to carry a high flux. Because of the ease of casting gray iron in thin sections and its electrical resistance properties, it is frequently used in resistance grids for control apparatus of heavy-duty direct-current motors.

Cast iron is used extensively in heat exchangers, stoves, radiators, drying equipment, and brake drums, not because of any unusual heat transfer properties but because of the low cost of castability.

Gray iron castings are not normally heat treated except when special properties are desired or when it is necessary to relieve internal casting stresses. It is generally more economical to improve physical properties of gray iron by control of composition or by addition of alloys. Residual stresses, induced by differential solidification or by cooling, can be accomplished with the least change in metal properties by heating the casting to a temperature between 800° and 1050° F, holding it at that temperature for about 1 hr per inch of section thickness, and then cooling it slowly in the furnace. Some castings are annealed to improve machinability, and occasionally a quench-and-temper treatment is applied to improve some physical characteristics of the metal.

The quantity of castings produced in gray iron far exceeds that of any other cast metal. The raw materials are low in cost and economical to melt. Its casting properties, such as fluidity and relatively low shrinkage, insure a high yield of good castings.

Nickel as an Alloy. Nickel serves extensively as an alloy in steel and cast iron. It is soluble in iron in both liquid and solid state. Small quantities of nickel produce fine-grained crystal structures and prevent segregation. In heat treating, nickel lowers the transformation temperature and retards grain growth at elevated temperatures. This is a distinct advantage in heat treating: first, because the casting may be heat treated at a lower temperature which reduces the possibility of cracking due to metal expansion; and second, because less accuracy is necessary in temperature and time control.

Nickel is alloyed with steel to improve tensile, impact, and fatigue strengths, and resistance to corrosion in fresh water, salt water, and many acids, salts, and alkalies. It is often alloyed with chromium, molybdenum, silicon, and other elements to obtain various desired properties in cast steels. Low-alloyed steels are often used in excavating and mining machinery, rolling mills, marine equipment, gears, etc. High-alloy nickel steels are used especially where high corrosive resistance is desired.

Nickel is often alloyed with cast iron to improve machinability as well as hardness, strength, and resistance to corrosion. Being a graphite-forming element, nickel prevents low-carbon cast iron from becoming white iron. Castings having both thick and thin sections can be cast with more uniform structure with addition of nickel because of its stabilizing effect. It prevents chill in the thin section and grain growth in the thick sections. In general, nickel additions vary in cast iron from 0.25 to 5.0 per cent. Additions greater than 5.0 per cent tend to make iron extremely hard. Such alloys are occasionally used for gears, dies, and brake drums.

Chromium as an Alloy. Pure chromium has a blue-white metallic luster. Although it is a fairly soft and ductile metal, it becomes quite brittle when combined with small quantities of commercial impurities. Ferrochrome (iron and chromium) is one of the most valuable alloys in the metallurgical control of iron and steels where resistance to corrosion and heat is desired. Heat resistance is the ability of metals to retain their metallic structure after prolonged heating. The percentage of chromium in alloyed ferrous metals varies from a fraction up to 35 per cent, depending on the properties desired.

Although chromium produces only a slight modification in the grain size of steel, it has the property of preventing segregation and thus producing a more uniform structure. High-strength structural steels are alloyed with chromium. Up to 5 per cent chromium is added to improve the magnetic properties of permanent magnets. It is often used in castings for sub-zero temperatures where high impact resistance is desired. Steels containing more than 12 per cent chromium are commonly referred to as stainless steels. Chromium is alloyed with other elements to obtain a variety of physical properties. Chromium improves the strength of cast iron by reducing the flake size of graphite and by retaining pearlitic structure of the metal. It is often alloyed in cast iron to increase depth of chill and to give added resistance to wear at high temperatures. Because of its unusual abrasion resistance, high-chromium cast iron finds many commercial applications.

Molybdenum as an Alloy. Resembling platinum in appearance, pure molybdenum is a soft ductile metal commonly employed in filaments of electrical equipment.

An outstanding effect of molybdenum in steel is to reduce grain growth. It is used occasionally in castings that cannot be liquid quenched because of large size or intricacy of design. It is frequently used with other alloys to modify the alloying characteristics of the principal alloys.

In cast iron, molybdenum tends to produce a fine-grained pearlitic structure because it inhibits the decomposition of austenite. Likewise, in cast iron as in steel, molybdenum is commonly alloyed with other elements such as nickel, chromium, manganese, copper, and vanadium.

Manganese as an Alloy. The metal, manganese, has a grayish luster, faintly tinted with red. It is used extensively as an alloy in both ferrous and nonferrous metals.

Manganese is almost indispensable in steel making because of its deoxidizing power and its ability to render sulphur inactive. It also serves as an alloying element in steel to produce a finer grain structure of greater strength and ductility. Medium-manganese steel, containing from 1 to 3 per cent manganese, produces a pearlitic structure of fairly high strength and excellent ductility with medium hardening properties. Its toughness and resistance to shock make it an excellent material for tool steel, road machinery, excavating buckets, and equipment subject to abuse and wear. Hadfield steels containing from 10 to 14 per cent manganese are very hard because of a large proportion of free carbide. Its tensile strength varies from 80,000 to 110,000 psi, and its Brinell hardness from 180 to 220. When subject to severe stress it becomes harder, reaching a Brinell hardness of 500 in extreme cases. This property renders manganese steel practically unmachinable, and finishing is usually done by grinding. It finds many applications where extreme toughness is required, such as railroad castings, crushing and rolling equipment, and other miscellaneous equipment. It possesses high electrical resistance and is practically nonmagnetic. An amount of manganese up to 1.00 per cent tends to improve machinability of cast iron and has little effect on mechanical properties, but an amount in excess of 1.25 per cent produces a marked increase in strength, hardness, and depth of chill.

Vanadium as an Alloy. Vanadium is a grayish white metal. Although it is a strong deoxidizer, its use is prohibited for such purposes by the availability of other lower-cost deoxidizers.

Used principally for its alloying effects, it is particularly effective in reducing grain size in steel and cast iron.

Vanadium inhibits dendritic segregation upon solidification and promotes grain refinement in the heat treatment of steels. It improves the strength of steel at both high- and low-temperature service conditions. Vanadium steels are no more difficult to machine than other steels of equal hardness. Tool steels are often alloyed with vanadium to produce good cutting properties. Among the various applications of vanadium steel are railroad castings and other heavy machinery, including gears.

Being a powerful carbide-forming element, vanadium is used in gray iron to restrain graphitization. Heavy gray iron castings whose centers tend to be spongy because of large grain structure and graphite size are often alloyed with vanadium. In cast iron, vanadium increases strength, hardness, and wear resistance.

Copper. Because of its relative cheapness as compared with other alloying elements, considerable interest has been stimulated in copper as an alloy in iron and steel.

In contrast to carbon steels which become softer when tempered, copper-alloyed steels increase in tensile strength, yield point, and hardness. This property is desired in castings that cannot be heat treated in the ordinary way.

Copper has a tendency to increase graphitization in the heat-treating process of making malleable iron. Its effect on strength is greater in high-carbon malleable iron than in low-carbon malleable iron.

In cast iron, copper functions primarily as a graphitizing agent. It is about one-tenth as effective as silicon but produces a dense microstructure which results in increase in strength and hardness. It is used in equipment requiring wear resistance, antifriction properties, and shock resistance as well as corrosion resistance.

Other Alloying Elements. Percentages of silicon in excess of that normally found in steel are sometimes added to steel in combination with manganese, copper, or chromium to obtain improved magnetic- or abrasion-resistant properties. The effect of silicon on the graphitization of cast iron has already been discussed. High-silicon-iron alloys (13 to 17 per cent) are frequently used for acid-resistant containers. The metal is very hard and extremely brittle. Its properties for heat-resistant castings are often improved by the addition of nickel and chromium.

Titanium is a strong deoxidizing element which is sometimes added to the ladle, prior to pouring, in order to improve fluidity as well as metal structure. It is sometimes alloyed with manganese steel to increase yield strength, ductility, and impact resistance. High-tensile railway castings are sometimes alloyed with titanium. In cast iron, it tends to reduce graphite-flake size and to reduce combined carbon.

Zirconium, like titanium, is a powerful deoxidizer. It reduces metallic oxides and scavenges nonmetallic inclusions which concentrate at the top of the metal in the form of slag. It frees steel of nitrogen by forming nitrides which also come out in the form of slag. It is more effective than manganese in its action with sulphur, but, because of its cost, manganese is preferred. The depth of hardenability is increased with zirconium.

Ductile Cast Iron. If a small amount of magnesium is introduced into cast iron, a spheroidal carbon (similar to malleable iron) is formed in the matrix instead of the customary flake carbon. The tensile strength of cast iron can be increased two to three times its original value by this treatment. It retains the low melting temperature, good fluidity, castability, and machinability of gray iron and approaches the strength, ductility, toughness, and impact resistance of steel.

Because magnesium becomes volatile at a temperature below the pouring temperature of iron, it is alloyed with copper or nickel to avoid an explosive condition. The amount of magnesium in such irons varies from 0.03 to 0.10 per cent, depending on the composition of the base iron. After the addition is made, the molten alloyed metal is allowed to stand for a short period of time until the reaction is completed. Before the metal is poured, a ferrosilicon addition is made to counteract any carbide-forming effects due to the magnesium addition.

The potential applications of this new material are many and varied. Various properties may be obtained by proper heat treatment. It can be successfully welded without regeneration of flake graphite.

PROBLEMS

1. How does heat treatment change the microstructure of steel castings?
2. Explain the difference between the heat-treating processes of annealing and normalizing, and state the differences resulting from these treatments.
3. Give some commercial applications for low-carbon steel.
4. Why is medium-carbon steel used more than other types of steel?
5. What factors influence the formation of white iron?
6. What factors prevent the formation of white iron?
7. How is white iron heat treated to form malleable iron?
8. Give some principal uses for malleable iron, and give reasons why it is preferred.
9. Why is gray iron the most widely employed cast metal?
10. What factors influence machinability in gray iron?
11. How does nickel affect the properties of steel, of cast iron?
12. What types of castings are often alloyed with ferrochrome?
13. Give the effects of manganese on steel; on cast iron.
14. Give the effects of vanadium on steel; on cast iron.

10

Properties and Uses of Nonferrous Cast Metals

Classification. Nonferrous alloys are classified according to the basic element of which the metal is composed. The principal base metals of commercial importance are copper, aluminum, magnesium, lead, tin, zinc, and nickel. Of these base metals, aluminum and magnesium are classed as the lightweight metals.

Copper-Base Alloys. Because of the large number of copper alloys in commercial usage, the American Society for Testing Materials has classified them according to the percentage of alloy in the metal. The classification is given in the table on pp. 242 and 243.

Copper-base alloys with zinc as the dominating alloy are classed as *brass.* When the main alloying constituent is some other element, it is termed *bronze.* Bronzes are distinguished from one another by the principal alloying element, as tin bronze, nickel bronze, aluminum bronze, etc.

The range of tensile strength of copper and its alloys varies all the way from 6000 psi for lead bronze to 200,000 psi for heat-treated copper beryllium. Other properties are correspondingly varied by alloy additions and heat treatment.

Brasses. Because of their unusual ductility, malleability, good strength, and excellent resistance to corrosion, brasses of various composition form one of the most useful groups of metals known to industry.

With increasing additions of zinc, the color of brass changes from a bronze color to red gold and finally to yellow. The addition of sufficient quantities of nickel produces a white color.

In general, machinability decreases with increasing amounts of most alloying elements. Although lead reduces strength and hardness, small amounts of it contribute greatly to machinability. Lead also improves castability of brass by increasing fluidity and reducing checks and cracks. Additions of tin within the limits of the classification increase strength and hardness of

Table 1. STANDARD CLASSIFICATION OF CAST COPPER-BASE ALLOYS *

(Courtesy of American Society for Testing Materials, ASTM B119-45)

COPPER

Class	Addition Elements	Remarks
Copper	Not over 2 per cent total of arsenic, zinc, cadmium, silicon, chromium, silver, or other elements.	Conductivity copper castings, pure copper, deoxidized copper, and slightly alloyed copper.

BRASSES

Class	Addition Elements	Remarks
Red brass	2 to 8 per cent zinc. Tin less than zinc. Lead less than 0.5 per cent.	Alloys in this class without lead seldom used in foundry work.
Leaded red brass	2 to 8 per cent zinc. Tin less than 6 per cent, usually less than zinc. Lead over 0.5 per cent.	Commonly used foundry alloys. May be further modified by addition of nickel. See ASTM B62 and B145.
Semi-red brass	8 to 17 per cent zinc. Tin less than 6 per cent. Lead less than 0.5 per cent.	Alloys in this class without lead seldom used in foundry work.
Leaded semi-red brass	8 to 17 per cent zinc. Tin less than 6 per cent. Lead over 0.5 per cent.	Commonly used foundry alloys. May be further modified by addition of nickel. See ASTM B145.
Yellow brass	Over 17 per cent zinc. Tin less than 6 per cent. Under 2 per cent total aluminum, manganese, nickel, iron, or silicon. Lead less than 0.5 per cent.	Commonly used foundry alloy.
Leaded yellow brass	Over 17 per cent zinc. Tin less than 6 per cent. Under 2 per cent total aluminum, manganese, nickel, or iron. Lead *over* 0.5 per cent.	Commonly used foundry alloy. See ASTM B146.
High-strength yellow brass (manganese bronze)	Over 17 per cent zinc. Over 2 per cent total of aluminum, manganese, tin, nickel, and iron. Silicon under 0.5 per cent. Lead *under* 0.5 per cent. Tin less than 6 per cent.	Commonly used foundry alloys under name of "manganese bronze" and various trade names. See ASTM B147.
Leaded high-strength yellow brass (leaded manganese bronze)	Over 17 per cent zinc. Over 2 per cent total of aluminum, manganese, tin, nickel, and iron. Lead *over* 0.5 per cent. Tin less than 6 per cent.	Commonly used foundry alloys. See ASTM B132 and B147.
Silicon brass	Over 0.5 per cent silicon. Over 5 per cent zinc.	Commonly used foundry alloys. See ASTM B198.
Tin brass	Over 6 per cent tin. Zinc more than tin.	Alloys in this class seldom used in foundry work.
Tin-nickel brass	Over 6 per cent tin. Over 4 per cent nickel. Zinc more than tin.	Alloys in this class seldom used in foundry work.
Nickel brass (nickel silver)	Over 10 per cent zinc. Nickel in amounts sufficient to give white color. Lead *under* 0.5 per cent.	Commonly used foundry alloys, sometimes called "German silver."
Leaded nickel brass (leaded nickel silver)	Over 10 per cent zinc. Nickel in amounts sufficient to give white color. Lead *over* 0.5 per cent.	Commonly used foundry alloys, sometimes called "German silver." See ASTM B149.

Table 1. STANDARD CLASSIFICATION OF CAST COPPER-BASE ALLOYS * (*Continued*)

BRONZES

Class	Addition Elements	Remarks
Tin bronze	2 to 20 per cent tin. Zinc less than tin. Lead less than 0.5 per cent.	Commonly used foundry alloys. May be further modified by addition of some nickel or phosphorus, or both. See ASTM B22 and B143.
Leaded tin bronze	Up to 20 per cent tin. Zinc less than tin. Lead over 0.5 per cent, under 6 per cent.	Commonly used foundry alloys. May be further modified by addition of some nickel or phosphorus, or both. See ASTM B61 and B143.
High-leaded tin bronze	Up to 20 per cent tin. Zinc less than tin. Lead over 6 per cent.	Commonly used foundry alloys. May be further modified by addition of some nickel or phosphorus, or both. See ASTM B22, B66, B67, and B144.
Lead bronze	Lead over 30 per cent. Zinc less than tin. Tin under 10 per cent.	Used for special bearing applications.
Nickel bronze	Over 10 per cent nickel. Zinc less than nickel. Under 10 per cent tin. Under 0.5 per cent lead.	Commonly used foundry alloys. Sometimes called "German silver" or "nickel silver."
Leaded nickel bronze	Over 10 per cent nickel. Zinc less than nickel. Under 10 per cent tin. *Over* 0.5 per cent lead.	Commonly used foundry alloys. Sometimes called "German silver" or "nickel silver." See ASTM B149.
Aluminum bronze	5 to 15 per cent aluminum. Up to 10 per cent iron, with or without manganese or nickel. Less than 0.5 per cent silicon.	Commonly used foundry alloys. Some may be heat-treated. May be further modified by addition of some nickel or tin, or both. See ASTM B148.
Silicon bronze	Over 0.5 per cent silicon. Not over 5 per cent zinc. Not over 98 per cent copper.	Commonly used foundry alloys. Some are readily heat-treated. See ASTM B198.
Beryllium bronze	Over 2 per cent beryllium or beryllium plus metals other than copper.	Most of these alloys are heat-treatable.

* Complete specifications or documents on all ASTM references may be obtained from ASTM headquarters, Philadelphia 3, Pennsylvania.

the metal. Zinc improves fluidity of the alloy and promotes freedom of gas porosity. Zinc, like tin, increases hardness and strength, but to a lesser degree. Nickel may be added in small amounts to produce a denser structure. Iron is an objectionable element because it forms hard spots. Because of the formation of aluminum oxides which exist in the metal as insoluble inclusions, even small traces of aluminum reduce the pressure tightness of brass castings.

An alloy consisting of 85 per cent copper and 5 per cent each of tin, lead, and zinc is one of the most widely used cast metals. It was originally called *ounce metal* because the mixture consists of 1 oz of each of the alloying metals to 1 lb of copper, but now it is most widely known as *eighty-five, three fives,* after its percentage composition. Its average tensile strength is in the neighborhood of 33,000 psi. It is a relatively low-cost brass, possessing good casting and machining properties.

Copper-base alloys containing from 17 to 40 per cent zinc are less expensive than red brass, but with few exceptions they are also less resistant to corrosion. These alloys, called *yellow brass,* are employed considerably in the plumbing industry and for machine parts and small gears. Because of their pleasing appearance and fair castability, they are used extensively for ornamental purposes.

Having the strength of mild steel, *silicon brass* is commonly employed where a combination of high strength and corrosion resistance is required. Commercial applications of silicon brass are found in chemical processes and boiler equipment, and in parts exposed to salt water.

An outstanding property of *nickel brass* is its white color. It is employed in equipment requiring moderate corrosion resistance and a pleasing appearance. Such requirements are found in laundry, dairy, and food-handling equipment.

Bronze. Tin bronze, consisting principally of copper and tin with small proportions of zinc, are relatively difficult to machine. Compositions of 88 per cent copper, 8 to 10 per cent tin, and the remainder zinc are commonly known as *gun metal.* Gun metal can withstand high pressures and therefore is a good bearing metal, if the rotating speeds are low. To prevent seizure at higher speeds, the metal is customarily alloyed with lead, which improves plasticity but lessens strength. The fine-grained structure of gun metal, coupled with good corrosion resistance, makes it an ideal metal for pressure castings, worm wheels, and pistons and bushings for salt-water pumps. Because of its color and polish, it is an excellent material for ornamental work and statuary.

Lead bronze, consisting of copper and lead, cannot be used where strength is involved because of the strength-reducing property of lead. It is a soft, weak, and ductile metal, used chiefly for packing around piston rods and valve stems of steam engines and air compressors. However an alloy consisting of 80 per cent copper, 10 per cent lead, and an equal amount of tin produces an excellent bearing metal.

An increase in nickel to form *nickel bronze* results in a proportional increase in strength and reduction in ductility. Commercial applications of nickel bronze are similar to those described for nickel brass.

Aluminum bronze is characterized by its high strength and resistance to shock, fatigue, and corrosion. It is well adapted for gun mounts, airplane and fan propeller mountings, and various types of gears that mate with steel gears.

Table 2. CHEMICAL AND PHYSICAL REQUIREMENTS OF ZINC-BASE ALLOY DIE CASTINGS

(Table 1 and appendix from ASTM Designation B86-48 combined in one table; courtesy of American Society for Testing Materials)

Composition	Alloy No. XXI	Alloy No. XXIII	Alloy No. XXV
Copper, %	2.5 –3.5	0.10 max	0.75–1.25
Aluminum, %	3.5 –4.5	3.5 –4.3	3.5 –4.3
Magnesium, %	0.02–0.10	0.03–0.08	0.03–0.08
Iron, max, %	0.100	0.100	0.100
Lead, max, %	0.007	0.007	0.007
Cadmium, max, %	0.005	0.005	0.005
Tin, max, %	0.005	0.005	0.005
Zinc, %	Remainder	Remainder	Remainder
Physical Property (Physical properties are not a part of designated specifications)			
Tensile test (round specimen)	46,000	35,000	40,000
Elongation in 2 in., %	4	10	5
Charpy impact on square specimens, ft-lb	4	35	35
Brinell hardness on square specimens (500-kg load on 10-mm ball)	90	65	80

Zinc-Base Alloys. Zinc-base alloys are most widely employed in die castings. The alloying constituents of die-cast zinc are principally copper, aluminum, and magnesium, the proportions depending on the properties desired. The total percentage of these alloying elements varies from 4 to 8 per cent, the remainder being zinc of high purity. Copper tends to increase strength but reduce ductility. Aluminum not only improves strength but also inhibits the rate of attack of the alloy on dies, thus prolonging the life of the die. Small quantities of magnesium are added to maintain dimensional stability of the casting. Lead and cadmium are held to low limits because of their devastating effect on dimensional stability and their tendency to aid oxidation. Zinc alloys are not stable when exposed continuously to steam, salt water, or alkaline solutions.

Among the numerous applications of zinc die castings are various parts and accessories for automobiles, business machines, cameras, household appliances, and lighting fixtures.

Lead-Base Alloys. Antimony and tin are commonly alloyed with lead in the production of low-priced bearing metals. These lead alloys have excellent casting properties because of their low melting temperatures and good fluidity. Because it causes brittleness, the antimony content seldom exceeds 15 per cent. Tin has a hardening effect, like antimony, but it does not produce brittleness. Small quantities of copper are sometimes added to prevent excessive segregation of tin and lead. Lead-base bearings are suitable where loads are not too excessive and where journal speeds are low.

Because of resistance to sulphuric acid, alloys of lead, tin, and antimony are commonly used in storage-battery grids. The toxic effect of lead compounds prevents their use where poisoning might result. Although lead was once a common die-casting metal, it has been replaced in most cases by zinc-base alloys.

Tin-Base Alloys. Tin alloyed with copper and antimony is frequently employed for automotive generator and motor bearings where severe service conditions are encountered. These alloys are customarily called Babbitt metal. Bearings subject to moderate service conditions are sometimes alloyed with lead to reduce cost.

Because of the high cost of tin, these alloys are limited in their use for special purposes such as food handling and low-cost jewelry. Tin is alloyed with antimony and lead for die casting, but when the casting is employed in the handling of food or beverages lead is eliminated.

Nickel and Alloys of Nickel. Nickel is a white malleable metal having a tensile strength of 55,000 psi. It has good corrosion resistance to fresh and salt water and also to many acids and alkali salts. Nickel castings are produced by specialized foundries for the production of photographic equipment and containers for various solutions, such as dyes, wines, soaps, milk, and in such processes where copper and iron corrosion contaminates the solution.

Nickel alloyed with copper and small amounts of iron and manganese is known as *Monel metal.* Monel metal possesses high strength and corrosion resistance and is able to retain its mechanical properties at temperatures up to 900° F. It is suitable for equipment for superheated steam processes and many other commercial applications, including valves, pump parts, and equipment in handling of caustic soda, salts, and photographic solutions.

Aluminum. With the exception of magnesium, aluminum is the lightest of all cast metals, its weight being approximately one-third that of iron. Pure aluminum is not sufficiently strong for most commercial uses, but when it is alloyed with copper, silcon, magnesium, and zinc a wide range of mechanical properties is possible. Other minor constituents seldom total more than 2 per cent. The alloys of aluminum are, in general, good conductors of heat and electricity. They possess good corrosion resistance to atmospheric conditions and are economically machined. Aluminum castings may be produced by die casting, permanent molds, and sand molds.

Heat Treatment. In the solidification of aluminum, various crystal aggregates precipitate out of the solution. This action is more pronounced at slow cooling rates. With a differential cooling rate, as found in castings of varying sectional thickness, the crystalline structure lacks uniformity in the as-cast condition. The thin sections that solidify rapidly will have a greater percentage of constituents in solution than the thick sections.

In order to obtain a homogeneous structure, the casting is heated to a temperature at which the precipitated constituents will be absorbed into the solid solution. This solution treatment takes place somewhere between 940° and 1000° F, depending on the alloy. The time required for complete diffusion varies from 12 to 15 hr, depending on the thickness of the casting, the thermal conductivity of the alloy, and the temperature to which the casting may be heated without distortion. In order to prevent re-precipitation, the casting is quenched as rapidly as possible without danger of cracking due to shrinkage. The customary quenching medium is boiling water.

At this stage the quenched casting is in an unstable condition. It is harder than it was prior to heat treatment, but it is more ductile. Distorted sections caused by thermal changes are best straightened immediately after quenching. If left for a period of several months, the casting becomes stronger and harder and less ductile. This is called *age hardening* and is caused by a very fine precipitation of the alloyed constituents. Increased strength is attributed to the formation of these finely dispersed compounds which tend to overcome slippage just as sand prevents slippage between two layers of ice.

Aluminum-Copper Alloys. Aluminum is alloyed with copper to increase strength and machinability. The alloy is more fluid and therefore more easily cast than pure aluminum. A commercial heat-treated aluminum-copper alloy contains approximately 4 per cent copper. Up to 5.6 per cent copper is soluble in aluminum at 1018° F. Alloys with higher percentages of copper, up to 12 per cent, are not heat treated. Additions of copper in excess of 12 per cent produce castings too brittle for engineering purposes. An 8 per cent copper addition is commonly used for automobile crank cases and manifolds, washing machine parts, and various appliances. Aluminum-copper alloys containing small proportions of magnesium and nickel are used for pistons in large Diesel engines and air-cooled aircraft motors.

Aluminum-Silicon Alloys. Aluminum-silicon alloys have better castings qualities than any other aluminum alloys. Increases in silicon up to the eutectic composition of 11.6 per cent increase fluidity and reduce hot shortness. This makes it a desirable alloy for the production of intricately designed castings with thin sections. (Brittleness at elevated temperature is termed *hot shortness*; it is an undesirable characteristic of some alloys like aluminum-copper.) Aluminum-silicon alloys are known for their low specific gravity and high corrosion resistance to atmospheric exposure and are preferred to other aluminum alloys for archi-

Table 3. TENTATIVE SPECIFICATIONS FOR ALUMINUM-BASE ALLOY SAND CASTINGS (CHEMICAL REQUIREMENTS)

(Courtesy of American Society for Testing Materials, ASTM B26-48T, Table 1)

Alloy	Aluminum (%)	Copper (%)	Iron (%)	Silicon (%)	Manganese (%)	Magnesium (%)	Zinc (%)	Chromium (%)	Titanium (%)	Nickel (%)	Other Elements (%)	
											Each	Total
C1	Remainder	4.0– 5.0	1.0	1.5	0.3	0.03	0.3	...	0.2	...	0.05	0.15
G1	Remainder	0.1 *	0.5 *	0.3	0.3 *	3.5 – 4.5	0.1	...	0.2	...	0.05	0.15
G3	Remainder	0.2	0.3	0.2	0.1	9.5 –10.6	0.1	...	0.2	...	0.05	0.15
S1	Remainder	0.1	0.8	4.5–6.0	0.3	0.05	0.3	...	0.2	...	0.05	....
S2	Remainder	0.3 †	0.8	4.5–6.0	0.3	0.05	0.3	0.2	0.2	...	....	0.3
CG1	Remainder	9.2–10.8	1.5	2.0	0.5	0.15– 0.35	0.5	...	0.2	0.3	....	0.3
CN21	Remainder	3.5– 4.5	1.0	0.7	0.3	1.2 – 1.8	0.3	0.2	0.2	1.7–2.3	0.05	0.15
CS5	Remainder	3.5– 4.5	1.2	2.5–3.5	0.5	0.05	1.0	...	0.2	0.3	....	0.5
CS22	Remainder	6.0– 8.0	1.4	1.0–4.0	0.5	0.07	2.5	...	0.2	0.3	....	0.5
GS1	Remainder	0.3 ‡	0.6 ‡	1.4–2.2	0.8 ‡	3.5 – 4.5	0.3	0.2	0.2	...	0.05	....
SC8	Remainder	3.3– 4.3	1.0	5.5–7.0	0.5	0.1	1.0	...	0.2	0.3	....	0.5
SC9	Remainder	3.0– 4.5	1.2	5.5–7.0	0.8	0.5	1.0	...	0.2	0.5	....	0.5
SC21	Remainder	1.0– 1.5	0.8 §	4.5–5.5	0.5 §	0.4 – 0.6	0.3	0.2	0.2	...	0.05	0.15
SC42	Remainder	1.0– 2.0	1.0	7.0–8.6	0.2–0.6	0.2 – 0.6	1.0	0.3	0.3	0.2	....	0.5
SG1	Remainder	0.2	0.6	6.5–7.5	0.3	0.2 – 0.4	0.3	...	0.2	...	0.05	0.15
ZG41	Remainder	0.3	1.0	0.25	0.3	0.5 – 0.65	5.0–6.0	0.4–0.6	0.1–0.3	...	0.05	....

* For cooking utensils, copper 0.3 per cent, max, manganese 0.6 per cent, max, and iron 0.6 per cent, max, are permitted.

† For general use other than cooking utensils, copper may be 0.6 per cent, max.

‡ If copper plus iron exceeds 0.5 per cent, a manganese content of at least 0.3 per cent is desirable.

§ If the iron content exceeds 0.4 per cent, it is desirable to have manganese present in an amount equal to one-half of the iron.

Note 1. When single units are shown, these indicate the maximum amounts permitted.

Note 2. Analysis shall regularly be made only for the elements specifically mentioned in this table. If, however, the presence of other elements is suspected or indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not present in excess of the limits specified in the last column of the table.

Note 3. The following applies to all specified limits in this table: For purposes of acceptance and rejection, an observed value or a calculated value obtained from analysis should be rounded off to the nearest unit in the last right-hand place of figures used in expressing the specified limit.

Table 4. TENTATIVE SPECIFICATIONS FOR ALUMINUM-BASE ALLOY SAND CASTINGS

(Courtesy of American Society for Testing Materials, ASTM B26-48T, Table 2)

Alloy	Condition	Tensile Strength (min, psi)	Elongation in 2 in. (min, %)
C1	T4 (solution heat treated—HT1)	29,000	6.0
	T6 (solution treated and aged—HT2)	32,000	3.0
	T62 (solution treated and aged—HT3)	36,000	*
	T7 (solution treated and over-aged—HT4)	29,000	3.0
G1	F (as cast)	22,000	6.0
G3	T4 (solution heat treated)	42,000	12.0
S1	F (as cast)	17,000	3.0
S2	F (as cast)	17,000	3.0
CG1	T2 (annealed—HT1)	23,000	*
	T61 (solution treated and aged—HT2)	30,000	*
CN21	T21 (annealed—HT1)	23,000	*
	T61 (solution treated and aged—HT2)	32,000	*
CS5	F (as cast)	19,000	1.5
CS22	F (as cast)	19,000	†
GS1	F (as cast)	17,000	*
SC8	F (as cast—HT1)	23,000	1.5
	T6 (solution treated and aged—HT2)	32,000	2.5
SC9	F (as cast)	23,000	*
	T6 (solution treated and aged)	31,000	1.5
SC21	T6 (solution treated and aged—HT1)	32,000	2.0
	T51 (aged—HT2)	25,000	*
	T71 (solution treated and over-aged—HT3)	30,000	*
SC42	F (as cast—HT1)	25,000	1.0
	T6 (solution treated and aged—HT2)	34,000	1.0
SG1	T6 (solution treated and aged—HT1)	30,000	3.0
	T51 (aged—HT2)	23,000	*
ZG41	T5 (aged)	30,000	3.0

If agreed upon by the manufacturer and the purchaser, other physical properties may be obtained by other heat treatments such as annealing, aging, or stress relieving.

* Not required.

† For information only, not required for acceptance.

tectural and ornamental castings as well as for marine, automotive, and airplane parts of a nonstructural nature. Higher percentages of silicon cause progressive increases in strength with corresponding decreases in ductility.

Aluminum-silicon alloys to which are added smaller quantities of copper, magnesium, and nickel are commonly employed for automotive pistons. The alloys have a low coefficient of expansion and better retention of strength at high temperatures than other aluminum alloys. They possess excellent bearing properties, have good wear resistance, and can be machined fairly well.

Aluminum-Magnesium Alloys. Aluminum-magnesium alloys produce a smooth, white, machined surface which has less tendency to tarnish than any other aluminum alloy. It also exceeds all other aluminum alloys in its resistance to alkaline corrosion. Additions up to 6 per cent magnesium improve strength and hardness. Because of appearance, good machinability, and corrosion resistance, these alloys are frequently used for cooking utensils, dairy equipment, and ornamental work. Although they are reasonably free of hot shortness and are moderately fluid in the molten state, casting difficulties are encountered because of the tendency of the metal to dross (form oxides) and to react with the moisture of foundry sand. The use of special synthetic molding and core sands and good control are important factors in successful production of aluminum-magnesium alloy castings.

Aluminum Die Castings. Aluminum-copper, aluminum-silicon, or alloying combinations of copper and silicon with or without nickel additions are commonly used in die castings. The production rate of aluminum die castings is less than that of zinc because aluminum is cast at higher temperatures and more time is required for the cooling cycles. Therefore zinc is a more desirable die casting metal than aluminum and is preferred to aluminum if engineering specifications can be met.

Magnesium Alloys. The outstanding characteristic of magnesium alloys is their extreme lightness. Magnesium weighs about two-thirds as much as aluminum, and one-fourth as much as iron. Of all engineering metals, magnesium is the most readily machined. Its mechanical properties are similar to those of aluminum. Corrosion resistance of magnesium is low, especially to sea atmospheres, and it must be surface treated and painted.

Table 5. TENTATIVE SPECIFICATIONS FOR MAGNESIUM-BASE ALLOY SAND CASTINGS

(Courtesy of American Society for Testing Materials, ASTM B80-47T, Tables 1 and 2)

CHEMICAL REQUIREMENTS

Alloy *	Magnesium (%)	Aluminum (%)	Manganese (min, %)	Zinc (%)	Silicon (max, %)	Copper (max, %)	Nickel (max, %)	Iron (max, %)	Other Impurities (max, %)
A8	Remainder	7.8– 9.2	0.15	0.3 max	0.3	0.10	0.01	....	0.3
A10	Remainder	9.0–11.0	0.10	0.3 max	0.3	0.10	0.01	....	0.3
A12	Remainder	11.2–12.8	0.10	0.3 max	0.3	0.10	0.01	....	0.3
AZ63	Remainder	5.3– 6.7	0.15	2.5–3.5	0.3	0.25	0.01	....	0.3
AZ92	Remainder	8.3– 9.7	0.10	1.6–2.4	0.3	0.25	0.01	....	0.3
AZ101	Remainder	9.0–11.0	0.10	0.5–1.5	0.3	0.10	0.01	....	0.3
M1	Remainder	....	1.20	....	0.3	0.10	0.01	....	0.3

Note 1. Analysis shall regularly be made only for the elements specifically mentioned in this table. If, however, the presence of other elements is suspected or indicated in the course of routine analysis, further analysis shall be made to determine that the total of these other elements is not in excess of the limits specified in the last column of the table.

Note 2. The following applies to all specified limits in this table: For purposes of acceptance and rejection, an observed value or a calculated value obtained from analysis should be rounded off to the nearest unit in the last right-hand place of figures used in expressing the specified limit.

TENSILE REQUIREMENTS

Alloy *	Condition	Tensile Strength (min, psi)	Yield Strength † (0.2 % offset) (min, psi)	Elongation in 2 in. (min, %)
A8	As cast	23,000	Not required	3
	Heat treated	32,000	Not required	7
	Heat treated and aged	32,000	12,000	4
A10	Heat treated and aged	29,000	17,000	Not required
A12	Heat treated and aged	27,000	17,000	Not required
AZ63	As cast	24,000	Not required	4
	Heat treated	32,000	Not required	7
	Heat treated and aged	34,000	16,000	3
AZ92	As cast	20,000	Not required	Not required
	Heat treated	32,000	Not required	6
	Heat treated and aged	34,000	18,000	1
AZ101	Heat treated and aged	30,000	19,000	Not required
M1	As cast	12,000	Not required	3

* These alloys were formerly designated Nos. 1, 2, 3, 4, 17, 14, and 11, respectively.

† See explanatory Note 2, above.

Magnesium alloys may be cast in sand molds, permanent molds, or die-casting machines.

Typical applications of magnesium castings are found in the transportation industry where lightness is of primary importance.

Many parts, such as gear housings, landing wheels, and instrumental housings for airplanes, are made of magnesium. Other applications are parts for instruments, typewriters, and vacuum cleaners. Many of these parts are produced by the die-casting process.

PROBLEMS

1. How are nonferrous alloys classified?
2. How is brass distinguished from bronze?
3. State the general engineering characteristics of brass.
4. List some uses for the following: (*a*) yellow brass, (*b*) silicon brass, (*c*) nickel brass.
5. State the properties of gun metal, and list some of its uses.
6. What is the effect of copper, aluminum, and magnesium on zinc-base alloys?
7. List some of the applications of lead-base alloys; of tin-base alloys.
8. What is Monel metal? What is it used for?
9. What elements are alloyed with aluminum?
10. How is aluminum heat treated?
11. What is age hardening?
12. What is the effect of silicon on aluminum?
13. What type of aluminum castings are alloyed with copper?
14. State some of the characteristics of magnesium alloys.

11

Melting of Cast Metals

Pit Furnace. The pit furnace is the oldest type of melting furnace known to man. Although it is considered obsolete commercially, many foundries still use a coke-fired pit furnace as a stand-by for an occasional heat of brass, bronze, or aluminum. The furnace consists of a cylindrical steel shaft, closed at the bottom with a grate and covered at the top with a removable lid. The metal is contained in a crucible which is embedded in the burning coke, as illustrated in Fig. 1.

The crucible is a melting pot of a clay and graphite composition which is molded to a standard shape and produced in sizes from 1 to 400. The crucible number represents its approximate capacity in pounds of aluminum. To determine the capacity of a crucible for another metal, the number may be multiplied by a factor representing the ratio of the density of aluminum to that of the other metal, as indicated by the following formula.

$$W = N\frac{D}{170}$$

where W = capacity of crucible in terms of the metal under consideration (pounds).
170 = density of aluminum (pounds per cubic foot).
D = density of the metal under consideration (pounds per cubic foot).
N = crucible number.

To prepare the furnace for melting, a deep bed of coke is kindled and allowed to burn until a state of maximum combustion is attained. Some of the coke is removed to make room for the crucible, and the crucible is then lowered into the furnace. The coke is replaced, and additional coke is added to surround the crucible on all sides. Metal is then charged in the crucible, and the furnace lid is replaced to facilitate natural draft. When the metal melts and reaches the desired temperature, the crucible is removed from the furnace with special long-handled tongs designed to grasp its exterior contour. It is then placed in a pouring shank and carried away to be poured.

Gas-fired pit furnaces are still being used in the production of some special steels, but they are becoming obsolete and are being replaced with the more modern electric furnace. In this type of furnace the hot gases are passed through compartments that contain the crucibles. Furnaces of this type have as many as five compartments, each containing six crucibles of 100-lb-steel capacity per crucible. The air for combustion may be preheated by regenerative chambers which consist of a heated brick structure containing a maze of passages through which the air must pass before it reaches the combustion chamber. Each furnace has two sets of checkers, one on each side, as shown schematically in Fig. 2. While one chamber is being used to preheat the incoming air, the other is being heated by the exhaust gases discharged by the furnace. When the temperature of the preheated air drops to some minimum point, the active burner is turned off and the system is reversed. When the reversing valve is turned through an angle of 90 degrees, inlet air passes through the heated chamber to the furnace at the other side of the furnace. Certain gaseous fuels are also preheated by this method. A

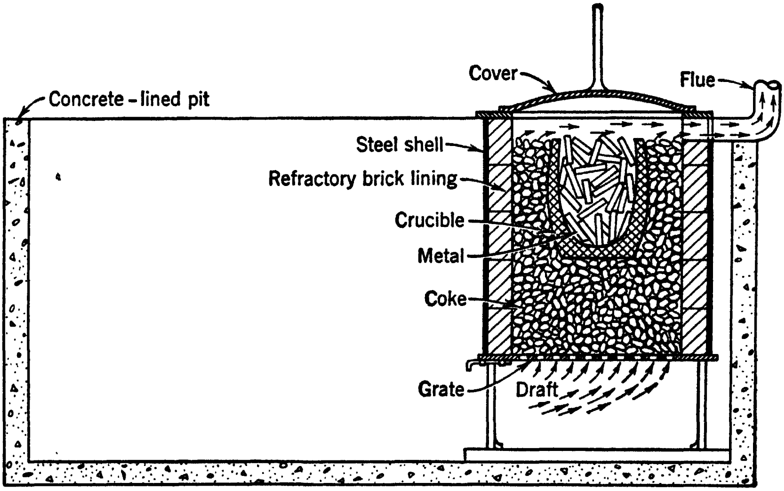


FIG. 1. Coke-fired pit furnace.

furnace of this type has two regenerative chambers on each side, one for air and the other for gas. Such a system is illustrated in Fig. 4.

Oil- and Gas-Fired Furnaces. Nonferrous metals are frequently melted in gas- or oil-fired furnaces. Furnaces of this type may be stationary or tilting. In most cases the melting pot is a graphite crucible. In the stationary furnace, special tongs and a hoist are generally used to remove the crucible for pouring. For some classes of work, aluminum is melted in an iron melting pot instead of in a crucible. Melting is more economical in an iron reservoir because of the higher heat conductivity of the iron pot, but it is often undesirable because of the absorption of iron by aluminum. In stationary iron-pot furnaces, the aluminum is dipped out of the pot with a specially designed hand ladle. The tilting furnace customarily employs a crucible with a long lip which extends to the pouring spout of the furnace.

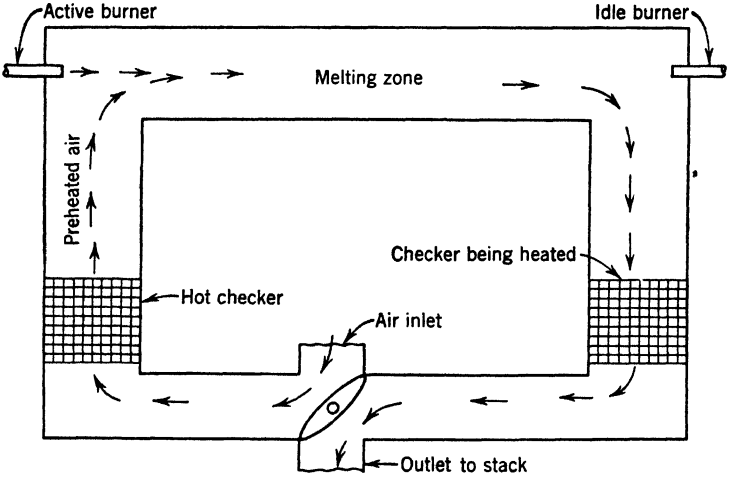


FIG. 2. Schematic diagram showing air being preheated by checker chambers for combustion.

Figure 3 illustrates a tilting crucible furnace as it appears in a tipped or pouring position. Gas or atomized fuel oil is fed through one of the trunnions which is joined to a manifold by a swivel joint to facilitate tilting. Fuel enters the furnace tangentially where it ignites and swirls upward between the crucible and the refractory lining. Small furnaces are tilted manually by a hand wheel and gear-reducing mechanism; large furnaces are motorized. Metal is charged through the opening in the center of the head. For furnace repair or crucible replacement, the head is raised and swung to one side or tilted back. One or more burners are employed, depending on the size of the furnace and the temperature desired.

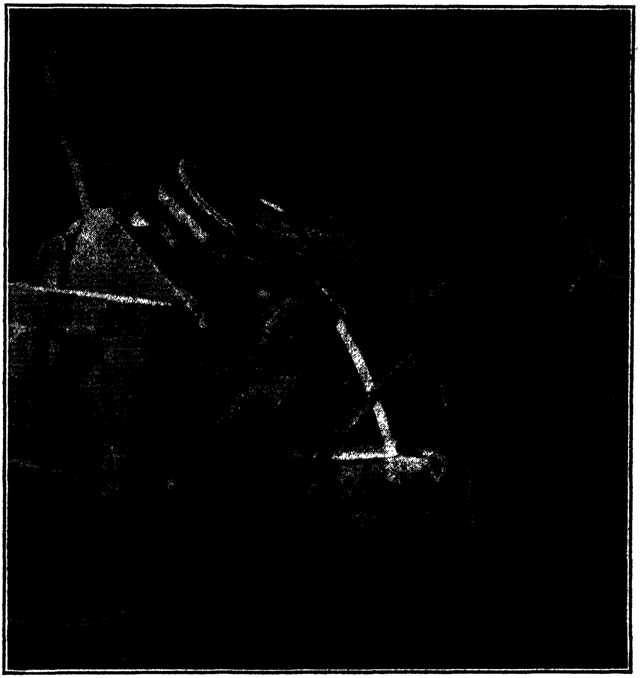


FIG. 3. Power-tilting gas-fired furnace. (Courtesy of Lindberg Engineering Co., Chicago, Ill.)

Among recent developments in this type of furnace is automatic proportioning equipment which produces a neutral flame by regulating the fuel and air ratio. Molten metal, especially aluminum, has a high affinity for hydrogen gas. Absorption takes place quite readily in a furnace of this type, especially if the flame is of a reducing nature. On the other hand, an oxidizing flame is undesirable because it reduces the life of the crucible.

In general, any metal that has absorbed an excess of hydrogen will produce a porous casting. In aluminum it is referred to as *pin-hole porosity.* To eliminate porosity it is most important to avoid all careless practices in melting. In spite of perfect combustion, the possibility of hydrogen absorption is not entirely eliminated because of a humid atmosphere resulting from the formation of water as a product of combustion. The higher the temperature and the longer the period at which a molten metal is held in a furnace, the greater are the possibilities for hydrogen to dissociate from moisture in the furnace atmosphere and be absorbed by the metal.

One of the best ways to release gas after it has been absorbed is by the flushing process. This consists of bubbling an inert gas through molten metal. The process of removing hydrogen by this method is purely physical. It is believed that the absorbed hydrogen in the metal is under a higher pressure than the flushing gas which is bubbled through the metal. As the inert gas passes up through the metal, it absorbs hydrogen until the partial pressure of the two gases becomes equal. For metals of low melting temperatures, the gas is introduced through a pipe or carbon rod containing about twenty holes of $\frac{1}{32}$-in. diameter within 2 in. of the end. Just before the metal is poured, the furnace is shut down and the flushing pipe is inserted and moved gently along the bottom to distribute gas through the metal. Although a number of inert gases may be used, nitrogen seems to be the most desirable for all nonferrous metals except magnesium. About 20 cu ft of gas is consumed per ton of aluminum.

Solid fluxes consisting mainly of aluminum chloride have long been used to prevent pin-hole porosity in aluminum. Although it was thought that a chemical reaction occurred between the chlorine in the flux and the absorbed hydrogen, it is now known that the mechanism is nothing more than that of flushing with chlorine.

Open-Hearth Furnace. About 65 per cent of the steel produced in this country is made in the open-hearth furnace. Furnace capacities in the neighborhood of 25 tons are commonly used in the casting industry. Large steel mills that produce ingots for rolled stock use open-hearth furnaces of capacities up to 350 tons.

The furnace, Fig. 4, consists of a rectangular brick structure with an arched roof. The hearth or reservoir which contains the metal has the appearance of a large saucer-shaped basin. It is constructed of sintered refractory material which is built up over a brick floor to a height of 14 to 18 in. Atomized oil, powdered coal, or gas is blown directly into the furnace through pipes or brick ducts, located in the end walls. Air is preheated by regenerative checkers located below the furnace at each end. Raw materials are mechanically charged into the furnace from a charging floor through doors located on one side of the furnace. The tap hole and pouring spout are located in the center of the opposite side and down low enough so that the metal will flow out by gravity when the tap hole is opened. The type of refractory used in the hearth and lower portions of the side walls is dependent on the nature of the refining process. If phosphorus is to be removed from the metal, the refractories must be basic in order to prevent reaction between the basic slag and refractory. This is referred to as the basic open-hearth process. In the acid

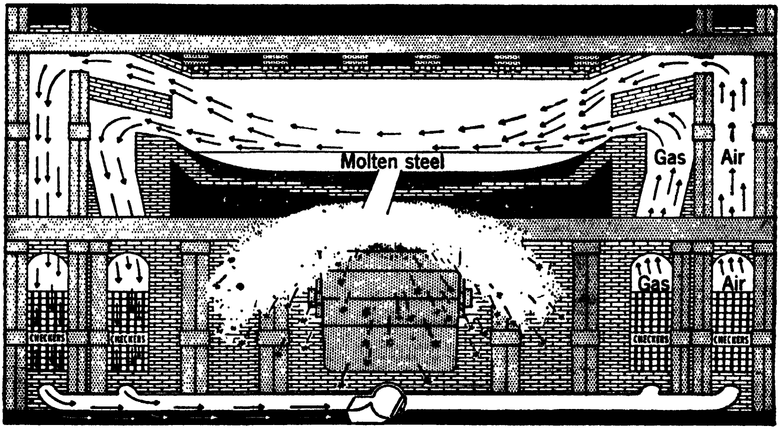


FIG. 4. Cross section of an open-hearth furnace showing regenerative checker chambers preheating incoming air and gas. The receiving ladle is in the foreground. (Courtesy of American Iron & Steel Institute, New York, N Y.)

open-hearth process, the entire furnace has an acid lining of silica refractory.

The principal advantage of the basic-type furnace is that low-cost pig iron of a high phosphorus content may be effectively reduced to produce a good-quality steel. Phosphorus makes steel brittle and should be kept safely below 0.05 per cent. Basic slag reacts with phosphorus to form a stable phosphate salt which separates from the metal and is removed with the slag. Slag is the fused nonmetallic substance which covers the molten steel in the refining process. It is made basic by additions of lime.

A typical basic open-hearth charge consists of about 20 per cent by weight of pig iron and about 80 per cent of scrap steel. Light scrap is charged on the bottom of the furnace and covered with limestone, equivalent in weight to approximately 10 per cent of the total weight of metal to be melted. This is followed by heavy scrap and topped off by pig iron. When the metal melts, limestone dissociates to carbon monoxide and carbon dioxide which bubbles up through the bath. The stirring action, referred to as lime boil, raises the metal temperature by circulating the top metal into the bath. Absorbed hydrogen is flushed out by the action of carbon dioxide gas. Phosphorus reacts with the oxides of iron and calcium and becomes stabilized in the slag solution.

When these reactions near completion, the sample of the metal is tested for carbon content and sufficient iron ore is added in several stages to reduce the carbon content to the desired amount. Reactions between the oxides in the ore and the carbon, silicon, and manganese of the molten metal produce a vigorous boil. Carbon goes off as carbon dioxide, and the oxides of silica and manganese enter the slag.

When the carbon content is reduced to a point slightly below that required in the finished steel, silicon and manganese are added to the metal to reduce iron oxide and to bring the metal to the desired composition. Iron oxide is objectionable because it decreases fluidity of molten metal. It causes increased hardness and reduces both the ductility and impact strength of castings. Most of the deoxidation is done with ferrosilicon because it is less expensive than ferromanganese. The latter is often added to the molten stream as the metal is being tapped, to avoid excessive loss caused by reactions with basic slag. Small amounts of aluminum are sometimes added to the ladle to complete deoxidation and to release absorbed gases. The open-hearth process of melting and refining steel takes from 5 to 6 hr.

Ferrosilicon is produced in various concentrations of silicon. Fifty per cent ferrosilicon furnished in lump form is customarily used as a furnace addition. Ferrosilicon is produced in concentrations of 15, 25, 50, 75, and 90 per cent silicon, the remainder of the composition being iron and a small amount of carbon. When ferrosilicon is added to the ladle, higher concentrations of silicon are preferable to avoid excessive temperature drops due to large amounts of added metal.

Ferromanganese is a good scavenger because of its deoxidizing properties and its effect on sulphur. Standard ferromanganese contains approximately 80 per cent manganese, the remainder being pig iron and a small percentage of carbon. In some steel processes, a high-manganese pig iron (15 to 30 per cent manganese, called spiegeleisen or spiegel) is added to the melt after oreing to clean up the bath.

The Cupola. Most of the 10 to 15 million tons of gray iron castings produced annually are melted in a cupola furnace. The cupola, Fig. 5, consists of a 20- to 35-ft refractory-lined cylindrical steel *stack* resting on a cast-iron bottom plate which is supported by four steel legs. The bottom of the cupola is closed by two heavy semicircular iron *bottom doors* which are hinged on a bottom plate and held in a closed position by a center prop. An opening in the shell next to the bottom plate contains the *breast*. A small cylindrical opening in the breast is called the *tap hole*. Extending from the breast is a refractory-lined *spout* which carries the molten metal from the tap hole to a *receiving ladle*. At a distance of some 10 to 20 ft above the bottom doors is the *charging door* through which the raw materials are charged into the cupola. The *tuyères* or openings through which the air blast enters the cupola are located some 10 to 20 in. above the bottom doors. Outside the cupola shell, surrounding the tuyères, is an air chamber called a *wind box* which is connected to a blower by an *air duct*. The wind box contains a small opening opposite each tuyère. A hinged *tuyère cover* fits over each

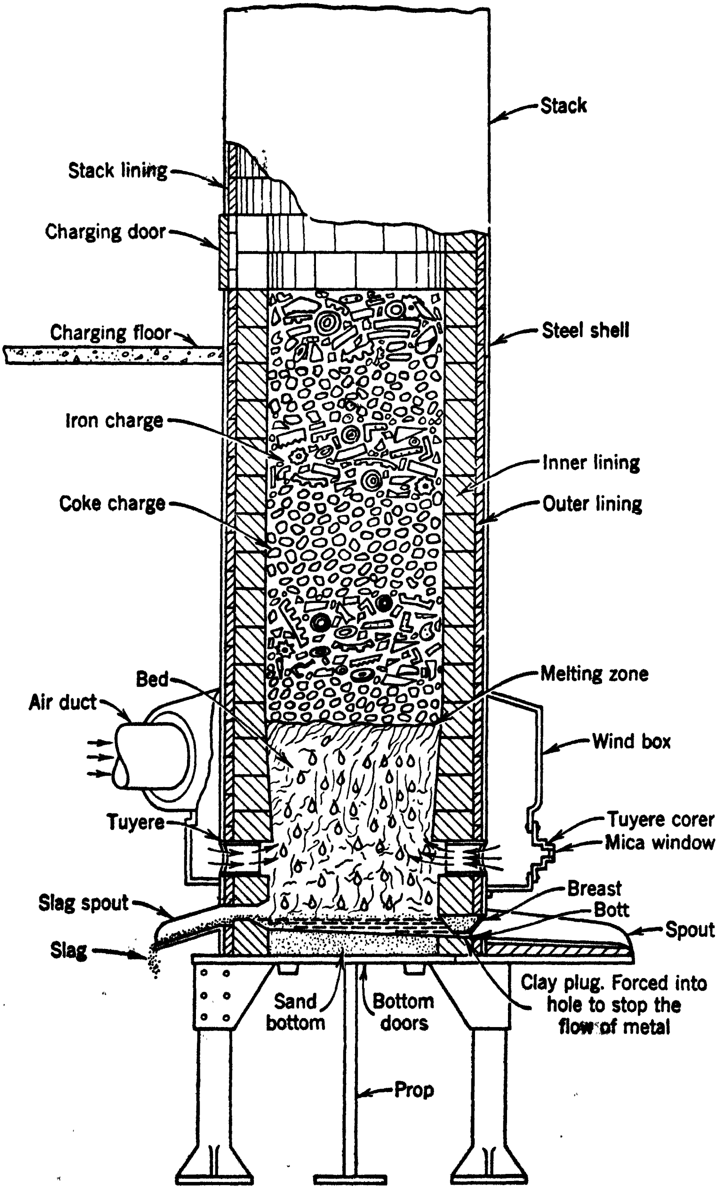


FIG. 5. The cupola furnace, illustrating the melting operation.

opening to prevent loss of air, and each door contains a transparent mica window so that melting operations may be conveniently observed. When a tuyère becomes obstructed with slag, the hinged tuyère cover may be opened and the obstruction loosened with a rod. A *slag hole* is located in the back of the cupola, opposite to the tap hole and some 2 to 6 in. below the tuyères.

Cupola Lining. Various standard shapes of firebrick are available for cupola lining. In lining a new cupola, the brick is dipped in a thin fire-clay mortar and laid about ½ to ⅜ in. from the shell to allow for expansion due to heat. No mortar is placed between brick except that which adheres to it when it is dipped. After a course of firebrick is laid, a thin coating of fire clay, fine sand, and water is poured in the space between the shell and brick. The shell lining extends to the top of the cupola. An inner lining of high-temperature-resistant firebrick is laid inside the shell lining, extending to the top of the charging door only. This lining must be replaced after a period of time, and it can be removed without disturbing the shell lining. The shell lining usually lasts the life of the cupola.

Operation of Cupola. In preparing the cupola for operation, the adhering slag from the previous heat must be chipped away. After the slag is removed, the damaged portions of the lining are daubed with a plastic mixture of 2 parts refractory sand to 1 part fire clay and water. The lining should be thoroughly dried before operation begins.

The *bottom* of the cupola is made of used molding sand which is relatively free of organic matter. It should have good permeability and be sufficiently low in strength to collapse when the bottom doors are opened to remove the remaining contents of the cupola at the end of a *heat.* To prepare the bottom, the doors are propped up and a measured quantity of sand is dumped into the cupola through the charging door. The bottom is then rammed down and sloped toward the breast at a pitch of 1 in. per foot.

Sufficient kindling to ignite the coke is placed in the cupola, and one half of the bed charge of coke is placed over the kindling. When the coke is thoroughly ignited, the remainder of the bed charge is added. The exact bed height is determined by experiment, but in most cases it varies from 20 to 30 in. above the tuyères. The breast and tuyères are left open to allow natural draft in order for the coke bed to ignite quickly and completely.

As soon as the bed is burned through, the breast is put in. A sprue pin is used to form the tap hole through the breast. Pieces of coke are jammed against the burning coke in the breast opening to form the backing for the breast. The breast material is a plastic mixture often consisting of sand and clay. It is rammed tightly into the breast opening, a funnel-shaped opening is formed around the tap hole, and the sprue pin is removed.

The cupola is then charged with alternate layers of iron and coke. Cupola melting is a continuous operation, and, as the charges move down into the melting zone, more charges are added. The coke charges should be from 4 to 9 in. deep, depending on the size of the cupola. The weight of the metal charge may be from eight to ten times the weight of the coke charge, depending on the quality of the coke and the type of metal being melted.

Flux is added to the top of each coke charge to make the slag more fluid. Natural slag is a thick, sticky material composed of rust and scale from the castings, ashes from the coke, and sand from the lining and cupola returns. Limestone, in 2-in. chunks, is commonly used for fluxing. The amount of flux depends largely on the length of operation, the composition of the coke, and the quality of metal charged in the cupola. Short heats require little if any flux. In general, the weight of flux is from 2 to 3 per cent the weight of a metal charge. Small quantities of fluor spar or soda ash are sometimes added to improve the fluidity of slag and also to improve the quality of the metal. Fluor spar melts high up in the melting zone and keeps the coke free of slag, thus improving melting efficiency. Soda ash is sometimes combined with limestone because of its tendency to desulphurize the metal.

When the cupola is filled to the charging door, the tuyère covers are closed and the blower is started. The pressure and volume of air are closely controlled to permit proper combustion in the cupola. After about 10 min of operation, molten metal begins to flow out of the tap hole. About 50 lb of metal is allowed to flow out before the tap hole is stopped up with a clay *bott*. Botts are composed of various mixtures, one of which is 7 parts of new molding sand, 3 parts of yellow clay, and 1 part of wheat flour, mixed with sufficient water to make a plastic mixture. Shaped in the form of a blunt cone, the bott is stuck to the end of a stopping bar as shown in Fig. 6.

With the rod at an angle to the molten stream, the operator forces the bott quickly and firmly into the tap hole and holds it in position a few seconds until the material bakes in the tap hole.

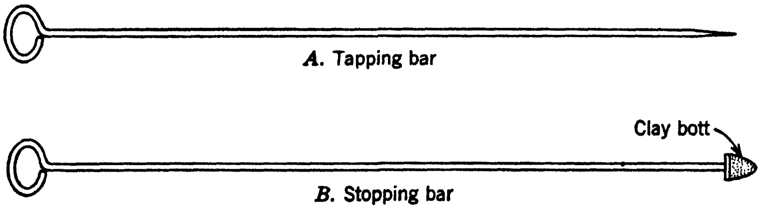


Fig. 6. Equipment for tapping and stopping a cupola. Short-handled bars are used when operations are performed from side of spout.

As metal melts in the zone above the tuyères, it trickles down through the coke and accumulates in the well below the slag hole. When sufficient metal accumulates in the well, the cupola is tapped. A pointed bar of about 4 to 5 ft long, Fig. 6, or a short bar handled by the operator standing beside the spout at the tap hole may be used to break the bott loose from the tap hole. When a long bar is used, tapping and botting are done in front of the cupola spout. When the metal is drained, the cupola is botted up again and the process is repeated until the heat is finished. After about 30 min of operation, tapping is delayed until the metal rises sufficiently high in the well to permit the top slag to run out of the slag hole. This is repeated off and on, depending on the rate of slag formation.

Very little use is found for slag as a by-product. With large cupolas the slag is allowed to flow into a stream of water which granulates the slag and makes it easier to be transported to the dump. Smaller foundries collect the slag in steel ladles. Granulated slag may be employed in the center of large cores for venting purposes.

Melting operations may continue from 1 to 16 hr, and even longer. As operation is prolonged, slag gradually accumulates on the lining and bridges over the tuyères to the extent that the charge will not move smoothly through the melting zone. Operations must then be halted. The blower is turned off, all the molten metal is drained through the tap hole, and the prop that supports the bottom door is tripped out from under. The bottom doors swing open, and the remaining contents of the cupola drop to the clay floor. When cool, the dump is removed, some coke and remaining iron is salvaged, and the cupola is prepared for another heat.

Foundry Coke. Foundry coke is made by heating certain grades of bituminous coals in the absence of air. A by-product coke oven is an externally heated retort of about 10- to 20-ton capacity. Usually from 30 to 75 ovens are situated next to each other in such a way that the walls of the adjacent ovens are heated by a single unit of flues. After the coal is charged in the oven, it is sealed tightly and heated at 750° to 1100° F for about 72 hr. The gases driven off by this so-called carburization process are collected and processed to obtain fuel gas, tar, ammonia, and light oil. The coke is then pushed out of the oven, quenched, and removed by a belt conveyor for classification.

The characteristic properties by which coke is judged for cupola use are size, cell structure, strength, porosity, and chemical analysis. Cold metal may result in coke lumps that are too large or too small. Although differences of opinion exist among melters, it is believed that lumps equal to one-twelfth of the cupola diameter produce optimum melting conditions. It is generally believed that a denser structure has slower burning properties and therefore is more desirable. By coke strength is meant the ability of coke to support (without being crushed) the burden of metal charges above it. It is also believed that the total volume occupied by the pores should be less than half the volume of the coke lump.

Chemical properties of coke are determined in much the same way as properties of coal. The properties of most concern to the foundryman are moisture, volatile matter, ash, sulphur, and phosphorus content. Excessive moisture does not affect the heat value of coke, but it does reduce the quantity of combustible content in a given weight of coke. With high moisture content, the weight per charge should be increased proportionally. Under normal conditions, the moisture content varies between 2 and 3 per cent. Volatile matter is objectionable because of its low ignition temperature and its tendency to produce chemical reactions unfavorable to cupola operations. Increased ash content reduces the fuel value of coke and increases the formation of slag. The fuel value of coke is based on the percentage of fixed carbon in the coke. Low sulphur content is desirable because sulphur is readily absorbed by molten metal. Phosphorus is also absorbed by cast iron, but its effects are not objectionable, except in the production of low-phosphorus metal.

The analysis of coke on the dry basis (moisture driven off) varies within the following limits.

Table 1. APPROXIMATE ANALYSIS OF COKE

Volatile matter, %	0.70– 3.00
Fixed carbon, %	86.00–94.00
Ash, %	6.00–12.00
Sulphur, %	0.40– 1.00
Phosphorus, %	0.09– 0.15

Air. Combustion in a cupola is accomplished by blowing air through the incandescent coke bed at tuyère height. Much of the oxygen of the air is quickly converted to carbon dioxide, but, as the gases pass up through the coke bed, a part of the carbon dioxide is reduced by the carbon in the coke to carbon monoxide. Although complete combustion to carbon dioxide produces maximum heat, it is not desirable because of the loss of silicon and manganese, and the formation of iron oxide in the presence of excess oxygen. It is believed that a cupola is operating at its best when the analysis of the effluent gas shows 14 per cent carbon dioxide and 11.6 per cent carbon monoxide. About 78 per cent of the air is composed of nitrogen and plays no part in combustion. As the effluent gases pass beyond the melting zone, they transfer part of their sensible heat to the charges.

Excessive moisture of the air on humid days affects cupola operation in many ways. Not only is the melting rate reduced, but the resultant castings have greater chill depth and reduced strength. Excess moisture is accompanied by increased losses in silicon and manganese and higher carbon pick-up. When the atmosphere is humid, as much as 2 tons of moisture may be blown in a cupola in an 8-hr period. To avoid variations in the properties of cast metal, excess moisture is often removed from the air by an absorption process. The air is passed through an absorbent solution such as lithium chloride, which can be made to absorb or give off moisture, depending on the solution temperature. The water-borne solution is circulated from the air-conditioning unit to a reconditioning system where it is heated to drive off the absorbed moisture. It is then cooled and recirculated through the conditioning unit.

A primary requisite in the control of melting is to supply a determined amount of oxygen to the coke at a definite rate. The percentage by volume of oxygen in air varies with atmospheric pressure and temperature, and the air volume must be correspondingly increased or decreased to maintain uniformity of combustion. Because of such variations in density, cupola air is preferably measured in terms of weight rather than volume. One type of control operates on the basis of power supplied to a constant volume blower. When the air is light, an ammeter on the motor circuit actuates a control apparatus which opens a blast gate in the air duct to admit more air; and, when the air is more dense, the ammeter causes the gate to restrict air flow. Another type of apparatus measures air flow volumetrically but compensates for changes in barometric pressure and temperature. Instead of a blast gate to control the air flow, some systems have a bleeder valve which exhausts excess air to the atmosphere. In such an apparatus the fan capacity must be in excess of the maximum cupola demand.

Pig Iron. Pig iron is a product of the blast furnace in which iron ore is reduced to iron. The molten metal is machine cast to a standard shape called a *pig*. The casting machine consists of metal pig molds which are poured at one end of an endless chain conveyor and dumped at the other end. Pig iron is the crudest form of iron and is suitable only as a raw product in the manufacture of cast iron and steel. Pig iron is purchased on the basis of the chemical composition of the metal. The principal elements are silicon, phosphorus, sulphur, and manganese.

Various grades of pig iron are commonly classed according to the type of metal most suitable for subsequent conversion into castings. The common classifications are:

1. Foundry pig for gray iron castings.
2. Malleable pig for malleable iron castings.
3. Basic pig for basic open-hearth steel.
4. Low-phosphorus pig for acid open-hearth and Bessemer acid steel.

Each of these classifications has a wide range of chemical compositions. Specifications of chemical composition for the various grades of pig fall within the percentile range shown in Table 2.

Table 2. TYPICAL GRADES OF PIG IRON

Grades of Pig Iron	Total Carbon (%)	Silicon (%)	Phosphorus (%)	Manganese (%)	Sulphur (%)
Foundry	3.25–4.00	1.25–4.00	0.02–1.50	0.25–1.25	Under 0.05
Basic	3.50–4.40	0.50–1.50	0.05–0.90	0.40–2.5	Under 0.05
Low phosphorus	4.00–4.40	1.25–3.25	Under 0.10	Under 0.10	Under 0.05
Malleable	3.75–4.30	1.25–2.25	Under 0.20	0.40–1.00	Under 0.05
Silvery	2.5	10	....	....	....

Scrap Metal. Domestic scrap is metal that is returned to the cupola for remelting. It consists of sprues, risers, and defective castings. Foreign scrap is purchased scrap obtained from outside sources. It is generally classified according to the machinery or equipment from which it was obtained. Examples of foreign scrap classifications are machinery, automotive, railroad, brake shoe, agriculture, radiator, malleable, rail, automotive steel, borings, and compressed bundles. Each of these classifications includes castings of common chemical characteristics which can be estimated to a fair degree of accuracy.

In addition to classifying scrap iron according to its previous use, its composition may be judged by the appearance of its fracture. A thin section with a gray fracture is very likely a high-silicon low-sulphur iron; and, at the other extreme, a thick section with a white fracture may consist of a low-silicon and possibly high-sulphur composition.

Estimating the composition of scrap iron is becoming more difficult because of an increased use of alloyed iron. When close control is necessary, the metal is melted and poured into pigs.

Samples of drillings are then analyzed, and the metal is accurately classified.

The estimated analysis of a few classifications is given in Table 3.

Table 3. APPROXIMATE ANALYSIS OF SCRAP IRON

Kind of Scrap	Carbon (%)	Silicon (%)	Manganese (%)	Phosphorus (%)	Sulphur (%)
Machinery (light)	3.40	2.50	0.60	0.50	0.08
Automotive	3.30	2.00	0.70	0.20	0.10
Brake shoe	3.20	1.15	0.55	0.35	0.10
Malleable	2.30	1.00	0.40	0.15	0.10
Steel plate	0.53	0.14	0.69	0.015	0.039

Mechanical Charging. The principal elements of a mechanical charging system are (1) the discharge bucket which contains the charge of iron, coke, and flux, and (2) the conveyance system which delivers the bucket to the cupola for discharge.

The charge may be dumped in the cupola by a top-discharge bucket which is automatically inverted as it enters the cupola, or it may be released through the bottom of a bottom-discharge bucket. The bottom-discharge bucket often consists of a hinged bottom door which swings open for discharging, or it may have a cone-shaped bottom, as illustrated in Fig. 7. This type of bucket consists of two principal parts, the shell and the cone bottom. In the load-carrying position the shell rests on the cone. The hoisting hook is attached to a rod which passes down through the center of the bucket and is attached to the cone at the bottom. When the bucket is inserted in the cupola, it is lowered so that the shell rests on a stationary yoke in the cupola. Further lowering of the hook causes the cone bottom to separate from the shell, and the charge drops out. There is about 10 in. of clearance between the side of the bucket and the cupola lining.

There are many variations in design for conveying the charging bucket from the loading station to the cupola discharge position. In general these methods may be classified as the skip-hoist type and the crane type. The skip-hoist charger is adapted to small- and medium-sized cupolas, especially when a limited amount of space is available. The bucket is mounted on wheels and guided by a track which may be vertical or inclined, the furnace. The converter is tipped at an angle of 15 degrees to the horizontal to receive the molten charge which is conveyed to the converter from a cupola. It is then returned to an upright position which brings the metal bath up to the bottom of the tuyères. An air blast of 4 to 5 psi is then turned on, and the refining process begins. A shower of sparks is followed by a dense reddish brown flame which rises to its full height, recedes, and rises again as the successive reactions take place. The operator watches the temperature indicated by a photoelectric cell as the blow progresses through the cycles; at various periods he adjusts the position of the converter and regulates the air pressure. He must be alert for below-normal temperature and make additions of ferrosilicon when and if necessary. After about 20 min, when the flame drops sharply, the air is turned off and the blow is over. At this point the steel contains some iron oxide, a maximum of 0.03 per cent silicon and manganese, and

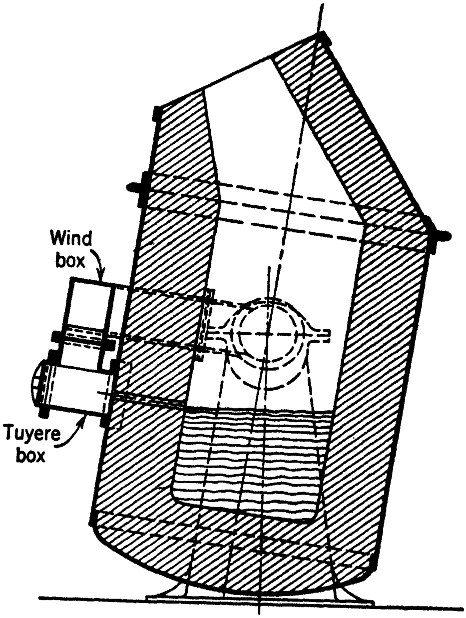


Fig. 9. Side-blow converter, showing metal charge, and blower in position for blowing action. (Courtesy of Whiting Corp., Harvey, Ill.)

about 0.06 per cent carbon. Enough cupola iron is then added to the steel to raise the carbon content to the desired percentage. This is followed by additions of silicon and manganese in the form of ferrosilicon and ferromanganese which reduce the oxidized metal as well as adjust the chemical composition. The remaining oxide is removed by a small addition of aluminum, and the entire charge is poured into a receiving ladle to be distributed at the pouring floor.

FIG. 10. Air furnace and cupola. In this duplexing process, gray iron is melted in the cupola and then transferred to the air furnace for refining. (Courtesy of Whiting Corp., Harvey, Ill.)

Air Furnace. The most widely used melting furnace in the production of malleable iron is the air furnace. Cupola iron is also used in malleable iron production, but, because of its limitations in the control of metal composition, it is restricted to the production of lower-quality malleable castings. An air furnace melts about 2½ lb of metal per pound of coal, and a cupola furnace melts about 10 lb of metal per pound of coke. Because of the high efficiency of cupola melting, metal is often melted in a cupola and transferred to an air furnace where it is refined to the correct analysis. This process is called *duplexing* and is illustrated in Fig. 10.

In some respects, the air furnace is similar to an open hearth. It is a long rectangular furnace with a removable arched roof consisting of a number of sections called *bungs.* Each bung consists of a cast-iron frame which contains the arched brick structure and lifting hooks for removal by crane. The older furnaces have a fireplace or combustion chamber at one end where coal is burned with the aid of an air blast, and a stack at the other end which draws the hot gases over the charge. Most modern air furnaces blow pulverized coal directly into the furnace where it ignites and melts the metal as it passes through the furnace to the stack. Pouring spouts are frequently located on both sides of the furnace. The capacity of air furnaces ranges from 20 to 80 tons.

The charge consists of pig iron, malleable scrap, and white iron scrap. It is composed in much the same way as for cupola mixing and consideration is made for the losses that will occur as a result of oxidation. In preparation for charging, the charging bungs are removed with a crane and the entire metal charge is placed in the furnace. After the charging bungs are replaced and sealed with clay, the kindling located near the burners is ignited. When the proper kindling temperature is reached, the pulverized coal burners are turned on. After about 3½ hr of melting, the bath is stirred with a long rod to speed up melting. Slag is then skimmed from the surface of the bath with a long-handled scraper called a skimmer. It is raked off the surface through the skim doors and into metal receivers which are trucked away for disposal. This is done three times during the heat, the last being shortly before the metal is tapped. When the temperature of the molten metal becomes high enough to cause oxidation, the metal begins to boil in the same manner as described for the open-hearth furnace. This is called the refining period and is allowed to continue until proper temperature and correct composition are reached. Samples of metal are removed and poured into test specimens which are quickly analyzed for silicon, manganese, and carbon. If the analysis discloses a deficiency, it is necessary to make additions of ferrosilicon, spiegeleisen, or petroleum coke for enriching the metal with elements in the order listed above. It takes about 7 hr to prepare a 20-ton heat for pouring.

Direct-Arc Melting Furnace. The direct-arc furnace may be used for melting, refining, melting and refining, or merely for holding metal at a constant temperature for pouring convenience. By the duplexing process, iron is melted more economically in a cupola and refined in the electric furnace. In the *triplexing* process, molten iron is transferred from the cupola to a Bessemer converter where it is made into steel. It is then transferred to the electric furnace where its properties may be altered or adjusted. Frequently the only function of the electric furnace in triplexing is to maintain a constant supply of metal for continuous pouring.

The direct-arc electric furnace is well adapted to the production of tool steels, stainless steels, and other special alloy steels. It is also used in small steel foundries and in iron foundries where high-strength products are desired. The practicability of such a furnace depends on the quality of metal desired and the cost of electrical power.

The electric furnace has the highest thermal efficiency of all melting furnaces. Heat is available quickly and at will, and the temperature may be controlled to a high degree of accuracy. The atmosphere produced by the arc is not deleterious to the metal. Such conditions as these are ideal for closely controlled metal composition. The body of the furnace, Fig. 11, consists of a heavy steel cylindrical shell with a spherical or flat bottom. Like the basic open hearth, magnesite refractories are employed in the reduction of high-phosphorus metal. The charge is contained in a bowl-shaped hearth which is sloped towards the short pouring spout at the front. The slag spout is located at the opposite end. Water-cooled furnace doors cover all openings to prevent circulation of air. The roof of the furnace is dome-shaped, and in many cases it can be removed for furnace charging. The three large carbon electrodes which pass through the roof are automatically raised and lowered to the proper arc length by means of motor-powered winches.

In preparation for melting, the electrodes are raised to clear the sidewall, and if the roof is removable it is swung to one side to permit top charging with a bottom-discharge bucket. Heavy scrap is placed on the bottom, and lighter material is charged above. The roof is then replaced, the electrodes are lowered, and the current is turned on. The electrodes melt their way nearly to the bottom where the molten metal begins to collect. As the molten bath rises, the electrodes recede. As soon as the refining period is reached, the current input is reduced to allow sufficient time for the necessary chemical changes to occur. The furnace rests on trunnions so that it can be tilted either clockwise or counterclockwise, one direction for slagging and the other for pouring. All operations, including the raising of doors and tilting of furnaces, are either motorized or hydraulically powered.

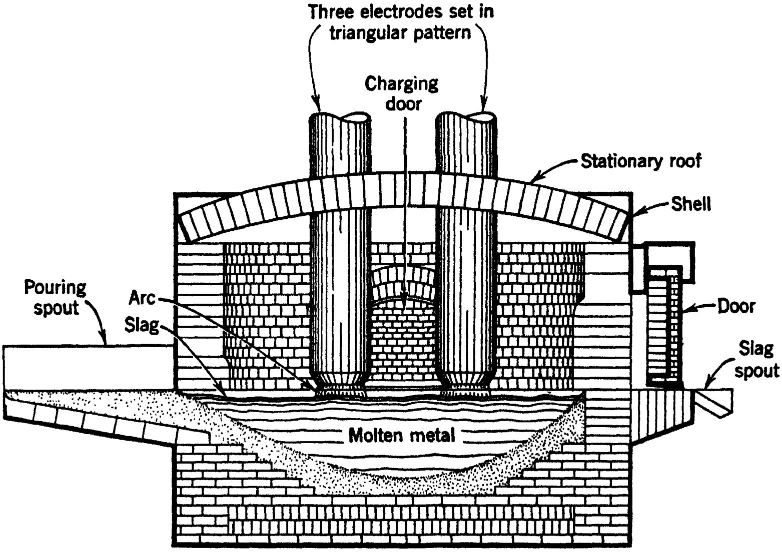


FIG. 11. Direct-arc electric furnace.

Indirect-Arc Rotating-Type Furnace. The indirect-arc furnace, Fig. 12, is used for melting all types of metals, but it is especially popular in the production of brass, bronze, copper, and nickel alloys. Small quantities of ferrous alloys, requiring special metallurgical characteristics, are conveniently produced without waiting to accumulate sufficient tonnage for large furnaces. The capacities of indirect-arc furnaces range up to 2000 lb. If small quantities of a variety of chemical compositions are desired, it is possible to plan the additions so that a number of alterations may be made in a single melt. After the castings of base composition are poured, the remaining metal may be altered by additions of alloy to accommodate another type of casting. This may be continued, each succeeding composition containing the accumulation of the previous additions plus an addition to meet a new specification.

The furnace consists essentially of a cylindrical or barrel-shaped shell, mounted horizontally on idlers and geared so that it can be rotated back and forth through an arc of 180 degrees. The shell is lined with insulating and refractory material, the latter forming the hearth of the furnace. Two electrodes are employed, one entering the furnace from each side, coincident with the horizontal axis of the shell. As the arc is struck, the electrodes separate from each other and are automatically maintained at proper arc length. Heat is radiated and reflected in all directions; some is absorbed by the metal and the remainder by the refractory wall of the furnace. As the shell rotates back

Fig. 12. Indirect-arc electric furnace discharging molten metal into a modern pouring ladle. Furnace capacity, 500 lb. (Courtesy of Kuhlman Electric Co., Detroit, Mich.)

and forth, molten metal flows over the heated refractory and absorbs heat energy from the refractory by conduction.

Induction Melting Furnaces. The electrical principles involved in the heating and melting of metals by induction are similar to those of the common transformer. The furnace consists of a crucible or monolithic lining surrounded by a water-cooled copper coil. The coil represents the primary circuit to which a high-frequency current of 1000 to 3000 cycles is supplied by a motor-generator or electronic-type generator unit. Secondary currents, called eddy currents, are induced in the crucible charge in much the same way as the secondary coil is energized in a transformer. These eddy currents flow through the metal by virtue of differences in potential in various parts of the charge. The resistivity of the metal causes current losses which are dissipated to heat energy which melts the metal. Within the temperature range where ferrous metals show magnetic properties, an added heat is produced by hysteresis loss. This is believed to be caused by friction between vibrating atoms as they attempt to adjust their polarity to the changing magnetic field of high-frequency current.

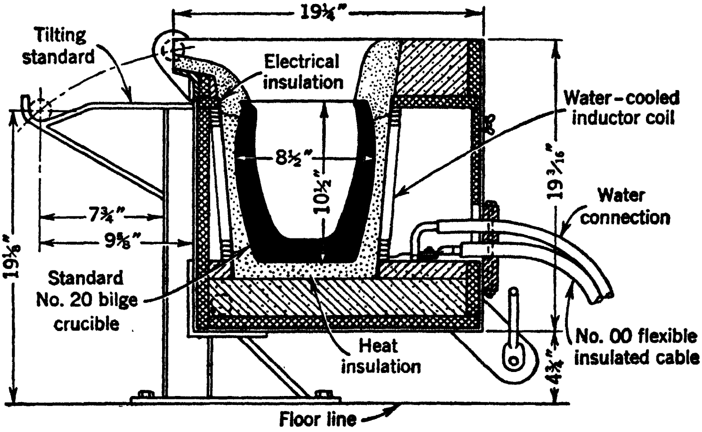


FIG. 13. Tilting-type induction furnace. (Courtesy of Ajax Electrothermic Corp., Trenton, N. J.)

Figure 13 illustrates a cross-sectional view of a tilting crucible induction furnace. The tilting trunnions are in such a position as to prevent the pouring spout from shifting through a large arc when metal is poured. The coils are insulated and located as near as possible to the metal charge. The frame of the furnace is made of brass. To prevent induction losses, the component members of the frame structure are sufficiently insulated from one another to prevent a closed circuit, such as a triangular or polygonal ring.

At 100-kw input, an induction furnace can melt 200 lb of brass in about 22 min. Metals are melted with extremely low oxidation losses and with no contamination.

In recent years a core-type induction furnace has been developed for melting of aluminum. Instead of the coil surrounding the metal charge, this type of furnace has a protected induction coil immersed in the metal. With ordinary power-line frequency, a 60-kw furnace will melt as much as 300 lb of aluminum per hour.

PROBLEMS

1. Give the approximate capacity of a No. 20 crucible in terms of (*a*) aluminum, (*b*) manganese bronze (the density of bronze is 525 lb per cubic foot).
2. Explain the cause of pin-hole porosity and state how it might be minimized.
3. Why is phosphorus undesirable in steel? How can it be removed?
4. What is the function of ferromanganese in steel making?
5. Given the analysis of two grades of pig iron and one grade of scrap iron, compute the mixture to be used in producing gray iron castings of the following analysis.

	Analysis of Materials on Hand			Required Analysis of Cast Metal
	No. 1 Pig Iron (%)	No. 2 Pig Iron (%)	Scrap Iron (%)	
Carbon	3.5	3.25	3.00	3.00–3.40
Silicon	3.25	2.75	2.00	2.25–2.50
Manganese	0.80	0.60	0.50	0.40–0.60
Phosphorus	0.90	0.50	0.60	0.60–0.70
Sulphur	0.03	0.05	0.08	0.10 max

Assume that the following changes will occur in the melting process.

(*a*) Addition of 0.15 per cent carbon to the computed analysis of aggregate charge.
(*b*) Loss of silicon (10 per cent × analysis of aggregate charge).
(*c*) Loss in manganese (20 per cent × analysis of aggregate charge).
(*d*) Increase in sulphur by 0.04 per cent.

6. Why would an air furnace be preferred to a cupola in preparing metal for malleable-iron castings?
7. Explain how the process of triplexing might be applied to an industrial process.
8. Explain the principles involved in induction melting.

12

Cleaning and Inspection

Preparing Castings for Cleaning. The first operation prior to cleaning is to remove the gates and risers. They are customarily broken off gray iron castings with a hammer or sledge. Although some gates and risers may be broken off steel castings, other methods, such as oxyacetylene cutting or sawing with a metal-cutting saw, are generally employed. Gates and risers on nonferrous castings are customarily sawed off with a metal-cutting saw. Occasionally a groove is chipped in a gate prior to the knock-off to prevent a break-out in the casting. To avoid chipping a groove in the gate, it is frequently *necked* or constricted at the entrance to the mold cavity. In order to maintain a molten passageway in the gate which joins the feeder and mold cavity, the constriction is sometimes made with a thin core, as illustrated in Fig. 1. The core, being surrounded on both sides by molten metal, prevents the constriction from solidifying prematurely.

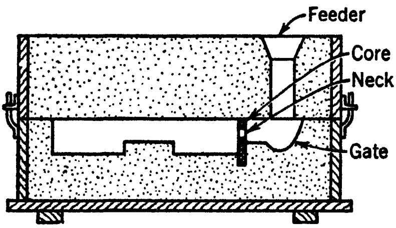


FIG. 1. Use of a core to neck the gate at mold entrance.

The operation of removing gates is often followed by a chipping operation with a pneumatic chisel to remove small pieces of gates, fins, and stems of chaplets projecting from medium- and large-sized castings. Arbors and other core reinforcements are removed from the castings and salvaged, if possible. Metal rods, bolts, and gaggers are straightened by being compressed between dies of a rod-straightening machine.

Loose sand and cores may be removed by striking the casting with a hammer or sledge. Production foundries frequently devise special fixtures in which the casting is clamped and vibrated. Loose sand and cores are sometimes removed from large castings by a power-operated device which shakes or pounds the casting. Tightly adhering sand is removed from large castings with pneumatically operated long-stemmed chisels.

Tumbling Barrels. The tumbling barrel, Fig. 2, consists of a cylindrical steel shell which is closed at its ends by cast-iron heads and supported on horizontal trunnions. Castings are charged into the tumbler through an opening extending the length of the barrel. Care should be taken to pack the castings tightly enough to prevent breakage, and yet not so tightly as to prevent motion between adjacent pieces when the barrel rotates. In order to avoid breakage, heavy castings are not charged with light, fragile castings. Small nonfragile castings and pieces of iron or small star-shaped castings called *milling stars* may be added to the charge to help clean and polish. When the mill is filled, a door is fitted over the opening and clamped down securely. Tumbling barrels are rotated at rates that vary from 25 to 50 rpm, depending on the type of castings being cleaned. A small steel pinion drives the tumbler through a cast-iron gear

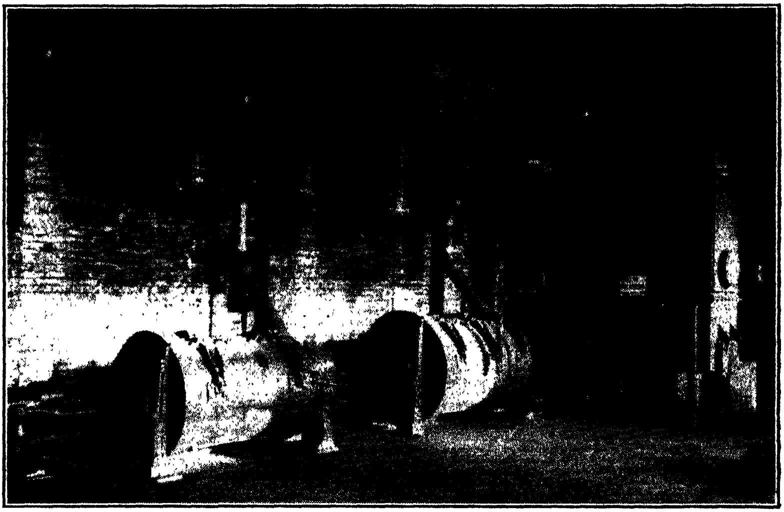


FIG. 2. Tumblers for cleaning castings. Ducts from tumblers lead to a dust collector at the right. (Courtesy of Whiting Corp., Harvey, Ill.)

mounted on the drivehead of the tumbler. Both direct motor drives and belt drives are in common usage. Tumbler capacities range from 9 to 130 cu ft.

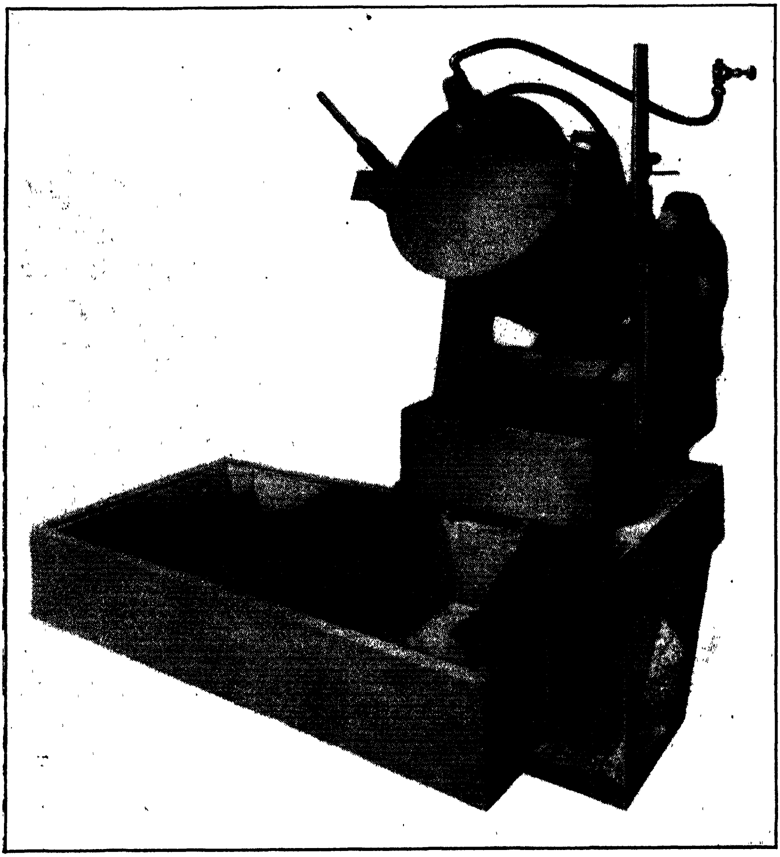
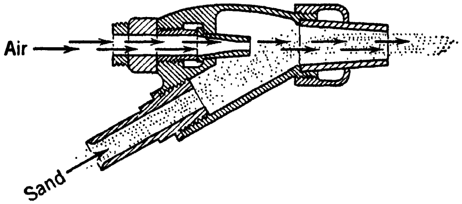


FIG. 3. Cut-away view of a typical Hydro-Blast Barrel for cleaning castings. (Courtesy of Whiting Corp., Harvey, Ill.)

In addition to economical cleaning and polishing, tumbling has the added advantage of removing fins and sharp edges from castings. Also, the peening action in tumbling tends to relieve internal strains caused by shrinkage gradients due to the cooling phase of the casting process.

Oblique Tumblers. Oblique tumblers, similar to that shown in Fig. 3, are sometimes used to clean small castings. With the open-end type, the cleaning progress may be observed and terminated when the castings are sufficiently clean.

Figure 3 illustrates a special type of oblique tumbler, called a Hydro-Blast Barrel, in which the castings are blasted with a high-velocity stream of water and sand as they are tumbled. This type of cleaning is more desirable for nonferrous castings because ferrous metals tend to rust after the water treatment. The lid containing the blast gun remains stationary as the barrel rotates and exposes the castings to the impinging stream of water. Cleaning time varies from 5 to 15 min, compared to the 1 to 3 hr required by the tumbler. Since the tumbler is absolutely dustless, no dust arrester or exhaust fans are necessary. Hydro-Blast tumblers range in capacity up to 1000 lb. Before the castings are discharged, the sand blast is turned off and the castings are rinsed with clean water. The bottom portion of the barrel is perforated to remove all sand and water. Castings are removed by unhinging the cover and tilting the barrel.



✓

FIG. 4. Sandblast gun.

Sandblasting and Shotblasting. The blast gun of a sandblast and shotblast machine, shown in Fig. 4, consists of a converging air nozzle which discharges a stream of high-velocity air through the mixing chamber directly into the discharge nozzle. This creates a vacuum in the mixing chamber and draws sand or shot up through the supply line. The blast gun is enclosed in a cabinet to avoid the scattering of sand and dust in all directions. In a small cabinet, the operator manipulates the gun by reaching through two rubber-gloved openings in the front of the cabinet. The interior is adequately lighted so that the operator may observe his work through a window in front of him. The blast gun in larger cabinets is mechanically controlled from without. In sandblast rooms, the operator wears a positive pressure helmet to which fresh air is supplied from outside.

Figure 5 shows a sandblast cabinet with the side door raised so that the casting may be placed within for cleaning. The door is then lowered, and the operator reaches into the gloved holes to manipulate the nozzle. To turn on the sandblast, the operator steps down on a foot lever. Dust is drawn out of the cabinet and passed through a dust collector. The heavier sand or shot drops through the grate and collects in the pyramid-shaped bottom. The vacuum produced in the gun draws the shot or grit up through the hose for re-use.

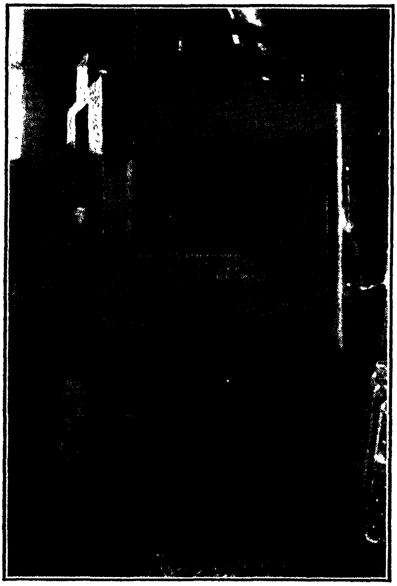


Fig. 5. Sandblast suction cabinet. Side door is opened to view interior of cabinet. (Courtesy of American Wheelabrator & Equipment Corp., Mishawaka, Ind.)

Sandblasting is well adapted to cleaning of castings that are either too fragile or too large to be tumbled. Castings too large for the sandblast cabinet are cleaned in a sandblast room such as that illustrated in Fig. 6. Air is exhausted through the ceiling to remove dust, and the discharged sand drops through the perforated floor where it is screened and conveyed up an elevator to a storage tank for re-use.

In another type of cabinet, the castings are placed on a rotating table which carries them past a series of blast jets located in various positions to clean the castings on all sides.

Another type of cleaning machine is the sandblast tumbler which sprays the casting with sand or grit as it is being tumbled.

Airless Abrasive Blasting. This type of machine makes use of an impeller wheel which hurls the abrasive or shot at the castings. Portions of the machine of Fig. 7 have been sectioned to illustrate the mechanical features. Shot is fed through the hub into the impeller wheel where it is picked up by the throwing blades and accelerated as it passes to the periphery of the wheel, leaving the wheel at a very high velocity. The rotation of the apron conveyor tumbles and cascades the castings under the blast. When the castings are cleaned, the direction of rotation of the conveyor is reversed, and the castings roll out the front

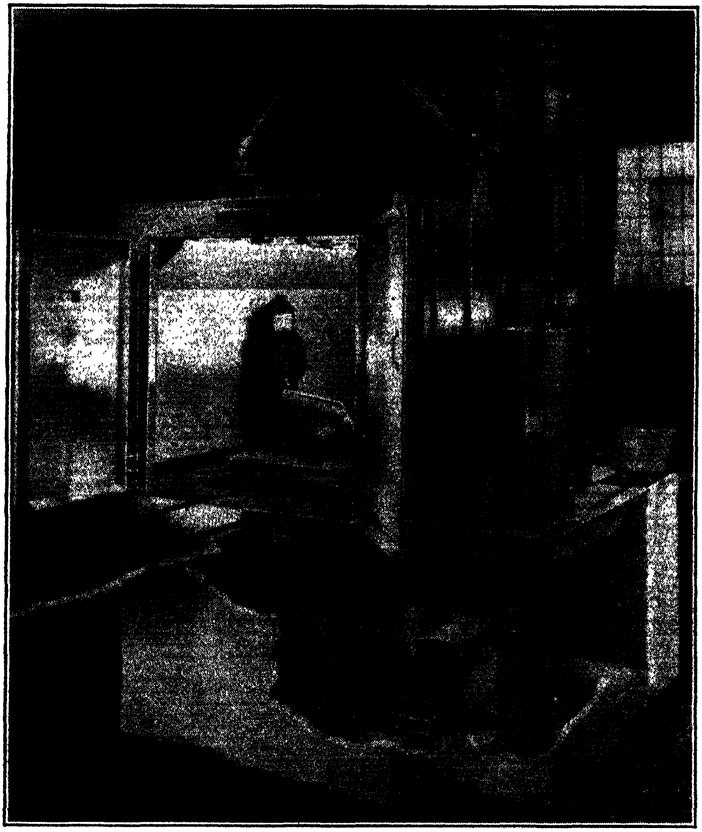


Fig. 6. Sandblast room showing operator in blasting position. Cut-away section shows method of collecting sand for re-use. (Courtesy of American Wheelabrator & Equipment Corp., Mishawaka, Ind.)

end of the machine. The blast material passes down through the perforated apron and is conveyed by a screw to a screen, and finally up an elevator for re-use. One of the principal advantages of this machine over the sandblast machine is the elimination of compressed air.

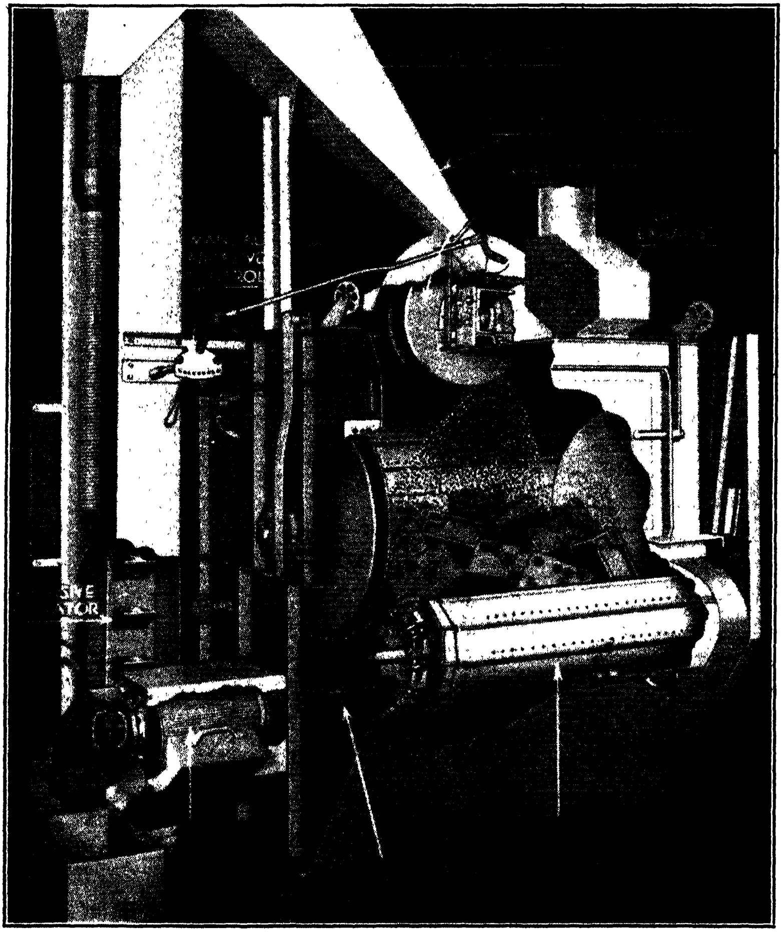


FIG. 7. Airless abrasive blasting. Phantom view of Wheelabrator Tumblast illustrates operation of machine. (Courtesy of American Wheelabrator & Equipment Corp., Mishawaka, Ind.)

Grinding. The cutting action of grinding wheels is similar to that of a milling cutter. The small abrasive grains on the cutting surface of the wheel act as cutting tools which produce small metal chips.

Abrasives commonly used in grinding wheels are silicon carbide (SiC) or aluminum oxide (Al_2O_3). The angular particles of silicon carbide are extremely hard and moderately tough. Although aluminum oxide is not so hard, it possesses greater toughness. Aluminum oxide wheels are recommended for use on hard and tough metals of high tensile strength, such as alloyed steels and a variety of tough alloys of bronze and aluminum. Silicon carbide is recommended for metals of low tensile strength, such as cast iron, and malleable iron before heat treatment, and for nonferrous metals, such as soft brass, aluminum, copper, and magnesium. Silicon carbide is produced synthetically in an electric furnace by combining pure silica sand and carbon in the form of coke. Aluminum oxide, also produced in an electric furnace, is purified from the ore, bauxite. Before the abrasive can be cemented into the form of a wheel, it must be reduced to the desired grain size by crushers and abrasive mills. It is then washed to remove impurities and graded by screens or hydraulic separators to obtain uniform grain sizes. The larger grain sizes are used in wheels for rapid removal of metal over large areas.

Materials commonly used in bonding the grinding wheels used in cleaning rooms are classified as vitrified, resinoid, rubber, and shellac bonds. Binders are graded from A to Z to indicate their degree of hardness. The vitrified bonds consist of a claylike material which fuses with the abrasive to form a glass-like matrix. It is resistant to oil, water, and acids and is unaffected by various climatic conditions and ordinary temperature changes. The wheels are porous and strong and remove metal at a high rate of speed. Rough grinding, called *snagging,* is commonly done with resinoid- or bakelite-bonded wheels. The rate of stock removed by a wheel is proportional to its speed and pressure. Resinoid bonds, being stronger, are operated at a peripheral speed of 9500 ft per minute; vitrified wheels run at 6500 ft per minute. Thin abrasive wheels are often molded with rubber and vulcanized under pressure. They are used where high strength and shock resistance are essential. Shellac-bonded wheels are used where low grinding heat is desirable. Aluminum castings are frequently ground on this type of wheel.

Fig. 8. Large casting being ground with a portable grinder. (Courtesy of Norton Co., Worcester, Mass.)

The types of grinders customarily employed in cleaning rooms are floor and bench stand, portable, cut-off, disk, and swing frame. Wheel mountings on floor stands usually range from 20 to 30 in. in diameter. If a battery of grinders is in use, the grinders are operated at different speeds so that partially worn wheels can be used at maximum efficiency. When a new wheel wears down and its peripheral speed drops below a certain velocity, it is removed and placed on a higher-speed grinder, etc. Grinding fixtures operated by foot pressure are sometimes employed to exert greater pressure against the wheel and to avoid injury to hands, due to slippage.

FIG. 9. Large casting being ground with a swing frame grinder. (Courtesy of Norton Co., Worcester, Mass.)

Bench-stand grinders having smaller and narrower wheels are used for special grinding operations on smaller castings. Portable grinders, powered by electric motors or air turbines, can grind surfaces inaccessible to other grinders, especially on large castings. Figure 8 shows a casting being finished with a portable grinder. Portable grinders often have special cone- and cup-shaped wheels to grind concave and convex surfaces. Cut-off grinders serve to cut gates and risers from nonferrous castings, the gate being ground flush with the casting, thus eliminating the necessity of further grinding. Gates of special ferrous alloys of exceptional hardness or heat-resistance properties are also removed by the cut-off wheel. Rubber-bonded wheels are employed in this process. Horizontal and vertical disk grinders are employed in some classes of work where large, flat surfaces are to be ground to exact dimensions and good finish. Swing-frame grinders are used to remove large quantities of metal from castings. The grinder illustrated in Fig. 9 is suspended by a cable at its center of gravity. This permits the operator to swing the grinding wheel in any horizontal direction. The two handles extending from the frame make it convenient for the operator to apply the full weight of his body to the wheel.

Grinders should be provided with work rests, guards, and hoods. Work rests should be firmly fastened and adjusted not over ⅛ in. from the wheel to prevent castings from being wedged between the wheel and rest. Guards should be adequate to protect the operator if the wheel breaks. All grinding dust should be removed with properly designed hoods and exhaust systems. Proper care and maintenance of wheels and grinders are important to avoid accidents.

Inspection. From the time a casting is designed until it is finished, assembled, and functioning, it passes through many hands and is inspected a great number of times in many ways. The inspection of tools, equipment, materials, and methods of producing the product is referred to as *process* inspection. The amount of inspection depends largely on engineering specifications and on production methods, designed to meet production schedules. In a highly mechanized process, a slight deviation in procedure may result in the loss of many castings. Greater accuracy, better quality, and larger quantities require more rigid inspection.

Pattern Inspection. When the patterns, core boxes, and other accessories are completed, they are carefully checked by another pattern maker or inspector who had no part in the making of the product. Sample cores are then made, and, if any difficulties arise in the core-making process because of core-box construction, the boxes are returned and corrected. Each core is carefully inspected for stability and dimensional accuracy. If it is to be a core assembly, the individual cores are pasted together and checked again. A sample casting is then made and inspected, first for defects, and then for specifications.

Layout Inspection. A competent layout man must be experienced in machinery processes, pattern design, foundry processes, and the interpretation of blueprints. For example, in checking the amount of additional stock required for finishing, the layout inspector should know the operational routing of a casting through the machine shop and have the ability to correlate that knowledge with allowances provided on the casting. He must be acquainted with the various machinery processes and know how much stock is necessary to produce the type of finish the specifications demand.

The layout inspector performs his work on a layout table with a smooth metal surface which may serve as a basis of reference for measuring dimensions. Some of the tools at his disposal are angle plates, straightedges, master squares, bevel protractors, surface gages, various types of calibers, and scribes. Cored holes in the castings are plugged so that the center of the holes may be located. The casting is then painted with bluing to make scribe marks visible. Small castings of irregular shape are clamped to angle plates so that measurements may be made from the top of the layout table. Relationships are obtained from locating centers established on the blueprint, to finished surfaces, and lines are scribed on the rough casting to indicate the amount of stock available for finishing. When all the dimensions are checked on a casting in a given position, the casting is turned over to expose remaining surfaces for checking. Gaging and checking of the casting in the new position are made with reference to the markings of the original position.

Castings with intricate internal designs are sectioned on a metal-cutting band saw after the external contours are checked. All results are noted on the blueprint and sent to the pattern maker if alterations are necessary. If the design is complex, castings may not shrink so much as originally anticipated, or defects may be discovered that may be eliminated by a change in the molding process. This may necessitate anything from a slight pattern alteration to a complete change in pattern equipment. If the difficulty is principally in the design of the casting, the designer may be consulted to consider possibilities of altering the design for more economical production.

Process Inspection. Before the casting is put into production, it is often necessary to design gages and fixtures for checking cores, molds, and the product at various stages of the production process. As production proceeds, methodical inspection is made of the pattern equipment, molding equipment, and the gages and templets used in the inspection process. The properties of molding sand are continually tested to locate the cause of defects and to eliminate them. Cores are tested for strength, collapsibility, and evolution of gas. The metallurgist is constantly testing, analyzing, and making adjustments in his mixture to improve the quality of his product. The watchful eye of the melter, aided by various instruments, is continually alert for symptoms that may affect the quality of the metal. All this inspection is integrated for one purpose, the efficient production of high-quality castings.

Casting Inspection. The methods employed in the inspection of castings prior to their shipment to the customer depend largely on the specifications established by the customer. The customer is aware that, the more rigid the specifications, the higher the cost; therefore, he is not likely to stipulate unnecessary requirements. Casting inspection varies all the way from observation of external appearances to complete radiographic study of the entire casting.

Whether the inspector is hired by the customer or by the foundry, he is in reality the customer's representative, for it is his responsibility to reject all castings that are not satisfactory to the customer. He should be acquainted not only with the blueprints and specifications but also with the customer's needs and problems connected with the processing and use of the casting. He must know the nature and cause of defects and know where certain defects are likely to occur according to the peculiarity of design or production methods. He must know how to correlate all the facts at his disposal and make clear, logical decisions. He must have a cooperative attitude from both the customer and the producer. If the customer is willing to accept certain imperfections that do not affect appearance or function, and if the producer cooperates to eliminate critical imperfections, the work of the inspector proves a valuable asset to both parties.

Casting inspection is classified as destructive and nondestructive. In the destructive method, a sample casting is sectioned on a metal-cutting saw and examined for internal defects and dimensional accuracy in a similar manner to that described for layout inspection. Success by this method depends largely on the ability of the inspector to anticipate the most likely location for a defect. Although the location of defects may often be anticipated, this method is by no means a positive one. The selected casting may not be a representative average casting, and many defective castings may be accepted as good ones before a trend of defects is discovered.

Nondestructive inspection methods include the following:

1. Visual examination.
2. Sound and percussion.
3. Impact.
✓4. Supersonic.
5. Pressure.
✓6. Penetrants.
✓7. Electrical conduction.
✓8. Magnetic particle.
✓9. X-ray.
✓10. Gamma ray.

Visual Examination. All castings are initially inspected for visible defects, and, if defective, they are discarded as early in the cleaning process as possible. In some cases, the defect is apparent when the casting is shaken out of the mold, but if the defect is small it may not be discovered until after cleaning.

Castings are also inspected for cleanliness. This may be important, especially in castings with compartments and passages that are to contain lubricants. To avoid excessive machining cost, castings are inspected for burned-on sand and hardness. Among the various hardness tests, a simple test made with a file may be adequate. The inspector becomes quite expert in determining machinability by a single stroke of the file. Castings are also inspected for improperly chipped fins, chaplets, and pads. These may result in considerable damage if they are overlooked. A fin left in a cylinder block may cause complete destruction of the engine.

Often a large gas hole or a volumetric shrink may show up on the surface as a small hole, appearing as a harmless little cavity. Such cavities are often probed with a tag (shipping-tag wire) to determine their depth and size. Subsurface defects may be disclosed by tapping the casting with a pointed hammer. If a thin skin covers the defect, the pointed hammer may break through, or if the skin is too thick to fracture, the sound of the impact may indicate a discontinuity in the casting. Castings that tend to be warped are often checked with a straightedge. All these and many other simple tests may be devised to inspect castings.

Sound or Percussion and Impact Tests. A simple but not too reliable test for cracks in castings is the percussion test. The casting is suspended by a hook and tapped with a hammer. A defect may often be detected by comparing the pitch or quality of the tone of the casting being tested with the pitch of a nondefective casting. This method is fairly satisfactory for large discontinuities, but it is not totally reliable because a crack in a certain direction may not effect a change in the wavelength. Various conditions, such as complexity in design and organization of crystalline structure, may dampen the tone and make it difficult to apply this method. A defect may be suspected, but with this method it is often difficult to determine its extent and to judge its harmful effect on the function of the casting. Its reliability in determining all harmful defects is doubtful even with the use of a stethoscope, especially on castings of high damping quality.

The impact test should also be used with caution. In this test a proper-sized hammer is employed to strike certain members of the castings where defects are suspected, and, if the casting is defective, it is expected to break. A drop test is sometimes devised in which the casting is dropped to a metal base from a determined height. A better method is to drop a weight on the casting. Tests such as these, if not properly controlled, may often result in destruction of sound castings.

Supersonic Testing. Supersonic testing is a relatively new development. Its application to the inspection of forgings and rolled stock has been quite successful, but its application to castings with rough surfaces and intricate design is still limited. However, the prospects for its future development are encouraging.

The principle of supersonic testing is based on the length of time it takes a high-frequency sound wave to travel from its source through the section of a casting and back to its source. If a discontinuity exists in the metal section, the wave is reflected from the surface of the defect and returns in a shorter period of time. The wave, which is above the audible range, is plotted and measured on an oscillograph. By this method, the defect is not only detected and located but even approximated in size.

Pressure Tests. Water, air, or steam is employed in testing for leaks in castings such as fittings, valves, and boilers. Although the test readily detects and locates any existing leaks, it does not assure that a leak will not occur later when the casting is put in service. Filamentary cracks may not extend through the section, but when the casting is put into service the crack may grow; or, if the dense outer structure is machined off after the test, the casting may not be pressure tight.

Hydraulic testing is often preferred because water is incompressible and little danger is involved if the casting shatters. A pressure of one and one-half times the service pressure is usually applied. Water pressure is preferably built up with a small hand pump for the safety of the inspector. Because of the incompressibility of water, a leak may readily be detected on the pressure gage, even if not immediately located. Leaks are sometimes classed as weepers, seepers, leakers, and squirters, depending on the degree of leakage.

Steam passes through smaller openings, and, in that respect, steam tests have a slight advantage over the water test. The principal advantage of steam, however, is the effect of heat which causes the filamentary cracks to grow as a result of expansion. To avoid accidents, castings are sometimes tested first hydrostatically and then with steam, the pressure of the hydrostatic test being higher than that of the steam test.

Testing with air does not eliminate the possibility of shattering, but it does eliminate the danger of scalding. Small castings produced in large quantities are frequently tested in a specially designed fixture in which the castings are easily clamped. If air is used, the fixture is designed to be submerged in a tank of water after the casting is attached and the pressure is applied.

Leaks are readily detected by the formation of air bubbles. Because of the difficulty of locating leaks in larger castings by submerging them in water, a soap solution, applied with a brush, is an effective alternate.

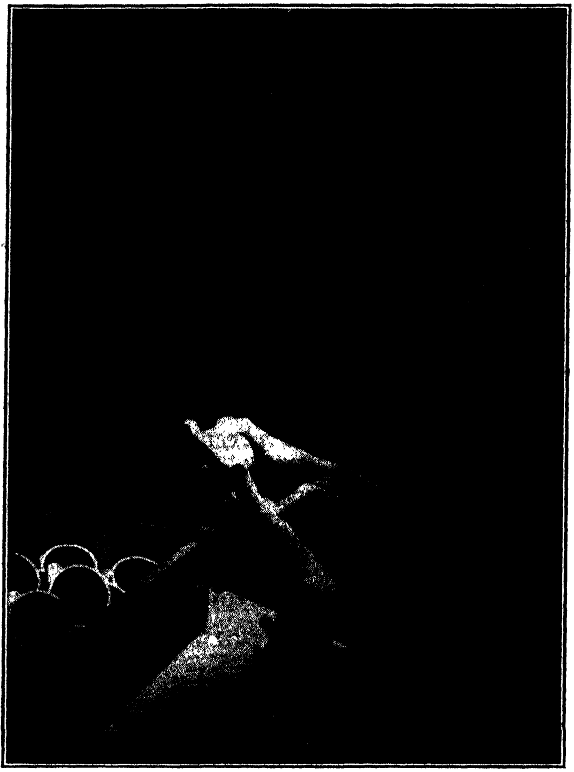


FIG. 10. The castings that pass visual and dimensional inspection are subjected to Zyglo inspection. This is a penetrative oil test which, under black light, reveals cracks or other surface imperfections by a fluorescent effect. (Courtesy of Haynes Stellite Co., Kokomo, Ind.)

Penetrants. Penetrants are sometimes employed to detect cracks that are too fine to be seen with the naked eye. A thin penetrating oil is applied to the surface of the casting and allowed to stand until the oil passes into the crack by capillary action. The oil is then removed from the surface, and the casting is set aside for observation. If a crack exists, the oil seeps back out of the opening and discloses the defect. To aid detection of defects, the casting is frequently painted with whitewash or powdered with talc. As the penetrant seeps out, the coating, which absorbs the oil, becomes discolored and forms a distinct pattern of the defect. Talc is often preferred to whitewash because it is easier to remove after the test. Commercial penetrating oils may contain ingredients that become highly fluorescent when viewed under an ultraviolet light after the dusting powder is applied. Figure 10 illustrates inspection of castings viewed under an ultraviolet light.

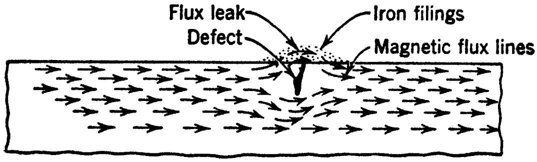


FIG. 11. Magnetic particle inspection. Lines of force are straight, as a result of indirect method.

Electrical Conduction. A simple test of passing a current through a casting and observing the current on an ammeter may serve to detect imperfections in castings. This method is limited to the inspection of castings produced in quantities large enough to justify the development of standards for control. Variations in dimensions and in metallurgical structure may cause changes in electrical conduction and reduce the reliability of this test.

Magnetic Particle Inspection. When iron filings are sprinkled in the path of a magnetic field, the magnetic particles align themselves in the direction of the lines of force and distribute themselves in proportion to the strength of the field. If no defects exist in a casting, the particles will be distributed uniformly along the surface; but, if a defect does exist, the particles will concentrate over the defective area and tend to outline the irregularity.

Because of the fact that a discontinuity in the casting is less permeable to magnetism, the flux lines tend to by-pass the discontinuity and produce a distorted field. This results in a high concentration of flux lines around the extremities of the defect as illustrated in Fig. 11. If the obstruction lies on or near the surface, some of the flux lines will be crowded to the surface of the casting to produce a leakage field in that area. Iron particles sprinkled over the surface will concentrate in that area of high flux and bridge the gap which obstructs the flow of flux. The nearer the defect is to the surface of the casting, the stronger and more highly localized will be the leakage field. A sharp, deep crack at right angles to the surface produces a stronger leakage field than one that is parallel to the flux lines. Magnetic particle inspection may be employed only on iron or steel and their alloys which show magnetic properties. Magnetic [illegible]

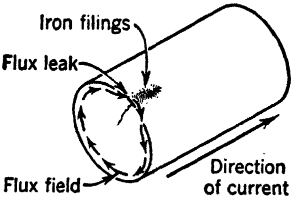


FIG. 12. Magnetic particle inspection. Circular flux lines are a result of direct method.

Castings may be magnetized by the indirect or direct method, the latter being the most satisfactory. In the indirect method, the casting may be magnetized by being placed between two magnetic poles. Another indirect method is to place the casting in a coil supplied by direct current, or to wrap a flexible cable around it. Magnetism is induced in the casting in the same way as the iron core of an electromagnet.

A more effective method of magnetizing a casting is by the direct method in which an electric current is passed through the casting. By this so-called *all-over direct method,* the direction of the field may be controlled by properly locating the contacts on the casting so that the current will flow in the desired direction. The flux lines follow a circular path in a plane that is normal to the line of flow of current, similar to the flux field set up around a wire in the transmission of current. This is referred to as *circular magnetism* and is illustrated in Fig. 12. However, because of irregularities in design, straight-line flow seldom exists, and magnetic fields are correspondingly distorted.

A popular testing method is the *prod method* in which two prods or contactors are applied to any part of the casting for the purpose of inspecting a part of the casting. The general procedure is to place the contactors from 6 to 8 in. apart. While the current is being applied, the iron filings are dusted over the surface of the casting between the prods, the excess being removed by blowing obliquely over the surface with lung power or preferably with an air blast regulated to a pressure of about 2 psi. Maximum sensitivity is obtained by the so-called continuous method in which the iron particles are applied simultaneously with the flow of current through the casting.

Alternating current is used when high surface sensitivity is desired, but for depths below the skin of the casting some form of direct current is preferred. Magnetizing equipment with both direct and alternating current is employed to get some indication of the depth of the defect. If an indication is registered with direct current but not with alternating current, the defect is beyond the effective depth of alternating current. (Direct current may be applied with an initial surge of high current to improve the mobility of the iron particles and then quickly dropped down to a lower steady value.) Full-wave and half-wave single-phase rectified alternating current produces a pulsating direct current which is even more effective in orienting the iron particles.

Iron powder may be applied dry or wet. When dry, it may be applied with a hand shaker on horizontal surfaces, or with a bulb blower on vertical sections. When wet, it may be sprayed on or poured over the surface. The powder may be suspended in such liquids as kerosene, gasoline, or carbon tetrachloride. Because kerosene and gasoline present fire hazards and carbon tetrachloride is toxic, a good exhaust system is necessary. The powder is often colored red with iron oxide in order to have good contrast between the casting and the inspection medium. The particles may be coated with some material which fluoresces when observed under ultraviolet light.

If the casting has low magnetic retentivity or if it is to be heat treated to a temperature at which iron looses its magnetism, demagnetization is not necessary. Demagnetization may be performed by passing the casting through a large alternating-current solenoid and slowly withdrawing it.

Considerable experience is necessary in the interpretation of results. A minor surface imperfection may have the appearance of a serious defect.

Radiographic Inspection. Materials through which light will pass without being completely absorbed are said to be transparent, the degree of transparency being commonly conceived as the ability of the human eye to detect objects through the material. The degree of transparency actually depends on the amount of light which will pass through, unabsorbed and without distortion. There are other electromagnetic waves with properties similar to those of light waves, whose wavelengths lie outside the range of human sensitivity but may be detected by photographic film. Electromagnetic radiation, with wavelengths shorter than those of light, will penetrate materials that are opaque to light. The shorter the wavelength, the greater the penetrating power. Metals of greater density have a higher absorption rate and therefore are less transparent. Steel, for instance, requires a shorter wave for radiographic inspection than aluminum or magnesium. Just as a thick glass is less transparent to light than a thin glass, metal sections of increasing thickness are more difficult to penetrate. Figure 13 classifies various electromagnetic radiations with respect to their wavelengths. Radiographic inspection is performed either with the use of an x-ray or gamma ray.

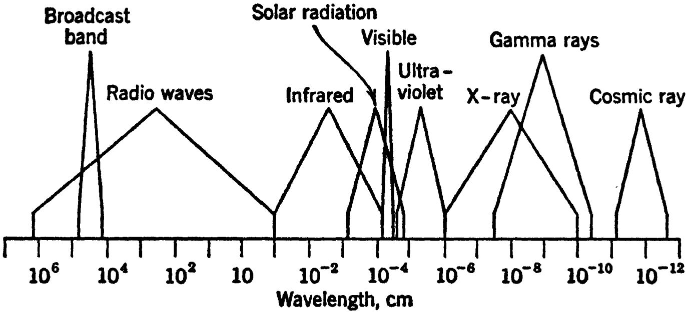


FIG. 13. Electromagnetic radiation diagram. (Courtesy of American Foundrymen's Society, Chicago, Ill.)

X-Ray. The x-ray tube consists of two copper elements, the cathode and anode, which are sealed in a vacuum tube, as illustrated in Fig. 14. Electrons generated by an electrically heated filament in the cathode cup are driven across to the positively charged anode by a high-voltage direct current impressed across the poles. As the negatively charged electrons strike the tungsten target, their motion is stopped and most of the kinetic energy is reduced to heat which is conducted away through cooling fins. The remainder of the energy is converted to electromagnetic waves, commonly known as x-rays. The waves, passing through the window of the tube, form the useful x-ray beam; the remainder of the scattered waves are absorbed by the anode and cathode or by the lead covering that surrounds the tube.

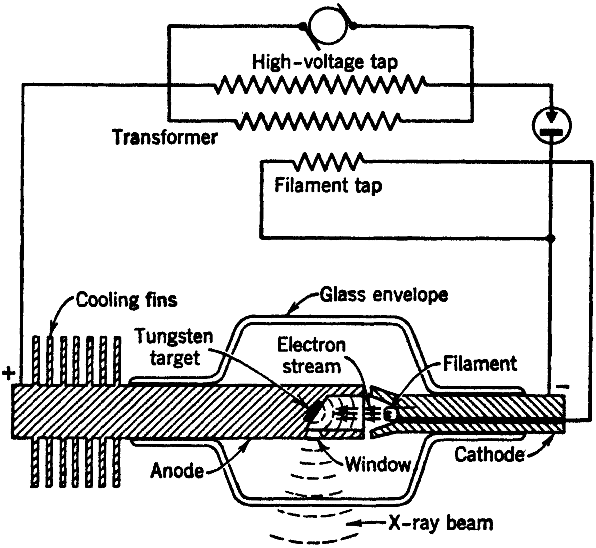


Fig. 14. Diagram of a simple x-ray tube. (Courtesy of American Foundrymen's Society, Chicago, Ill.)

The intensity of the ray is directly proportional to the quantity of current passing through the filament. Increase in filament current produces more electrons and therefore greater concentrations of x-rays. The wavelength of the ray is inversely proportional to the voltage impressed across the two poles. Thus, higher voltages produce shorter wavelengths of greater penetrating power.

The chemicals on a photographic plate are affected in a manner similar to that in which light affects ordinary photographic film. Because a cavity produces less obstruction to ray penetration, more rays pass through the casting at the location of the cavity. Not all the rays are absorbed by the film, but the number of rays absorbed is proportional to the number that strike it. It therefore follows that the part of the plate opposite the defect is exposed more than the rest of the plate and will produce a contrasting image on the negative. Special films with an emulsion coating on both sides are used to increase ray absorption in order that more reliable results may be obtained with reduced exposure time.

A fluoroscopic screen sometimes replaces the film in the inspection of light metals. The screen is made of zinc sulphate and suitable activators which fluoresce brilliantly in a dark room when exposed to the action of x-rays. Commercial fluoroscopes may be of the stationary or conveyor type, the latter producing images of moving castings. In either type, the image on the screen is reflected by a mirror through a lead-glass window. By means of the periscope principle applied to the mirror, the observer may be located out of the path of the x-ray beam. The lead-glass window protects the observer from scattered rays. The intensity of glow on the screen is proportional to the intensity of the rays striking the screen.

Low-voltage x-rays have longer wavelengths but are more sensitive in the detection of small defects, providing the casting thickness is within the limits of the penetrating power of the rays. Because few castings are uniform in cross-sectional thickness and defects occur more often at intersections, it is usually necessary to resort to higher voltages in order to prevent overexposures of the thin sections and underexposures of the thick sections. When a machine of higher voltage is not available, the thin section may be covered with a layer of lead of desired thickness to slow down the rays and produce a uniform exposure.

The voltage of x-ray machines for the inspection of aluminum and magnesium castings varies from 3000 to 150,000 volts, depending on the size of the castings to be x-rayed. A 150,000-volt machine is not satisfactory for steel sections more than 1 in. thick. Machines of 60,000- to 250,000-volt capacity are commonly used on light steel sections up to 2 in. thick. One-million-volt machines are used on steel castings up to 5 in. thick, and 2,000,000 volts on 8-in. sections.

Among recent developments is a 20,000,000-electron-volt Betatron whose x-ray will penetrate 20 in. of steel in 20 min. A 10,000,000-volt Betatron, now in production, will take pictures of 1-in.-thick steel in 1 sec. Its rays will penetrate 12 in. of steel in 1 min. Higher voltages and greater penetrations are in the offing.

FIG. 15. Radiographic inspection of castings with use of radium. (Courtesy of Haynes Stellite Co., Kokomo, Ind.)

Gamma Rays. Radiography with radium depends on the emission of gamma rays, which are a product of the decomposition of radium. The wavelength of the gamma ray is equivalent to that of a 1,500,000-volt x-ray machine. Little difficulty is experienced in radiographing thick and thin sections in the same exposure because of the high penetrating power of the wave. With radium, it is quite possible to radiograph sections varying from 1 to 4 in. in thickness. Because of the short wavelength and high penetrating power, only a small portion of gamma radiation is absorbed by the film emulsion; the remainder passes through the film, leaving no impression whatsoever. The amount of radiation is directly proportional to the quantity of radium in use. In industrial radiography the radium supply varies from 100 to 500 mg.

Radium in the form of radium sulphate is contained in a small, hermetically sealed silver capsule, which in turn is kept in a steel or aluminum conical-shaped cartridge case. In transportation, the container is placed in a lead-lined carrying case for the protection of personnel. In operation, the cartridge is suspended by a string at the end of a pole and manipulated into position from a safe distance. If a number of castings are to be radiographed, they are placed on the floor in a circle, and the radium cartridge case is suspended in the center of the circle. When the interior of a casting is too small to contain a film, the film may be placed on the outside of the casting and the radium suspended in the hole.

Figure 15 illustrates a variety of castings being inspected with radium.

PROBLEMS

1. How are gates removed from castings?
2. How are large castings cleaned?
3. Explain the operation of a tumbler, blast gun, and airless abrasive blasting machine.
4. List the characteristics of silicon carbide and aluminum oxide abrasives used in grinding wheels.
5. List the various types of grinders, and state the type of casting (according to size, finish, or shape) which might be ground on each machine.
6. What precautions should be taken for safety in operation of grinders?
7. What is meant by the following terms? (*a*) Process inspection. (*b*) Layout inspection.
8. Describe the various visual inspection methods.
9. Why are sound and percussion tests unreliable?
10. Why is steam more reliable than water in pressure tests? Why is water used more often than steam?
11. What type of current is preferred in the detection of surface checks by the magnetic particle inspection method?
12. What is the effect of higher voltages in x-ray inspection?
13. How are gamma rays produced?
14. Why is supersonic testing more reliable on forgings than on castings?
15. Describe inspection with penetrants.
16. How does the magnetic field differ in the all-over direct method from that of the indirect method?

13

Design for Economical Molding

Design Responsibility. In designing a casting, the responsibility of the engineer goes beyond proper function and service. Economy of production is usually a very important factor, and consideration of molding procedures should be constantly incorporated in the development of the design. Variations in foundry procedures and in the form and construction of patterns and core boxes should be thoroughly investigated to insure the most economical plan for producing castings of specified quality. Furthermore, operations other than those of the pattern shop and foundry must be considered, and the design of the casting and pattern equipment should be such that the cost of all other operations is reduced to the minimum. Such operations may include finishing, or the elimination of finishing where possible, in whole or in part; assembly of this part to other parts; and economical servicing during the useful life of the casting. When a casting is to be produced in large numbers, the final plan of production is determined only after many changes and alterations have been made. During such developments much apparatus is rendered obsolete, with consequent monetary loss, but the production of greater quantities of castings assures an overall gain.

Irregular Parting Changed to Straight Parting. The engineer should strive to design castings with parting planes that are straight or as nearly straight as possible. Figure 1*A* shows a casting to be molded on an irregular parting. With proper consideration for production cost, it might be redesigned as illustrated in Fig. 1*B* and molded on a straight parting. The portions of the hubs projecting above the parting plane at the center of the casting and the end of one arm are loose pattern parts and are assembled to the main pattern with dowel pins.

When an irregular parting results in a deep mold pocket, it may be more economical to redesign the pattern equipment and change to a molding method with a straight parting involving the use of cores. Figure 2*A* illustrates a casting to be molded with a deep sand pocket. To prevent a drop-out when the cope is drawn, gaggers may be needed to reinforce the sand projection of the deep pocket. Considerable difficulty may be encountered by the molder in rolling over the mold if a follow board is em-

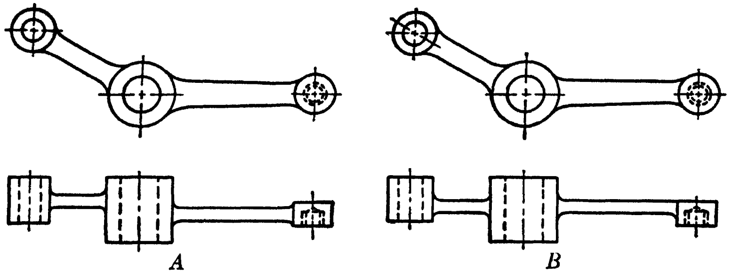
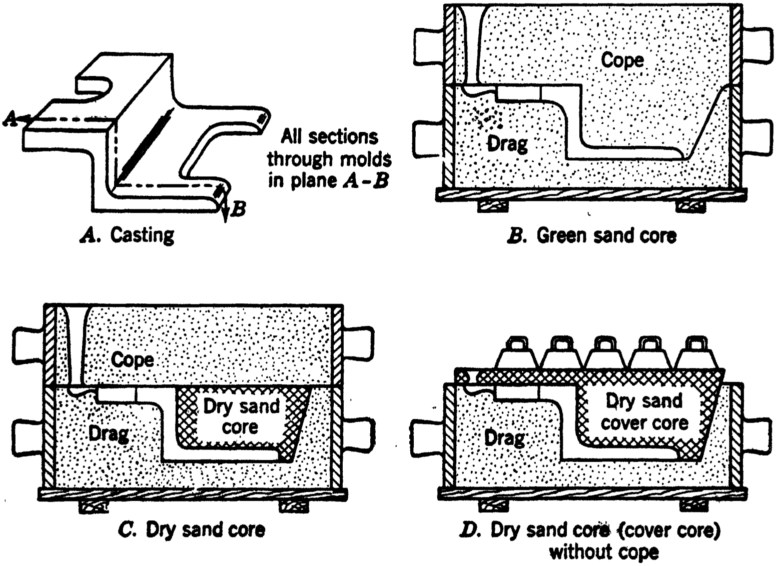


FIG. 1. *A*. Casting designed with an irregular parting. *B*. Casting redesigned with a straight parting.



***A*. Casting**

***B*. Green sand core**

***C*. Dry sand core**

***D*. Dry sand core (cover core) without cope**

FIG. 2. Various methods by which a casting may be produced.

ployed. By this method a jobbing molder is able to make relatively few molds per day, and losses due to defects may be quite large. Figure 2*C* shows how a core may be designed to replace the green sand projection. A core print on the new pattern eliminates the deep pocket and changes the parting to a straight line. The simple parting makes it possible to attach the pattern to a drag molding board which may be installed on a roll-over machine, the net result being many more molds per day with little loss in defective castings. The advantage gained in the new molding process justifies the additional cost of making and baking cores. To avoid the use of two machines (one for copes and the other for drags), the dry sand core may be designed as a cover core, as shown in Fig. 2*D*, and no cope is necessary.

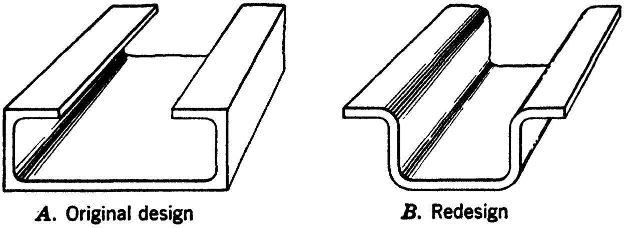

A. Original design *B*. Redesign

FIG. 3. Redesign to eliminate a dry sand core.

Redesign to Eliminate Cores. Frequently, a slight change in casting design may improve the cost of production by eliminating cores. Figure 3 shows an original design *A* which required a core to form the interior of a casting. With redesign of the casting, as *B*, a green sand core was substituted for the dry sand core. Such a change in design may alter the parting from straight to irregular, and the cope may contain either a cavity or a hanging sand pocket. If the casting is relatively small and the pocket is not too deep, no gaggers are necessary to support the sand.

In Fig. 4*A*, cores were required to form the pocket made by the two flanges, parallel and opposite each other. The redesigned casting not only eliminated the core but made the bolt holes more accessible.

Redesign to Avoid Loose Pattern Parts. Bosses are frequently used to increase the sectional thickness of housings in order to provide longer bolt or tap holes or to improve the strength of certain parts of the casting. This may be done satisfactorily if the axis of the cylindrical boss is parallel to the direction in which the pattern is drawn out of the mold. When this condition does not exist, the boss on the pattern must be loose, and the skilled technique of molding loose pattern parts must be employed. The four bosses marked *a* in Fig. 5*A* are in a satis-

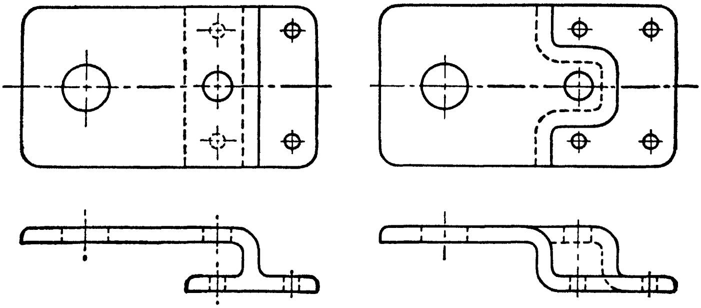
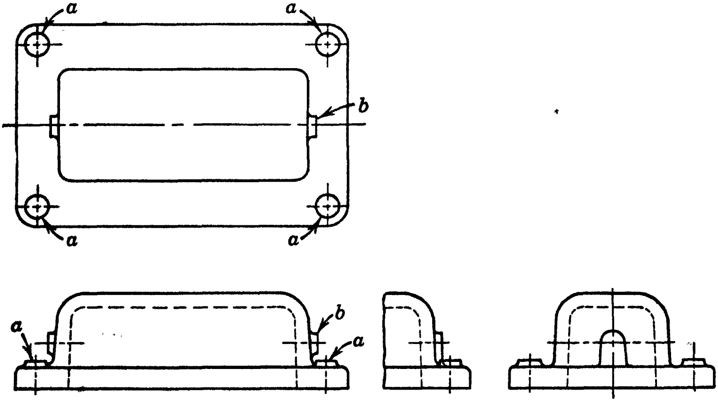

A. Original design *B*. Redesign

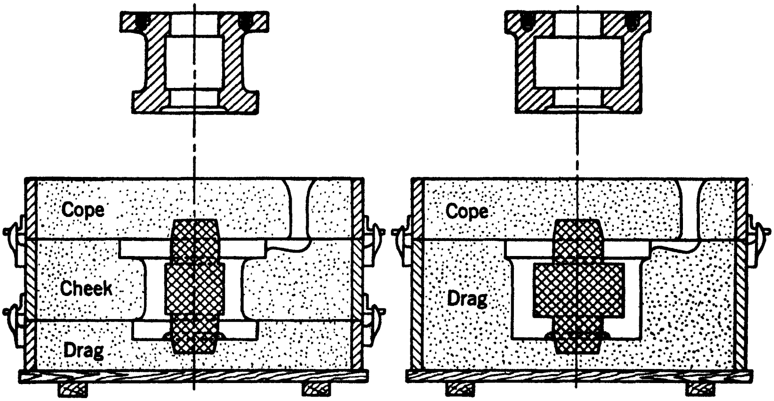
FIG. 4. Redesign to eliminate a dry sand core.



A. Original design *B*. Redesign

FIG. 5. Design to avoid use of loose pattern parts.

factory molding position, but bosses marked *b* must be molded as loose pattern parts and drawn out through the mold cavity after the main pattern is removed. Because of the small amount of space in the mold cavity, considerable difficulty would be encountered in removing the loose pattern parts, and the cost of the casting would be high. If a pad were used instead of a boss, as in Fig. 5*B* the loose pattern parts would be eliminated.



***A*. Original design** ***B*. Redesign**

FIG. 6. Redesign to change mold production from a three-part to a two-part mold.

Redesign of Casting to Avoid a Three-Part Mold. The smaller the number of partings in the mold, the less work required to make the mold. Not only is the pattern equipment less complicated in a two-part mold, but it can be adapted more readily to machine molding. Figure 6*A* shows a sectional view of a hub made in a three-part mold. If the diameter of the hub is increased to the diameter of the smaller flange, as shown in Fig. 6*B*, a three-part mold is no longer necessary. Only the designer has the right to make such changes because he is the only one who knows how the change would affect the function of the casting. Consequently, it is his responsibility as an efficient engineer to consider the molding process carefully.

Core Used to Avoid a Three-Part Mold. If at all possible, proper design is the best way to avoid a three-part mold. When this cannot be accomplished, the next choice of simplifying the process is by means of cores which incorporate the parts of the design that obstruct pattern draw. A core may be made in several parts and assembled by pasting the parts together, or the parts may be set in the mold individually. Figure 7 shows a hub as originally designed, and molded with a dry sand core in a two-part mold.

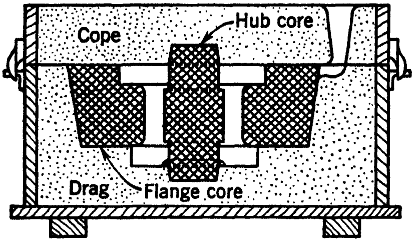


FIG. 7. Changing mold production from a three-part mold to a two-part mold with use of cores.

Selection of Production Method. In the production of the lamp base casting illustrated in Fig. 8, at a rate of 1000 per month, four patterns were mounted on a match plate and molded in a tapered flask, as illustrated in Fig. 9. To insure a smooth surface free of defects, the face of the casting was molded down in the drag and a cover core was used to form its interior.

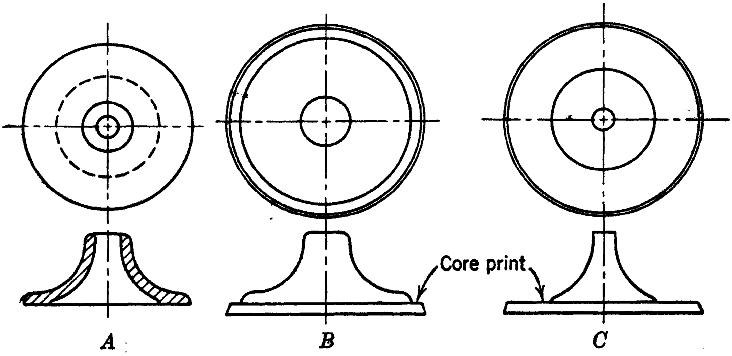
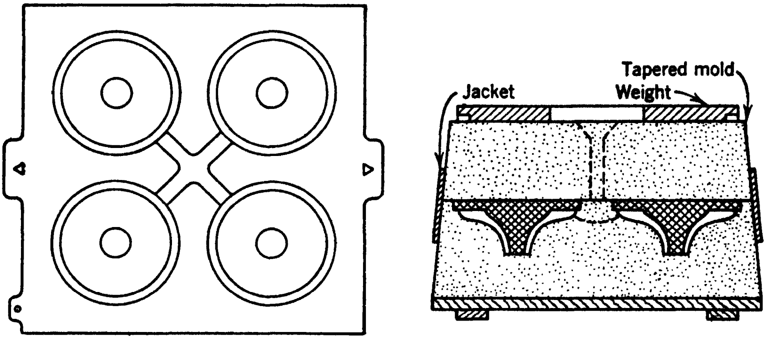


FIG. 8. Pattern and core for the production of a lamp base casting. *A*. Lamp base. *B*. Lamp base pattern. *C*. Lamp base core.

Although this was a satisfactory casting procedure, it was decided to investigate other methods, with the possibility of reducing the cost of production. In his study to improve the production method, the production engineer considered the following possibilities:



A. Four lamp base patterns mounted on a match plate

B. Completed mold of four lamp base cavities

FIG. 9. Production of lamp base castings by conventional method.

1. Dry sand mold without a cope, with a dry sand core, Fig. 10.
2. Green sand mold without a cope, with a dry sand core, Fig. 11.

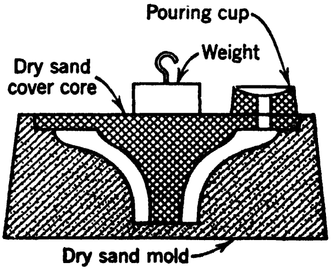


FIG. 10. Lamp base in a dry sand mold.

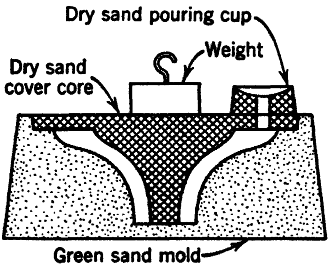


FIG. 11. Lamp base in a green sand mold.

3. Permanent mold with a dry sand core, Fig. 12.
4. Die casting.

Die casting was immediately eliminated because the initial cost of the die and equipment was too high for the relatively small number of required castings. However, a permanent mold with a dry sand core deserved careful consideration. No ejector would be necessary, as with a metal core in die casting. Not only would a permanent mold eliminate the labor of making molds, but the castings would be smoother because of a fine grain structure resulting from a chilled surface. The cost of the mold would not be excessive because of the simplicity of the design. It was not difficult to see that the permanent mold was a better choice than the dry sand mold, not only because it reduced the labor cost of core making but also because it required less expense for core ingredients and heat energy in baking.

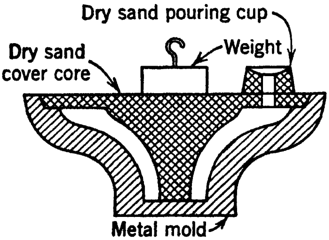


Fig. 12. Permanent mold with a dry sand core.

With a bit of experimentation, it was found that a green sand mold, as illustrated in Fig. 11, could be successfully poured without any supporting jacket. When the permanent mold was compared with the green sand mold, the latter method seemed less advantageous because a new mold had to be made for each casting. However, this might be an advantage, in that any number of green sand molds may be made up and poured at convenience.

Considering the advantage of producing four castings by the original match plate method of Fig. 9, and the advantage of the cover core in a green sand mold of Fig. 11, it was believed that the two methods could be successfully coordinated to gain the advantages of both. The original match plate was mounted on a small jolt roll-over pattern-draw molding machine, and only the drag of a tapered flask was used. Cover cores were placed in the mold cavities, and weights were placed on each of the four cores. The gate was improved slightly to avoid sand erosion. On the basis of previous experience with the method of Fig. 11, no jackets were employed. The molten metal was poured directly into the gate. Efficiency was further improved with the use of a shallow flask (Fig. 13) to reduce the amount of sand per mold. Thus, the monthly requirement was produced with a total of 250 drags.

Effect of Quantity on Production Cost. After determining the various engineering requirements desired in a casting, the engineer must then consider the type of material to be used and the method to be employed in the production of the part. The number of castings of a given design is an important factor in determining the material and method. To illustrate this, the simple design of Fig. 14 was selected and quotations were asked from various reliable concerns for the production of the casting in quantities from 100 to 25,000. It is apparent from the graph in Fig. 15 that methods employing dies and other expensive production equipment are excessively high for smaller quantities, but in larger quantities they become increasingly competitive. Die casting, for example, is among the most costly of production methods for quantities of 2500, but for quantities of 25,000 it is in close competition with stamped steel, and for larger quanti-

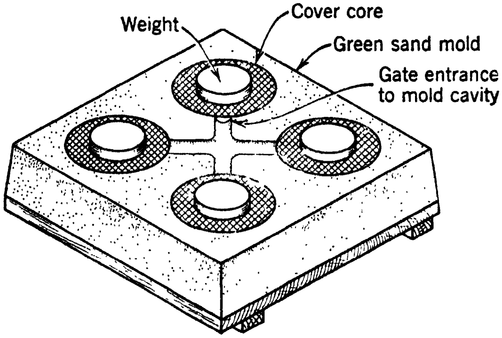


FIG. 13. Production of casting without use of cope or jacket.

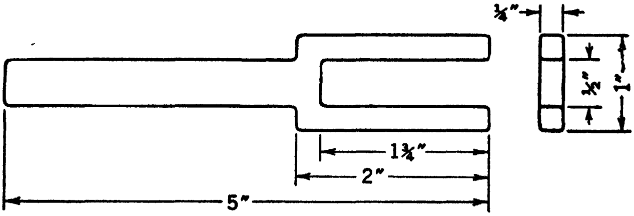


FIG. 14. Flat forked shape, number 1.

ties it is quite possible that it would be least expensive. Frequently a die casting may cost more than an unfinished sand casting, but, because of the close tolerances obtained in die casting, the finished sand cast product may be more expensive.

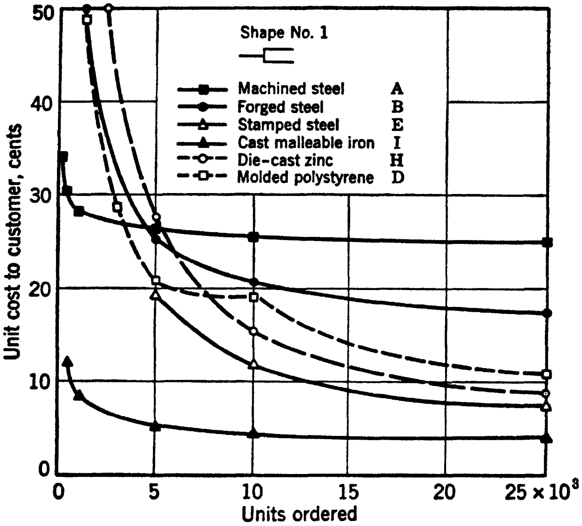


FIG. 15. Comparison of unit costs of shape made by using several materials-method combinations. Costs quoted by companies A, B, E, I, H, and D, respectively, for orders up to 25,000 units. (Courtesy of Walter Bergren, Master's Thesis, Purdue University.)

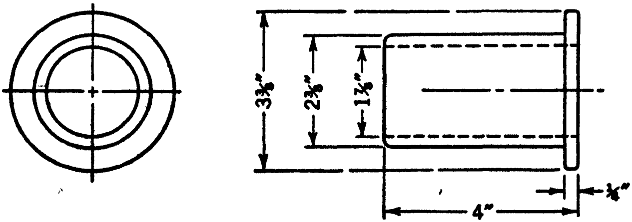


FIG. 16. Flanged cylindrical shape, number 2.

The design of Fig. 16 was investigated in the same manner, and the results are shown graphically in Fig. 17. It should be emphasized that the graph shows unit cost to the customer, based on a customer's order of 10,000 units. Figure 18 shows graphically the cost of the equipment in the production of the shape

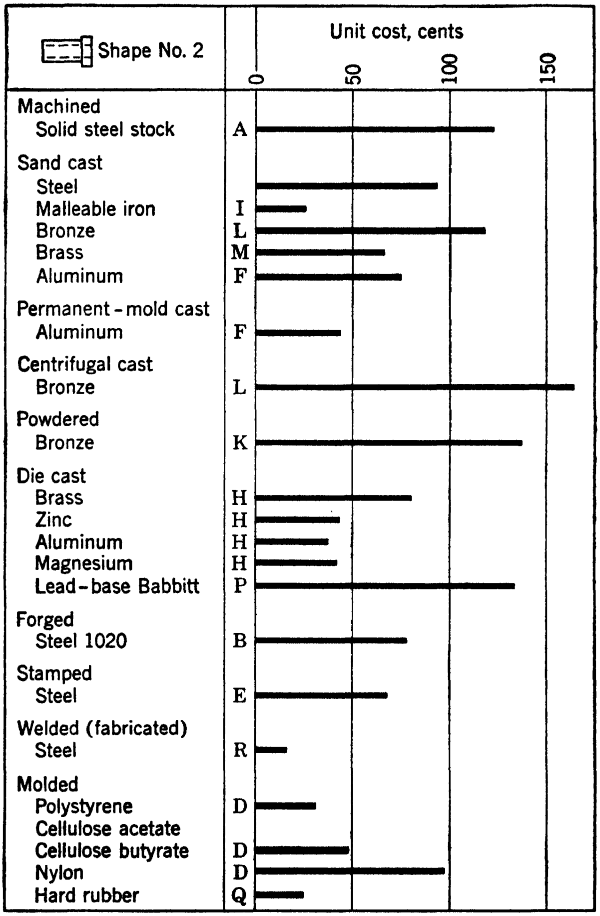


FIG. 17. Comparison of costs of shape manufactured using several materials-method combinations. Costs quoted by companies indicated by respective alphabetic letters listed adjacent to the material. Costs based on customer's order of 10,000 units. (Courtesy of Walter Bergren, Master's Thesis, Purdue University.)

described. It is clear that, owing to the high cost of production equipment, some of the methods are priced entirely too high for the quantity required. It should be kept in mind that other considerations relating to function, endurance, and appearance may eliminate a less-expensive process.

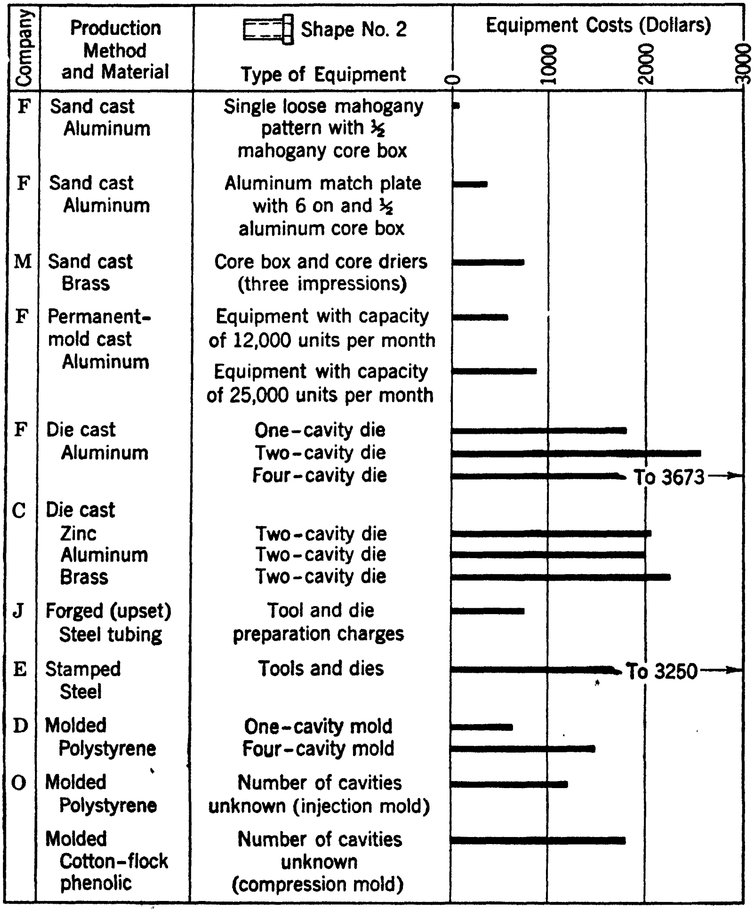


Fig. 18. Comparison of tool and die costs for shape number 2. (Courtesy of Walter Bergren, Master's Thesis, Purdue University.)

Choosing the Parting Plane. Careful consideration should be given to all parting possibilities in order to make best choice for a given design. The principal objectives in the selection are (1) to produce castings as economically as possible and (2) to avoid defects.

As a general rule, it is more desirable to have all or the greater portion of the mold cavity in the drag, because it is easier to draw the pattern from the drag than to lift the cope off the pattern. Hanging sand projections and slender mold sections in the cope are more likely to drop out unless they are properly reinforced with gaggers, nails, and specially designed flask bars. All these problems may often be avoided by proper choice of parting plane. It is usually preferable to choose a parting which avoids a deep drag in order to reduce the weight of the mold and the labor of ramming excess sand. Reduction in weight of the cope is even more important than reduction in weight of the drag because the cope requires more handling. Consideration should also be given to other arrangements of the patterns in the parting plane in order to utilize all the useful space on the parting surface. It is usually preferable to arrange the casting so that its thickest sections appear in the parting plane in order that the casting may be fed most effectively. It is also important to arrange the casting in the position most desirable for pouring to avoid mold erosion and turbulence. For example, if a stream of metal strikes a given sand core or if it strikes a ledge of a mold cavity, erosion is likely to ruin the casting. Metal should not be allowed to drop through too great a height when entering the mold cavity.

In pattern design, the least number of cores and the simplest cores usually result in more economical production. Chaplets should be avoided whenever possible because of the time lost in setting them and the possibility of defects due to the lack of fusion.

Because of the flanges on the casting in Fig. 19*A*, it is apparent that some type of a core is necessary to form part of the external shape. If the parting plane is passed through the axis as illustrated in Fig. 19*B*, the bolting bracket and one half of the rectangular outlet has to be cored. In order for the core to be set in the mold cavity, it must project up to the parting plane. This may be done with a core such as that shown in Fig. 19*C*. The core not only forms a part of the contour of the casting but also serves as a core print to support the center core shown in Fig. 19*D*. If the casting is large, the print for the small opening may not have sufficient bearing surface and the core is likely to be misaligned by sinking down in the mold. A simple core as illustrated in Fig. 19*E* may be designed to serve this purpose as well as to form the boss. Such cores whose purpose is to support other cores are sometimes called *setup cores.* Figure 19*F* shows the pattern containing the core prints for this molding procedure. When the pattern is drawn from the mold, the two setup cores are placed in position and the center core is set in. The drag half of the completed mold is shown in Fig. 19*G*.

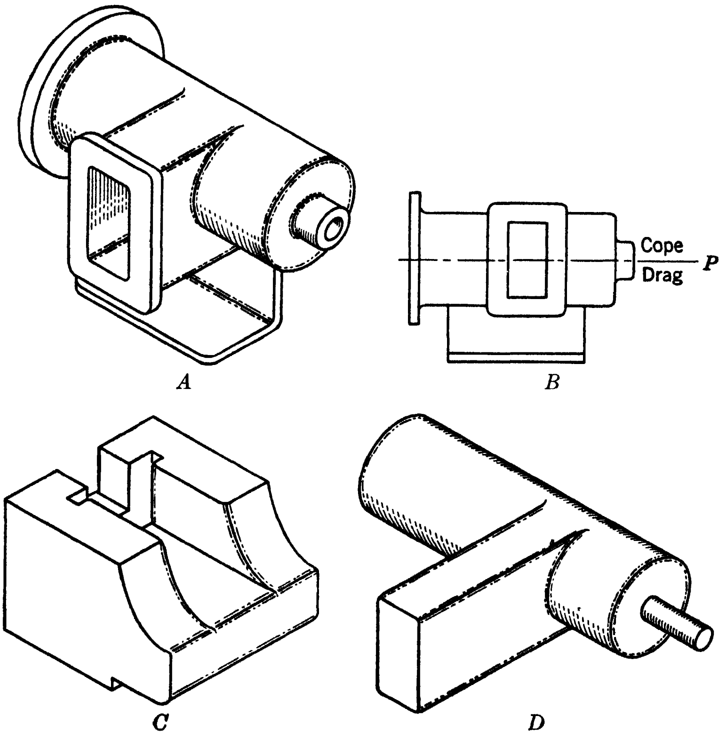


FIG. 19. *A*. Casting. *B*. Parting plane. *C*. Core to form part of casting and to support center core. *D*. Center core.

If the parting plane were chosen as illustrated in Fig. 20*A*, there would be no difficulty in drawing the bolting bracket from the drag, but the entire rectangular outlet would have to be formed with a core such as that illustrated in Fig. 20*B*. Although a setup core might be necessary when molded as in Fig. 19, there is no need for it here because the center core gets vertical sup-

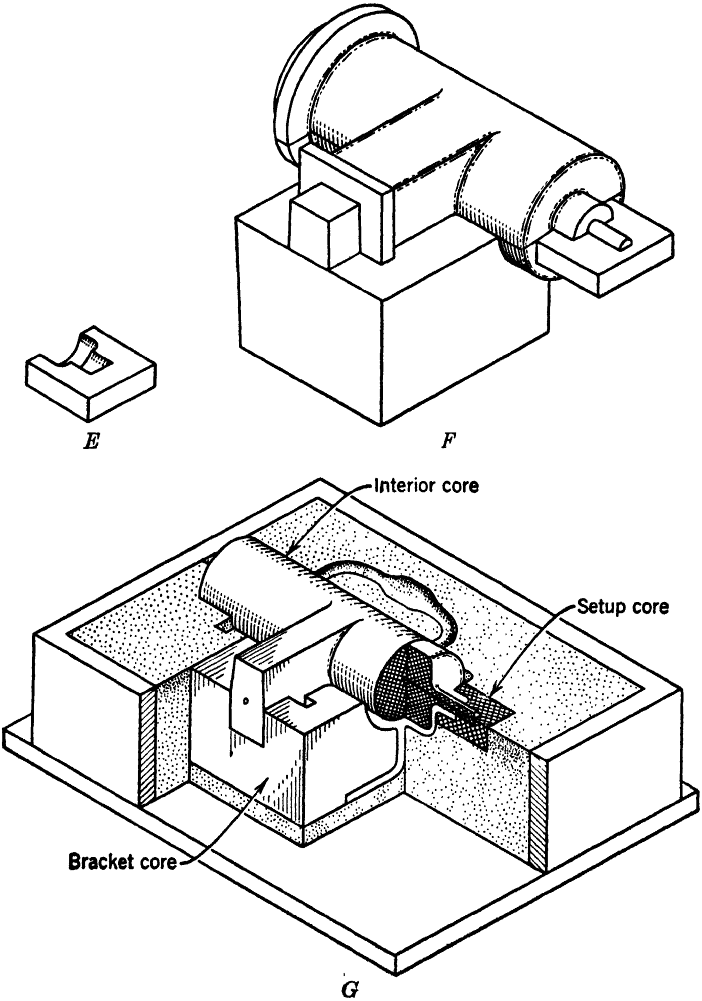


FIG. 19. *E*. Setup core. *F*. Pattern. *G*. Sectional view of completed drag.

port from the print of the rectangular opening. The core is more complicated, and a decision as to the best method would involve an analysis in the cost of core production. The pattern and

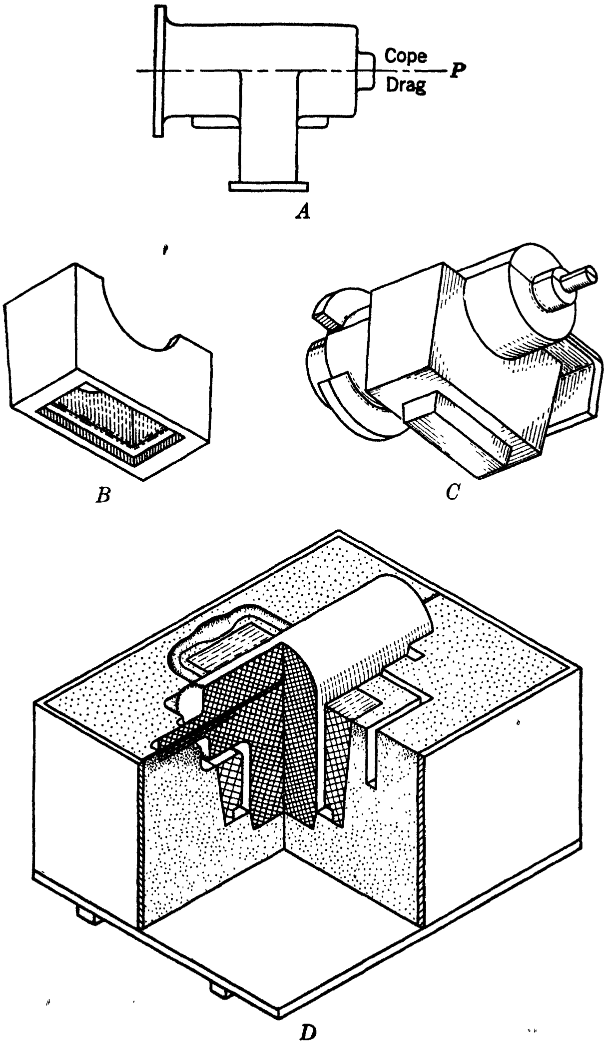


FIG. 20. *A*. Parting plane. *B*. Core. *C*. Pattern. *D*. Sectional view of completed drag.

completed drag half of the mold are illustrated in Figs. 20*C* and 20*D* respectively.

If a change in design were possible, the molding procedure might be simplified considerably. For example, if the flange on the rectangular outlet were omitted, the pattern could be cast in the position illustrated in Fig. 20*A* and no core would be required to form any exterior design. Another redesign which would simplify molding would be substitution of bosses for the bolting bracket, as in Fig. 21. If the metal has high volumetric shrinkage properties, objectionable defects may develop in the bosses. Methods of eliminating these defects (described in Chapter 14) may be more objectionable than the use of cores to form the exterior contours.

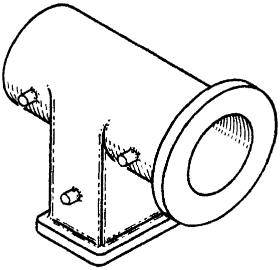


FIG. 21. Redesign to eliminate core.

Cast-Weld Construction. Economy of production is an important factor in determining whether a part should be fabricated by welding, cast as one piece, or made by cast-weld construction. Welding and acetylene cutting are indispensable aids in foundry industries using a metal such as steel, which is very adaptable to these processes. Parts of castings requiring special physical characteristics may be cast with an alloy of most suitable metal and bolted, riveted, or welded to other castings requiring different alloys.

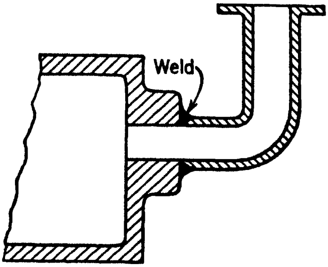


FIG. 22. Cast-weld construction. Elbow is made of a special acid-resistant steel to avoid corrosion.

The cast-weld construction process is applied to many types of steel castings varying from small to large intricate valves, gun-turret roller tracks, and other castings of all sizes. The cast-weld process may be conveniently employed in the construction of a steel casting such as illustrated in Fig. 19*A* by casting the flange of the rectangular outlet separately and welding it to the casting afterwards.

Castings Incorporating Too Many Features. Too many features should not be incorporated in one casting. Not all parts are subjected to the same action, and the life of the casting is equal to that of the weakest part. Figure 22 shows a chemical process casting with a 90-degree inlet elbow for introducing hot acid. The elbow was consumed by erosion long before the main body of the casting. Redesign for cast-weld construction eliminated the elbow and not only tripled the life of the casting but reduced the total production cost considerably by simplifying molding, core making, and the cleaning processes. A special high-alloy elbow was cast to resist the hydraulic cutting action of the acid and assembled to the main casting by welding.

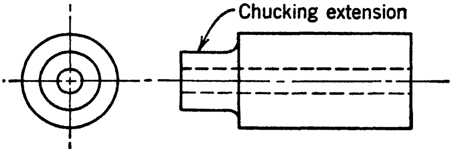
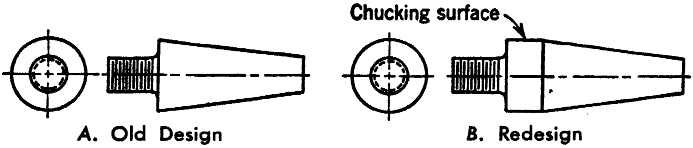


FIG. 23. Casting designed with a chucking extension to facilitate machining of entire casting without removing from chuck.



A. Old Design

B. Redesign

FIG. 24. Casting redesigned to aid chucking.

Features to Aid Finishing and Handling of Castings. It is not uncommon to neglect provisions on a casting for holding it in the machine during the finishing process. Also, accidents occur when large castings slip from their hitch when hoisted, because of lack of hitching facilities.

When a casting is to be machined to a close tolerance, it is often desirable to do as much finishing as possible without removing the piece from the machine. Figure 23 shows a chucking extension on a casting which will permit the entire casting to be machined on a lathe with one setting, the last operation being the cut-off.

Castings with tapered sides are difficult to chuck in a lathe and if possible should be provided with pads or flats. Figure 24 shows a conical-shaped casting with a threaded flange at one end. The redesigned casting has a cylindrical section for chucking.

If a casting of cylindrical or irregular contour is to be fastened to a machine table for finishing, it is often convenient to incorporate clamping lugs on the casting. Figure 25 illustrates lugs on the outside; however, it may be more desirable to cast them inside the casting.

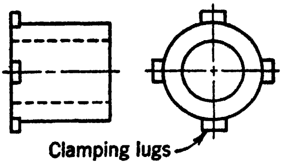
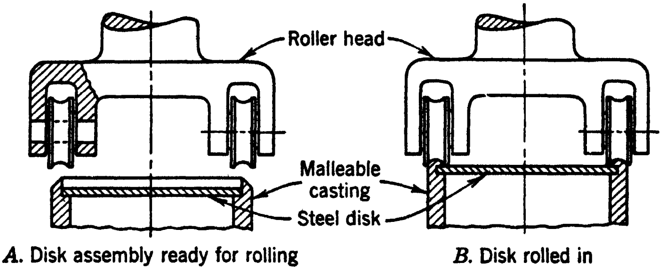


FIG. 25. Casting designed with lugs to aid clamping when it is machined.

Rolling, Crimping, Staking, and Forming. Complicated castings made of ductile metals may be cast in several pieces, and these parts may be assembled by rolling, crimping, or staking. Curved surfaces may be cast straight and formed to the desired curve after casting. Figure 26 illustrates how a bead may be rolled over a disk to hold it in place in a malleable iron casting. Figure 27 illustrates a malleable casting that has been crimped, and Fig. 28, one that has been staked. Small holes are sometimes punched rather than cored or drilled in small ductile castings.



A. Disk assembly ready for rolling *B.* Disk rolled in

FIG. 26. Assembly by rolling.

Evolution of Design. Many present-day products contain castings that are the result of a long evolutionary process of experimentation.

Figure 29*A* shows a casting originally made of three parts. The tool steel body was bored, and splines were milled on the outer surface. A flange was shrunk over one end of the body, and a bronze bushing containing an oil groove was pressed in. Because of a large number of failures, replacement of this part became a sizable item in the operating cost of the machine. After considerable study and experimentation, the flange and body were redesigned to be made as a one-piece chilled casting.

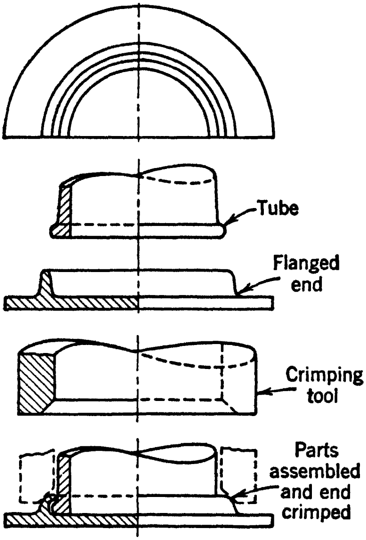


FIG. 27. Assembly by crimping.

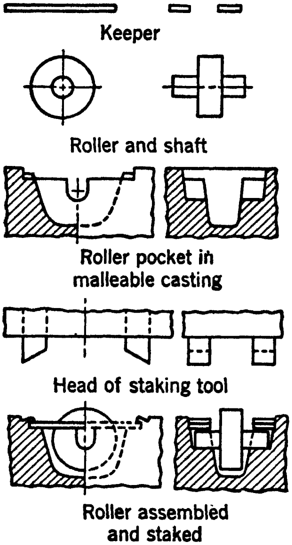
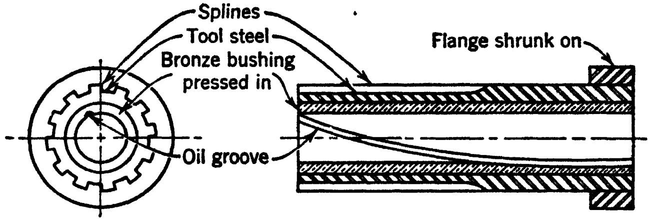


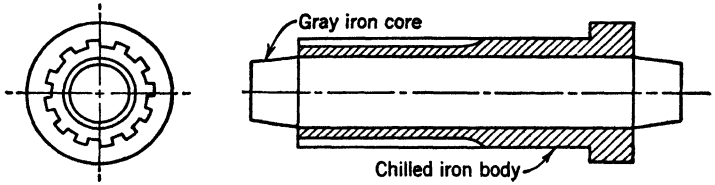
FIG. 28. Assembly by staking.

The former bronze bushing was replaced by a portion of a soft iron center core, which was used as a chill. The exterior of the casting, including the splines, was made with a dry sand core. This core was formed in, and drawn from, a stripping plate machine, since it was necessary that the casting be round and that the splines be uniform in shape and size throughout. The inside of the casting was formed cylindrically by means of a soft iron core and set in the mold, concentric with the outer dry sand core. This core chilled the casting effectively. In finishing, the core prints were sawn off, and a hole was drilled through the iron core and reamed to shaft size. Finally an oil groove was cut in the metal of the iron core for lubricating the shaft bearing.

Production Design. In the past, decisions on casting processes were left largely up to the pattern maker. Now it is common practice in planning production of large castings or of small castings in large numbers to call a conference of the supervisory personnel of all departments having responsible interest in the job, including the design and production departments, pattern shop, foundry, machine shop, and finishing and assembly departments. They scrutinize the layout closely and make decisions cooperatively in the interest of the most economical way to carry the process through to completion. The routine used by some foundries in planning the pattern is as follows. (An oil-base colored pencil is used to note the decisions on the blueprint.)



A. Old design



B. New design

FIG. 29. Evolution of design.

1. Determine parting line, cope, and drag.
2. Determine gating and feeding requirements.
3. Sketch core prints on the blueprint. Check possibilities of redesign to reduce the number of cores or to simplify them.
4. Sketch in loose pattern pieces on the blueprint.
5. Letter each core in the sequence in which it is placed in the mold.
6. Sketch outline of plate and flask around pattern, allowing sufficient room for gates and risers.

7. Provide written pattern specifications in detail, specifying pattern material, fixtures, driers, and special plates.

After the pattern is made and the casting is produced and processed, another conference is called for further alterations, if necessary.

Use of Models. Costly new designs must be carefully planned in order to obtain the best results from expensive pattern equipment which is too costly to change when once made. In a complicated design it is often difficult to visualize the casting from the blueprint. Judgment in making various decisions may be erroneous because of misconception of the proportionality of the design or lack of consideration of some features unnoticed on the print. A model of the casting scaled down to a convenient size (say ¼ in. = 1 in. for medium-sized castings and 1 in. = 1 ft for large castings) is worth more than a hundred blueprints. If the model is closely scrutinized by experts in all the trades that are involved in its production (foundryman, pattern maker, metallurgist, welder, draftsman, and machinist), the most economical and best procedures will result. In spite of the time required to make the model, its use may decrease delivery time, reduce casting costs, and produce better castings.

PROBLEMS

1. What are the responsibilities of a design engineer?
2. Give two methods that may be employed in converting an irregular parting to a straight parting.
3. Sketch a sectional view of a completed mold for the production of the casting illustrated in Fig. 4*A*.
4. Sketch a sectional view of a completed mold for the production of the redesigned casting illustrated in Fig. 4*B*.
5. List the steps necessary in the production of (*a*) the three-part mold in Fig. 6*A* and (*b*) the two-part mold (including core making) in Fig. 7.
6. List the advantages of the following:

   (*a*) Die casting over permanent molds.
   (*b*) Permanent molds over dry sand molds.
   (*c*) Dry sand molds over green sand molds.

7. How does quantity affect the choice of a production method?
8. What metal is best adapted to cast-weld construction?
9. How may castings be designed to aid machining and handling?
10. What is the procedure for planning the production of a casting?

14

Design to Eliminate Defects

Inherent Characteristics of Metals. It is the purpose of this chapter to investigate the effects of poor design, the techniques used by skilled foundrymen to minimize these effects, and the methods of redesign to overcome them. The common defects encountered as a result of poor design are shrinkage cavities and tears due to internal stresses. To understand the cause of these difficulties, it is necessary to recognize some of the inherent characteristics of cast metals, namely, (1) volumetric contraction both in the liquid and the solid state and (2) low ductility and low strength at high temperatures.

General Characteristics of Shrinkage. The specific volume of most metals increases as the temperature rises. In other words, the volume of 1 lb of metal increases in definite proportions through the various phases as the temperature rises from room temperature to the molten pouring temperature. During cooling, the opposite is true. The foundryman is continually confronted with problems relating to the cooling of metal in molds. The three general phases of shrinkage considered by the foundryman are:

1. Volumetric shrinkage (reduction in volume as molten metal cools to its solidification temperature).
2. Solidification shrinkage (reduction in volume as metal passes through the solidification range).
3. Contraction shrinkage (reduction in size of the casting as it cools from solidification temperature to room temperature).

Each metal and every alloy of each metal is characterized by shrinkage properties which must be dealt with individually in order to avoid the many resulting difficulties. For purposes of comparison, the following data show the characteristics of 0.30 per cent carbon steel and a typical cast iron of 3.20 per cent total carbon and 2.00 per cent silicon.

Table 1. COMPARISON OF SHRINKAGE IN STEEL AND GRAY IRON

Shrinkage	Steel	Gray Iron
Volumetric	1.6%/100° C drop	1.1%/100° C drop
Solidification	3.0%	0.6%
Contraction	7.2% to room temp.	3.0% to room temp.

For further comparisons of contraction shrinkage in commonly cast metals, one may refer to Table 2 of Chapter 4. It should be noted that malleable iron may contract as much as steel (¼ in. per foot), but when annealed it will expand ⅛ in. per foot, leaving a net contraction of ⅛ in. per foot. This phenomenon is based on the fact that chemically combined carbon occupies less space than carbon in the free or nodular state. Design to prevent defects should be based on the higher shrink value. Good design is important in the production of all types of metal castings but especially in the production of steel castings. Because of the many engineering properties found in the various types of steel, there is a big demand for such castings, both large and small and of various complexities in design. The high shrinkage characteristics of steel make it more difficult to produce satisfactory castings, especially if the design is not good.

Volumetric Shrinkage. If a container is filled with any hot liquid and the liquid is allowed to cool, the result will be a container only partially filled with liquid. This is true of molten metal as well as any other liquid with one exception. As soon as molten metal strikes the surface of the mold cavity, it solidifies to form a thin skin along the mold surface, and, when the mold cavity is filled, the so-called container completely encloses the liquid within its boundaries. As heat is emitted from the casting, through and normal to the mold face, the shell thickness increases until solidification is complete. It should be noted that the shape of the interior of the casting which contains the molten metal is continually changing as solidification progresses. As crystals form, they tend to displace the molten metal at the bottom of the container, and the last metal to freeze is somewhere in the upper portion of the casting. The portion that is last to freeze contains a shrinkage cavity equal in size to the loss in volume due to the shrinkage characteristic of the metal.

The shrinkage cavity may or may not be visible, but it can be detected by nondestructive inspection methods described in Chapter 12. Often, when rigid inspection is not required, a casting goes into service with a hidden cavity that is not discovered unless failure takes place. Cracks often begin at such cavities and work outward as the casting is stressed in service.

Figure 1 illustrates progressive solidification at various intervals of cooling time. It should be noted that solidification progresses from the thin to the thick section. It should also be noted that external angles have a greater cooling rate than re-entrant angles, the reason being that sand around the re-entrant angles is surrounded on two sides by the heat source.

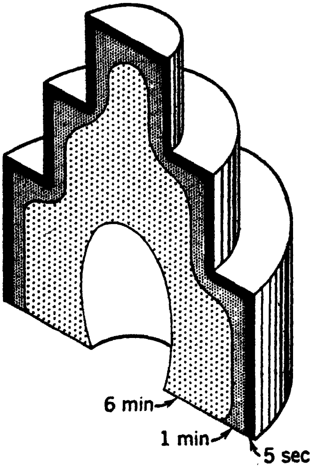


FIG. 1. Solidification of a casting after various intervals of time. Shaded areas indicate progress in solidification.

Isotherms. An isotherm is a constant-temperature trace throughout a casting, taken at some moment during the cooling phase. Although temperature gradients are spherical for a sphere and cylindrical for a cylinder, they appear as circles when represented in a given plane as in Fig. 2*A*. With a sphere or a cylinder, the temperature within the casting is proportional to the radial distance from the center. This is not true of the rectangle of Fig. 2*B*, whose external edges are cooled from two sides. Note that the external corner is considerably cooler than the surface midway between the corners. On the other hand, a re-entrant angle, as in Fig. 2*C*, is considerably hotter than if it were an external edge.

Rate of Solidification. Solidification or crystallization is directly proportional to the heat diffusivity coefficient of the mold (the ability of the mold material to carry away heat), directly proportional to the area (surface exposed to sand), and inversely proportional to the volume of the casting (the greater the volume of metal, the greater the quantity of heat to be dissipated). The rate of heat transmission is constant as long as the temperature difference between the center of the casting and the exterior of the mold remains constant. The greater the difference between the metal temperature and room temperature, the more rapidly is heat transmitted away from the casting; but the higher the temperature of superheat, the more heat must be removed before solidification takes place. Thus, a metal of high pouring temperature may solidify more rapidly if the temperature range between pouring and solidification is the same and the specific heat of the two metals is the same.

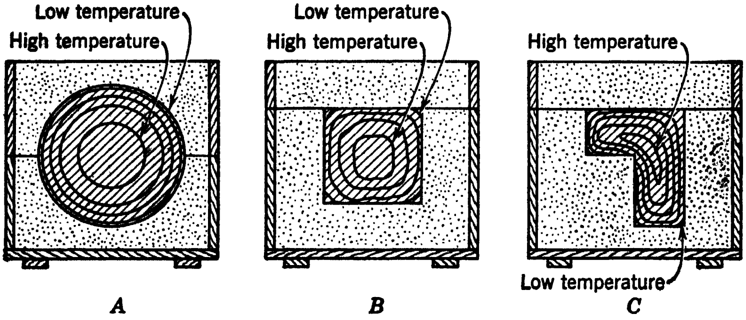
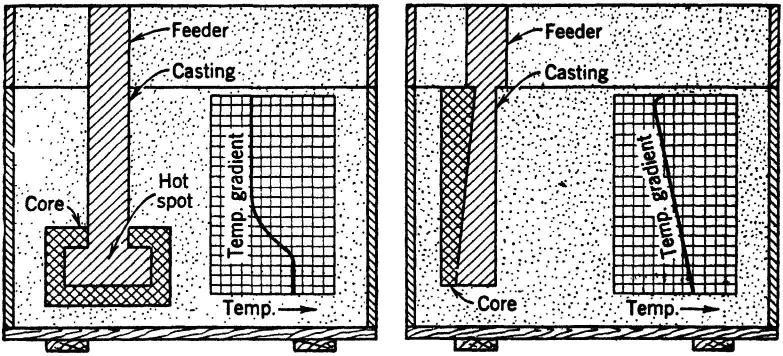


FIG. 2. Diagrams illustrating isothermal contours in various standard shapes.

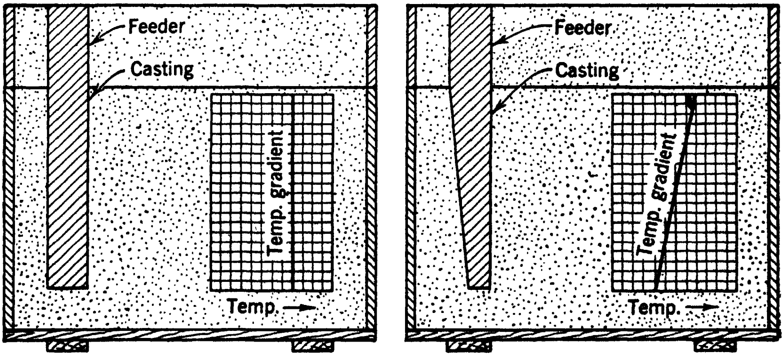
Temperature Gradient. If temperatures were taken simultaneously at various positions on a casting of uniform width and thickness, no temperature variations would exist throughout the length of the casting. However, if the casting had nonuniform cross-sectional areas, the temperature would vary considerably, depending on the variation in sectional thickness. Figure 3*A* illustrates schematically a temperature gradient of a casting of varying sectional thickness. The high temperature position, as indicated on the graph, is called a *hot spot.* Unless a casting is properly fed, volumetric shrinks often appear at these hot spots. The best way to avoid volumetric shrinks is by designing a casting that has no isolated hot spots which cannot be properly fed. If good design is not sufficient to prevent defects, various foundry techniques such as the use of chills, feeders, and cores must be resorted to. These will be discussed as separate topics.

Directional Solidification. Design is the least expensive and most effective expedient to prevent shrinkage defects. The designer should try to place and proportion members and their intersections in such a way as to establish a positive temperature gradient which is lowest at points farthest away from the feedhead and which gradually increases toward the feedhead. Figure 3 shows the trend of temperature gradients for various types of designs. In Fig. 3*A*, the section connecting the feeder and the heavier mass at the end of the casting cools more rapidly and therefore solidifies while the heavier mass is still partially molten.



A. Isolated hot spot

B. Section tapered away from feeder



C. Straight section

D. Section tapered toward feeder

Fig. 3. Temperature gradient of various designs in relation to the location of feedheads.

When the connecting member solidifies, the source of feed metal is cut off and a volumetric shrink results in the hot spot at the end. The same situation exists in Fig. 3*B*. A more desirable design is illustrated in Fig. 3*C*. This type of design may be satisfactory for gray iron, but often it is not adequate in steel casting design because of the high shrinkage characteristics of steel. The design illustrated in Fig. 3*D* is ideal for the promotion of solidification in the direction of the feedhead and is recommended for all metals having high volumetric shrinkage properties. This is referred to as *directional solidification*. Ordinary pattern draft is not adequate in the promotion of directional solidification.

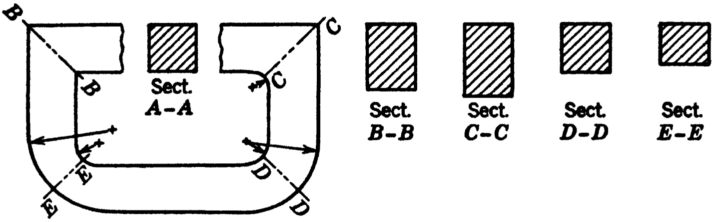
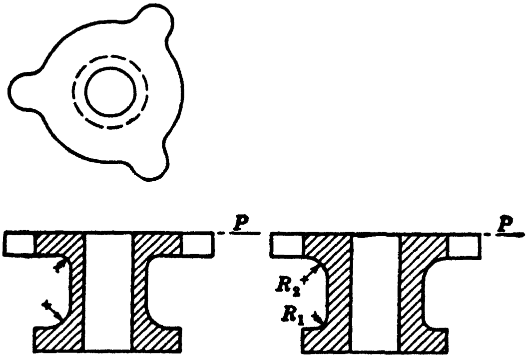


Fig. 4. L junctions illustrating thickness at intersection of members.

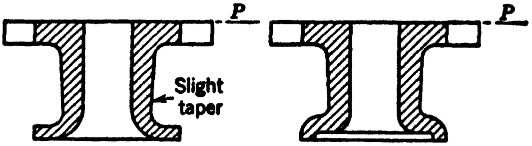
Intersections or Junctions of Uniformly Thick Members. When two members join or intersect, the point of junction forms a hot spot which increases the prospect of a defect, especially with a high-shrinkage metal. The junction and intersection of metal sections are generally classified according to the letters L, V, X, T, and Y.

L and V Sections. A hot spot formed by the junction of two members, whether they form an acute or an obtuse angle, may be reduced by radii or by coring out the center of the junction. In comparing the sectional views of Fig. 4, it is apparent that a hot spot is located at the intersection of the two members in the line *B–B*. The ratio of the volume of metal in the section to the heat-conducting surface of this part of the casting is greater than the ratio of the section at *A–A* to the heat-conducting area of that part. Also, the re-entrant angle at *B* contributes toward an increased temperature gradient because of the fact that the sand in that area is bounded on two sides by hot metal.

During the cooling period, the metal loses liquidity, becoming more and more sluggish, first at the mold's inner surface, and gradually toward the inside. The skin which forms along the mold surface has little mechanical strength and remains plastic during the solidification period. When flow finally stops through the center of the casting at *A–A*, some of the metal at *B–B* is still liquid and occupies more volume than it will when cooled. As cooling proceeds, the pressure within the casting drops in proportion to the reduction in volume. At the same time, atmospheric presure, acting on all the casting surface through the porous sand of the mold, is most effective on the weakest part of the casting, namely, at the re-entrant angle of section *B–B*, because it remains hot longest. The effect of this differential pressure often results in a rupture and break-through at the point of the hot spot.



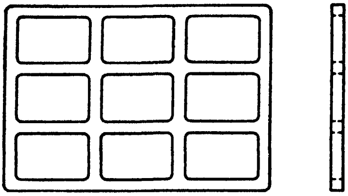
Section *A*. Hot spot caused by poor fillet design **Section *B*. Hot spot reduced by good fillet design**



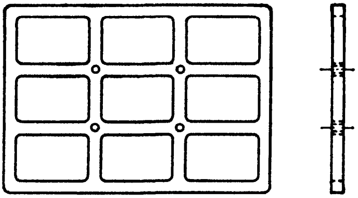
Section *C*. Design to promote directional solidification **Section *D*. Alternate design to promote directional solidification**

FIG. 5. Design changes to improve directional solidification.

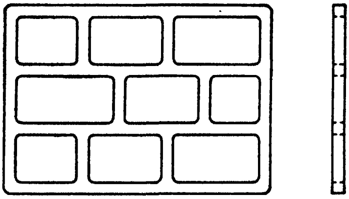
A fillet as illustrated at junction *C–C* is an improvement over *B–B* in as much as the incipient crack is eliminated. It does not eliminate the possibility of an internal shrink, especially if the point of junction is inaccessible to feeders. Under such conditions, where the hot spot cannot be fed and the characteristics of the metal are conducive to volumetric shrinkage, it is desirable to eliminate the hot spot by such a design as shown at *D–D*. Sometimes it is desirable to make the cross-sectional area at an intersection slightly smaller than the cross-sectional area of the members, especially if it is believed that internal stresses due to contraction shrinkage will form and concentrate at the junction. A reduction in sectional thickness, as illustrated at *E–E*, promotes more rapid solidification and faster cooling, thus forming a stronger junction when stresses develop.



A. X section illustrating hot spots at intersections



B. Cores used to reduce hot spots at intersections



C. Ribs staggered to reduce hot spots of X section

FIG. 6. Design methods involving X sections.

Figure 5*A* illustrates a poorly designed casting with an isolated hot spot in an L section at the bottom of the mold cavity. In Fig. 5*B*, the temperature gradient was improved by reducing the radius R_1 of the fillet to the minimum and increasing the radius R_2 to the maximum. This may be further improved by rounding the outside corner of the L section, as illustrated in Fig. 5*C*. Another variation to promote directional solidification is shown in Fig. 5*D*.

X and T Sections. The hot spot resulting from the intersection of two members to form an X section may be reduced by coring out the center of the intersection, as in Fig. 6*B*. This may be done with a stock core or a core specially designed for the purpose, provided that the length of the section does not go beyond the practicability of a slender core. The core does not improve the heat-conducting properties of the mold because it is surrounded on all sides, except the ends, by metal. The principal advantage is that the core displaces an equal volume of metal and thus eliminates a portion of the internal heat which would have to be removed if the section were of solid metal.

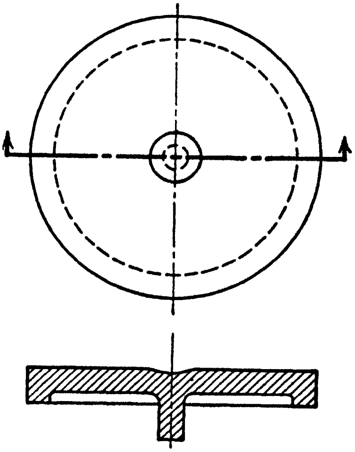


FIG. 7. Reduction of a hot spot by dishing out the top of a T section.

Under certain conditions where a reduction from an X section to a T section satisfactorily avoids defects, the ribs may be staggered, as in Fig. 6*C*. These members should be staggered far enough apart to avoid too rapid a transfer of heat between the T junctions. If the intersections are spaced too closely, a greater hot spot may be created than the original X design. T sections may be cored in the same manner as described for the X section. Another satisfactory way of reducing the temperature gradient of a T junction is by dishing out the top of the T, as shown in Fig. 7.

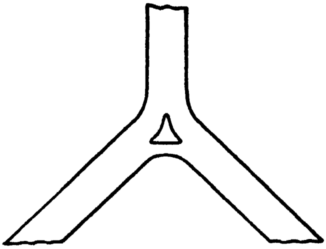


FIG. 8. Reduction of a hot spot at a Y intersection by means of a core.

Y Section. The hot spot formed by the junction of three or more members may be reduced by coring the junction with a cylindrical stock core, as in the hub of a spoked wheel, or with a special core, as illustrated in Fig. 8.

Hot Spots Formed by Bosses, Bolting Pads, and Raised Letters. Bosses that are to be drilled and tapped for studs and fasteners often produce isolated hot spots, unless the principles of directional feeding are incorporated in the design. In the design shown in Fig 9*A*, there are strong possibilities that shrink cavities will occur in the centers of the bosses where the tapped holes are to be located. To avoid this the boss may be made continuous, as in Fig. 9*B*, and under extremely difficult conditions it may be made of decreasing thickness at points farthest away from the feedhead.

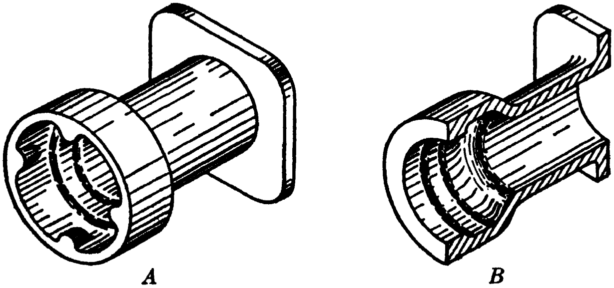


Fig. 9. *A*. Design illustrating isolated hot spots caused by bosses. *B*. Design to eliminate isolated hot spots caused by bosses.

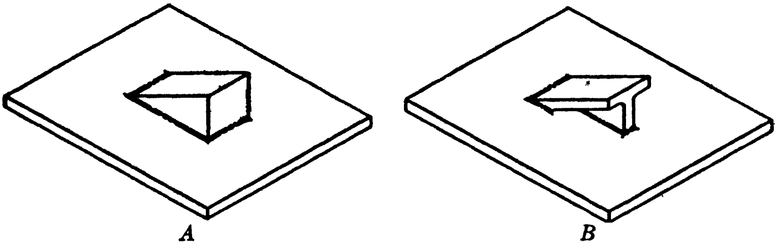


Fig. 10. *A*. Old design with hot spot. *B*. Design with hot spot eliminated.

Various projections, such as bolting pads, often distort the temperature gradient and cause defective castings. Much can be done by coring out the hot spots and using ribs for reinforcements, as in Fig. 10. It should be noted that special coring such as this adds to the production cost and should be resorted to only when necessary. In some cases a solid chunk may be hollowed out with a green sand core, as in Fig. 11*B*.

Raised letters often contribute to shrinkage cavities, especially when the casting is thin, as in Fig. 12.

Mid-Wall Shrinkage or Center-Line Shrinkage. Although mid-wall shrinkage may occur in all types of metal, it is more likely to be found in steel castings of sections under 4 in. in thickness. As the metal solidifies in the mold cavity of a thin section, the flow of molten metal from the feeder is soon stopped and a deficiency due to shrinkage is left through the center of the casting, as illustrated in Fig. 13. The defect may be a porous structure of numerous filamentary veinlets or an actual cavity, depending on the ratio of sectional thickness to length of member. Figure 14 shows graphically the length that may be obtained without defect for various metal thickness.

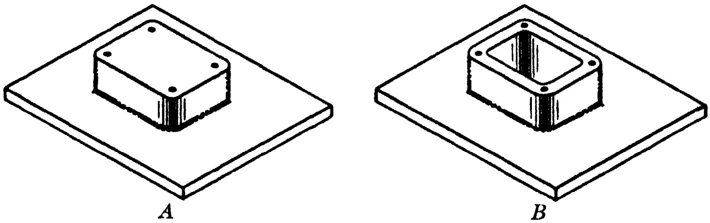


FIG. 11. *A*. Old design with hot spot. *B*. New design with hot spot eliminated.

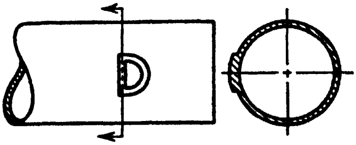


FIG. 12. Hot spot caused by raised letters.

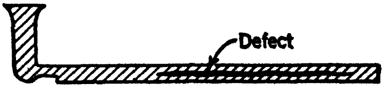


FIG. 13. Section of a casting illustrating a mid-wall shrink.

The most effective way of avoiding center-line defects is to design each member so that its temperature gradient increases in the direction of the feedhead. This is done effectively by tapering the casting in that direction, the large end of the tapered section being joined to the feedhead. When a tapered section is not desirable, a pad of metal may be added to the section which tapers in the direction of the feedhead. If the pad is objectionable, it may be removed from the casting by chipping or with an acetylene torch. This, of course, is an added expense in production of castings and should be avoided if possible. The amount of slope necessary to avoid center-line shrinks in steel castings is shown in the graph of Fig. 15.

It is not only a theory but a fact confirmed by experience that a casting with a center-line shrink is serviceable and satisfactory when the load is flexural, but when exposed to high fatigue and impact stresses or high pressures it is entirely unsatisfactory. Under the conditions of reversed stress, cracks are likely to start at the center-line shrink and be propagated to sound portions of the casting. Castings to be subjected to high pressures, especially if they are to be machined, should be sound in structure throughout.

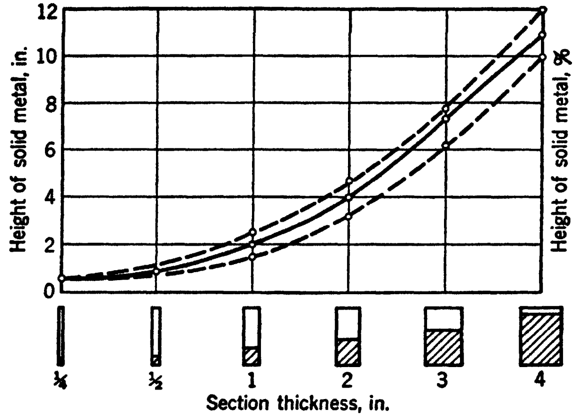


FIG. 14. Effect of section thickness on center-line shrinkage, showing height of solid metal in unpadded sections 12 in. high. (Courtesy of American Foundrymen's Society, Chicago, Ill.)

Foundry Methods to Control Volumetric Shrinkage. The molder may avoid volumetric shrinkage by (1) feeders, (2) proper gating and pouring technique, (3) chills, and (4) heaters.

Feeders or Shrink Heads. The only way to prevent a shrinkage cavity is to supply liquid metal to a freezing (solidifying) casting by means of a gate, a feeder, or both. A feeder is a cavity made as a part of the mold, which supplies hot liquid metal to the casting. After the casting is shaken out of the mold, the feeder (having served its purpose) is broken off or cut off the casting and discarded for remelt. It has the feature of a pouring gate, except that it is large enough in cross section to remain liquid as long as, or longer than, the part of the casting it feeds. Molten metal flows down into the section by gravity, leaving the void space in the feeder instead of the casting, as shown in Fig. 16. If a feeder is located in such a position that it will be filled by the first metal that is poured in a mold, its effectiveness as a feeder is much reduced. This may be overcome by completing the pouring operation through the feedhead as soon as metal appears at the bottom of the feeder. Occasionally a feeder is made of a nonconducting material so that it will retain the metal heat longer. This practice is more common in England than in the

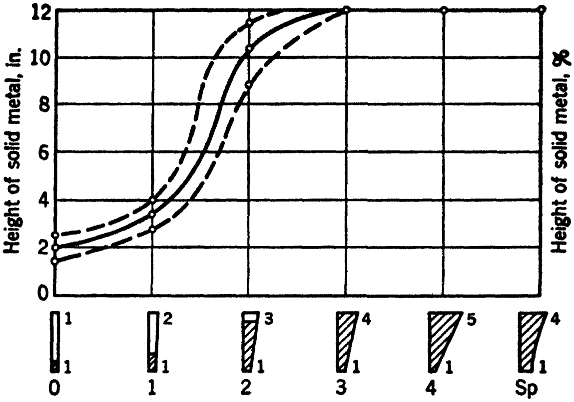


FIG. 15. Effect of taper on center-line shrinkage. Chart gives height of solid metal obtained in sections 12 in. high, 1 in. thick, and padded as indicated. (Courtesy of American Foundrymen's Society, Chicago, Ill.)

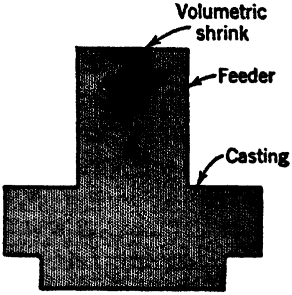


FIG. 16. Sectional view of casting illustrating function of a feeder.

United States. Sometimes Thermit or thermic material is used to reheat the feed metal of large castings.

An *atmospheric feeder* functions on the principle of differential pressures, the pressure in the casting being less than atmospheric pressure because of volumetric shrinkage. The atmospheric core of Fig. 17 is embedded in the cope; when the mold is closed, it projects down in the feeder cavity. After the mold is poured and the entire cavity (including the gate) is surrounded with a skin which gets progressively thicker, a partial vacuum forms within the casting. This drop in pressure is equalized by atmospheric pressure which enters the mold cavity through the core of the feedhead, forcing the molten metal ahead of it into the mold cavity of the casting. Atmospheric feeders are frequently used in the production of steel castings.

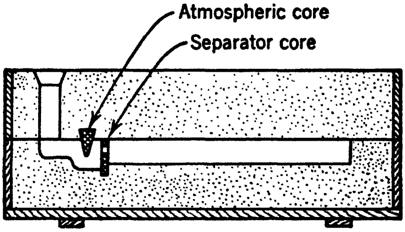


Fig. 17. Atmospheric feeder to eliminate volumetric shrinkage.

Churning is the action in which a molder moves a wrought-iron rod slowly up and down through the center of a feeder to aid the flow of metal down into the mold cavity and to keep the feeder open as long as possible. Additional hot metal is added to the feeder during the churning process.

A blind feeder is one that does not extend to or through the top of the mold but is embedded somewhere in the mold to feed a section which may or may not be accessible to a regular feeder. An atmospheric feeder is a variation of the blind feeder, except that the latter is placed above the casting cavity and depends on gravity for feeding action.

Gating and Pouring. The location, size, and number of gates determine to some extent the temperature of the molten metal at the moment the mold is filled. Temperature gradients may be controlled somewhat by these factors. A certain steel foundry states that it gates about 75 per cent of its molds into feeders. Speed of pouring may also affect the temperature gradient. Suppose, for example, that a heavier portion of the casting existed at a point farthest away from the gate entrance. If poured slowly, the metal in the remote portion would lose much of its superheat before entering its final resting place and consequently would be nearer the temperature of the remaining casting during the solidification phase.

Chills. The rate of solidification is directly proportional to the rate of heat transmission and depends on the heat conductivity of the mold. If the mold surface at a hot spot is made of metal, conductivity is high and the solidification rate is increased, thus reducing the hot spot. A metal chill may be embedded behind the mold wall for indirect chilling, or it may be a part of the mold face which comes in direct contact with the molten metal. Chills are sometimes embedded in a core to cool interior portions of the casting. Metal inserts which fuse with the cast metal are occasionally placed in the mold to control temperature gradients. An insert does not cool so much by heat conduction as it does by displacement of an equal volume of molten metal and by absorption of heat as it approaches the temperature of fusion. Small spiral-shaped inserts are sometimes placed in the mold cavity at various junctions where minor hot spots are likely to cause trouble.

Crystallization. Crystallization begins at the mold's inner face and progresses inwards in the direction of the hottest metal. The crystals align themselves in the direction of heat transmission, which is normal to the isotherms. Grain size in castings is affected by melting practice, heat treatment, type of metal, and proportions of alloying elements. The crystal structure of chilled castings is dense in the outer layer, longitudinal in the next layer, and finally equiaxed in the center of the casting. The size and direction of crystals have a great effect on the mechanical properties of castings. Figure 18 shows how crystals align themselves in castings of various shapes. It should be observed that, where there is an unfilleted edge, two independent planes of crystal growth exist which interfere with each other at their intersection. This intersection, referred to as a *cleavage plane,* weakens the casting at points where greatest strength is usually desired. Maximum strength and reliability are secured when all corners are rounded.

Mass Effect. The strength of castings, as measured in terms of unit area, decreases as the mass increases. This is more true of gray iron than of steel because gray iron is used in the as-cast condition, whereas steel is often heat treated first. The as-cast properties of the centers of massive sections are fundamentally functions of the cooling rate: the greater the mass, the slower it cools, and consequently the larger will be the coarse equiaxed crystals. A high-carbon iron has a greater tendency to produce spongy structures at the center of heavy sections than iron of lower carbon content. Although there are ways of refining the grain and retarding grain growth, such difficulties should be avoided through design whenever possible. It is more economical to avoid massive sections or to make a section hollow to avoid mass effect. When it is necessary to design massive sections, the designer should not expect the casting to have the same strength as test bars cast of the same metal but in smaller sizes. The results of various investigators indicate that a soft

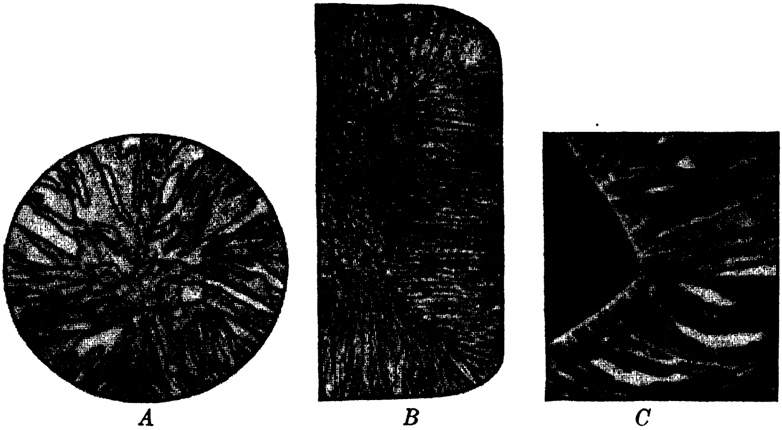


FIG. 18. *A*. Crystallization of hot steel in a cylindrical mold. *B*. Crystallization of hot steel in a square container. *C*. Crystallization of hot steel at a re-entrant angle. Note the normal disposition of the peripheral dendrites. (Courtesy of American Foundrymen's Society, Chicago, Ill.)

iron test specimen of 3-in. diameter shows as much as a 45 per cent drop in tensile strength and a 21 per cent drop in transverse strength as compared to the strength of a 1-in. test bar. Higher-strength irons do not have so great a variation in strength as soft irons.

Stress Distribution. A casting may fail under loaded conditions because of the concentration of stresses on a small portion of the casting. Sharp corners are often the cause of high stress concentrations. This is readily shown by photoelastic analysis where a polarized light is passed through a plastic model of the casting under stress and observed on a screen. The stress pattern of Fig. 19 shows stress fringes concentrating at the sharp re-entrant angle of an L junction. This illustration also shows how the stress of that same member may be more uniformly distributed with a fillet. Another way of detecting stress distribution is by a brittle-lacquer process. The casting is coated with a specially prepared lacquer and dried. When stress occurs, the lacquer cracks along constant stress lines to indicate a pattern of stress contours.

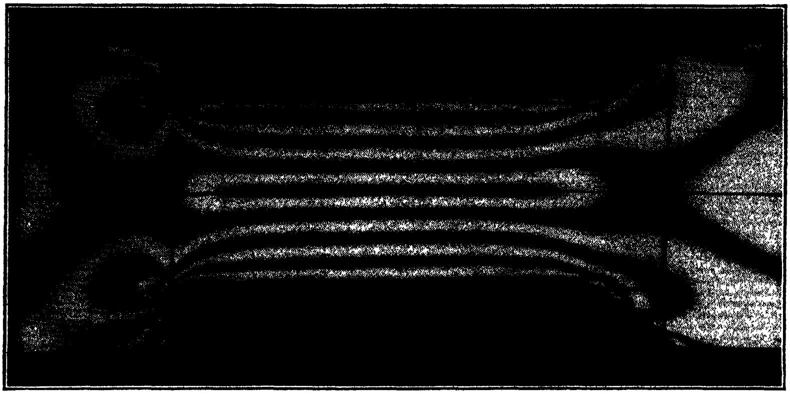


FIG. 19. Photoelastic analysis of a plastic model containing sharp edges and filleted edges, illustrating the distribution of stresses. (Courtesy of E. O. Stitz, Professor, Purdue University.)

Fillets and Rounds. Fillets and rounds not only increase soundness in castings but aid in pattern draw. Sand adheres to sharp re-entrant corners of a pattern much more readily than to filleted corners. Also, when the mold is poured, sharp corners of sand are more likely to be broken and washed away by the inflowing metal. Stress intensity as viewed by photoelastic analysis may concentrate at sharp corners to the extent that it may be many times greater than the computed values of the elastic limit of the metal. Furthermore, due to the formation of a plane of cleavage at the intersection of crystal planes in an unfilleted junction, the junction becomes the weakest part of the casting.

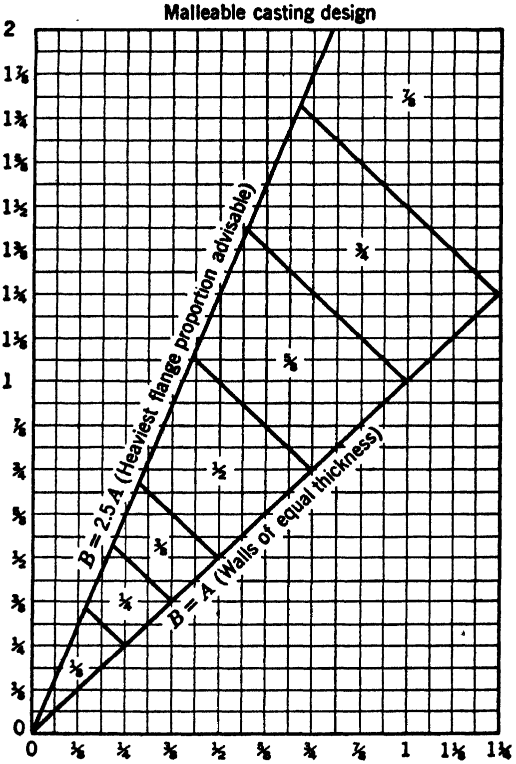


FIG. 20. Recommended fillet radius to be used in casting design for all joints with walls at right angles to each other and for walls of all unusual thicknesses and combinations of thicknesses. (Courtesy of Malleable Founders' Society, Cleveland, Ohio.)

A flaw or check due to an undersized fillet may be so small that it is unnoticed, and, although frequently quite harmless, it may be the cause of eventual failure, especially if the casting is subjected to repeated stresses.

In determining the size of a fillet, the designer should take into consideration the type of joint, its wall thickness, the size of the casting, and the characteristics of the metal. Fillets in cast metals like steel and malleable iron, with a high contraction shrinkage, must be designed with extreme care, whereas a normal amount of caution is sufficient for cast iron. The radius of a steel casting is seldom greater than the thickness of the intersecting members, and rarely does it exceed 3 in. Fillets varying from ½ to 1 in. are commonly used on V, X, and T sections; they are seldom larger because of the detrimental effect of increased hot spots. On the other hand, the radius should be large enough to avoid the effects of stress concentrations which are more objectionable than the effects of added heat to the section. To judge the size of the radius at the juncture of unequal sections, the mean thickness of intersecting members is usually considered.

More precise data on fillet size has been developed for malleable iron than for any of the other metals. Recommended fillet sizes for malleable castings are given in Fig. 20. It is also recommended by the Malleable Foundries' Society that fillets on malleable iron castings should never be less than the sectional thickness of the section. Seldom does the sectional thickness of malleable castings exceed 4 in., whereas in steel the sections may be 4 ft thick.

Hot Tears. When the metal in a mold becomes solid, it begins to contract, first at a high rate and then at a rate that tapers off in proportion to the rate of temperature drop in the casting. The effect of this contraction in the solid state is a reduction in the size of the casting. Although this reduction in size is readily compensated for if the pattern is made larger by an amount equal to the shrinkage, the problem of preventing hot tears and distortion as a result of shrinkage is more difficult. Not all parts of a casting shrink at the same rate because of peculiarities in design, mold obstruction, and irregular temperature gradients. This results in internal stresses which may cause warpage and often lead to cracks. The best way to avoid serious internal stresses is to design the casting so that all parts of it will shrink at the same rate. Since the rate of shrinkage depends on the rate of temperature change, it is desirable to design the casting so that a uniform temperature gradient exists. In other words, from the standpoint of avoiding hot tears and warpage, a casting of uniform sectional thickness is most desirable. Although it is not often possible to do this, the designer can usually improve on his design to the extent that internal stresses are reduced to a point where the casting may be satisfactorily produced. It frequently happens with complicated designs that the internal stresses within the casting are not great enough to cause cracks, but when the casting is put to use the additional strain in operation results in breakage. Such castings are often annealed to relieve these initial internal stresses.

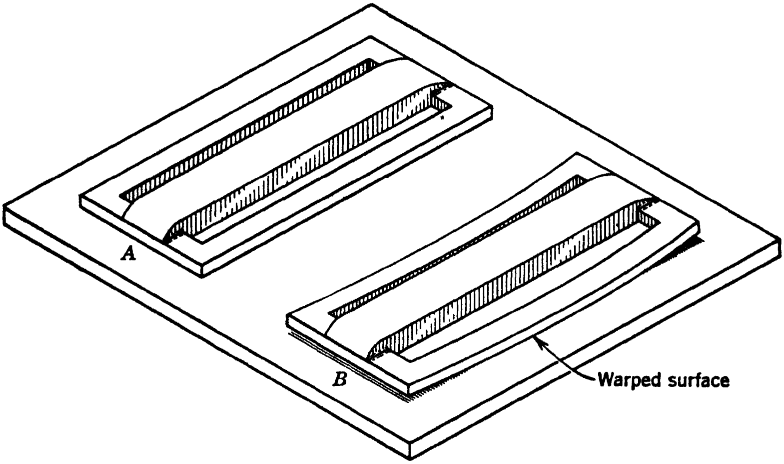


FIG. 21. Castings with varying sectional thickness may warp as illustrated in drawing *B*. Drawing *A* shows the pattern used in producing the casting.

Warpage of castings is one of the most common problems encountered in the industry. Small- and medium-sized castings of ductile metals like steel and malleable iron are frequently straightened in a press after heat treatment, but this is quite difficult with complicated designs and impossible with gray iron because of its brittle characteristics. To illustrate the mechanism of warpage due to design, the center member of the casting in Fig. 21 was made heavier than the two outside members. It is quite apparent that the two outside arms will make considerable progress in contracting before the center member begins to shorten. As the outside members contract, they shorten the overall length of the casting, the center being liquid or quite plastic. When the center member begins to contract, the outside members have no other alternative but to buckle in compression.

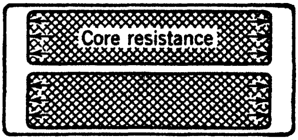


Fig. 22. Stress caused by core resistance.

If shrinkage is resisted by a green or dry sand core as in Fig. 22 a hot tear is likely to occur. The horizontal members, being thinner, will begin to shrink while the heavier vertical sections are still in the state of solidification at a temperature too high to resist much stress. The most likely place for the tear to occur is at the weakest point, namely, at the junction of the thick and thin sections.

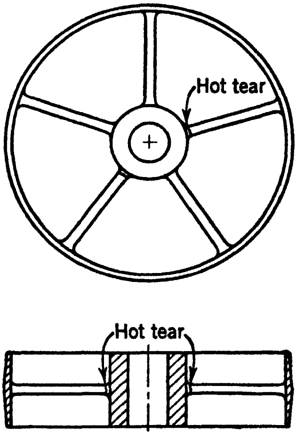


Fig. 23. Hot tear formation in a pulley.

The pulley of Fig. 23 illustrates how a hot tear may result from unequal shrinkage and lack of strength at hot spots. The rim, being thin, will cool and shrink before the rest of the casting does. Compressive stresses in the spokes are absorbed by the hub which at this stage is still in a plastic state because of its size. The next phase of high shrinkage takes place in the spokes which are now attached to a rigid rim and a plastic hub. The rapid shortening of the spokes creates a tensile stress which is likely to tear the spokes out of the hub. A thinner hub does not reduce stress, but it may reduce the hot spot sufficiently to strengthen the casting so that it can resist this stress. If further design steps are to be taken in the prevention of hot tears, the spokes may be waved, as in Fig. 24. Instead of tearing out of the hub when stresses develop, the spoke will tend to straighten out.

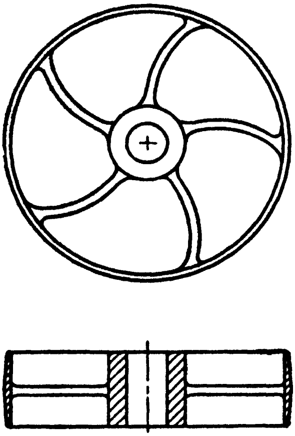


Fig. 24. Waved spoke construction.

Ribs or stiffening webs are occasionally used to reinforce a junction to prevent a hot tear. The rib, being thinner than the joining members, solidifies and cools more rapidly and prevents the members from pulling apart. Generous fillets, as shown in Fig. 25, should join the rib to the casting in order to obtain a more uniform distribution of stresses.

Streamlining not only adds to the appearance of a casting, but it reduces stress concentration and mold resistance. To join thick and thin members it is always better to make the change by gradually tapering one member into another.

When design fails to eliminate the possibility of a hot tear, special consideration must be given to mold and core collapsibility, chills, and other molding techniques to relieve stresses or to reduce the temperature gradient. Core bond is reduced to a minimum; cores are baked for longer periods of time; and sometimes special cores with coke- or cinder-filled centers or hollow internally notched cores are designed for rapid collapsibility. Molds for such castings are preferably made of green sand, and, if greater collapsibility is desired, less green bond and moisture are used, wood flour may be added to the sand, and the mold is rammed as soft as possible. Contraction strains may often be relieved if sand pockets are dug out, clamps and flask tie bars are released, or removable flask sections are taken away as soon as the casting solidifies in the mold. The metal may be alloyed to increase yield strength, to improve elastic properties, or to reduce shrinkage characteristics.

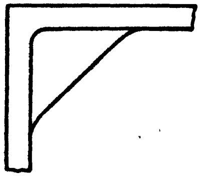


Fig. 25. Reinforcing rib to avoid tear at hot spot.

Cast-Weld Construction to Eliminate Defects. Isolated mass concentrations located in places inaccessible to feedheads are contributing factors to hot tears and volumetric shrinks. It is occasionally advisable to cast such parts separately and weld them to the casting. The welding of lugs, pads, brackets, and various appendages not only helps to eliminate defects but often avoids complicated molding processes. Sections are sometimes made solid to promote directional solidification and removed afterwards if they obstruct casting function.

Thermit Welding. By means of the Thermit process, castings and forgings of iron and of steel may be welded to a strength equal to that of the original parts. The process is applied in the repair of castings and forgings broken in service and also in joining new parts. In joining new parts, the process is important where it is necessary to make a casting in several parts, rather than as an entirety, transport these parts to the point of assembly, and there weld them into a single large unit, which then may be finished as required and assembled into the structure needed.

This procedure was followed during World War II to fill the need of large castings in greater quantity than could be supplied by large-capacity foundries. By this means foundries having a melting capacity too small for an entire casting made the casting in several parts. Also, castings too large to be transported as a unit have been cast in parts, then transported, and welded. The process is used also in producing castings of such shape and large size as to make the pattern difficult to mold. In some cases the pattern is made in two or more parts to produce simpler castings which then are welded.

The materials constituting Thermit are finely divided aluminum mixed mechanically with iron oxide (and usually other ingredients to make of the resulting ferrous alloy one which has the same characteristics as the metal to be welded). This is a stable mixture until the aluminum is ignited. Then a violent reaction takes place in which the oxygen of the iron oxide combines with aluminum. A great deal of heat evolves, raising the temperature to an estimated 5400° F and melting the iron of the iron oxide, the steel particles, and other ingredients which form the required alloy. Chemically the reaction is $Fe_2O_3 + 2Al = Al_2O_3 + 2Fe$. The aluminum oxide, being light, floats on top of the molten mass as a slag and is kept out of the weld because of its light weight. The right amount of steel is computed for each weld so that steel only and no slag may enter the weld.

To make a weld the two parts are held in proper alignment (usually by clamping) but separated from 1 to 2 in. The cavity between the parts is filled with pattern wax which is made to extend somewhat beyond the surface of the parts to be welded, as a bead. In this way the weld will be a little larger than the pattern when the weld metal replaces the pattern. Next, a casting box or flask is fitted about the wax pattern and the ends of the castings to be welded, and a mold of high-clay-bonded green sand is rammed within it. This mold is made to contain sprue, gate, and riser by means of wood patterns for these details. Also, a vent is provided at the bottom of the mold for preheating the casting to be welded. The wooden parts are then withdrawn, and the preheating flame is applied at the bottom of the mold to melt out the wax pattern. This is continued until the parts to be welded are heated to a temperature of red heat. The preheating vent is then stopped off with clay, and the mold is ready to be poured.

In the meantime the Thermit is placed in a crucible which is supported above the pouring basin of the mold. The charge contains the required amount of Thermit (containing iron oxide) and sufficient small steel punchings to weigh twenty-three times the weight of the pattern wax melted from the mold. The charge also contains the proper amount of such alloying elements as may be needed to make the weld metal identical with the metal to be welded.

After the castings have been preheated, the Thermit is reacted by igniting the aluminum. Within a minute, this reaction generates sufficient heat to produce a temperature about twice the melting point of steel, which is sufficient to raise the temperature of the red-hot castings to the fusion temperature.

The crucible is tapped into the pouring basin, and the hot metal flows through the sprue and gate to fill the mold. The amount of charge is great enough so that only steel enters the mold and slag remains in the pouring basin.

The weld is left in the mold until it is cooled to minimize stresses resulting from rapid cooling. In repair work on finished castings, particularly large ones, the entire casting is preheated in order to reduce the stresses to a safe working point and to avoid distortion. The entire casting is then enclosed in a temporary brick or metal structure and preheated to a red heat; the Thermit charge is next tapped into the mold to form the weld.

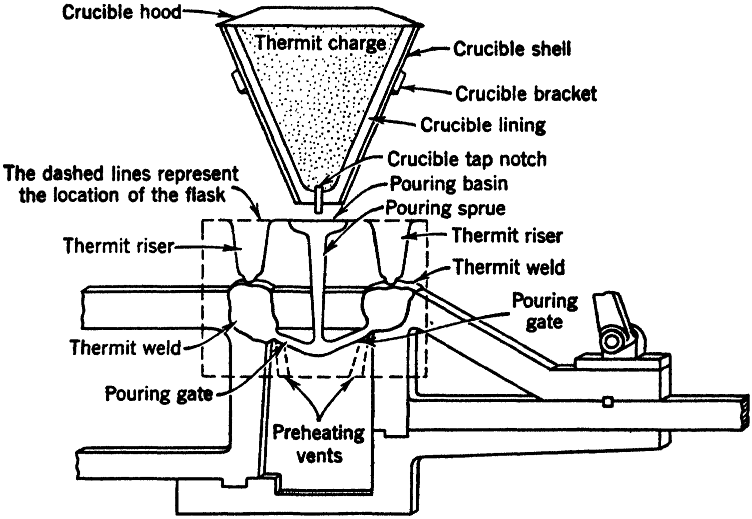


FIG. 26. Thermit welding of a locomotive side frame.

The apparatus for making two Thermit welds on a locomotive side frame is shown in Fig. 26.

PROBLEMS

1. Give the various methods by which a foundryman is able to control the temperature gradient of a casting in a mold.
2. How should designers apply the principles of directional solidification?
3. Illustrate with sketches how the hot spots of an X intersection may be reduced.
4. State the effect that sharp corners have on (*a*) stress concentrations, (*b*) crystal structure, (*c*) mold erosion, and (*d*) molding.

5. Explain the methods employed in preventing mid-wall shrinkage.
6. Describe the function of an atmospheric feeder.
7. What is meant by mass effect, and what can be done to reduce it?
8. What is the cause of hot tears?
9. Explain how the following methods avoid hot tears? (a) Design (b) Molding procedure.
10. How can the cast-weld method be employed to prevent defective castings?

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Appendix

Table I. APPROXIMATE MELTING POINT, SPECIFIC GRAVITY, AND WEIGHT OF CAST METALS

Metal	Melting Point (°F)	Specific Gravity	Weight (lb/cu in.)	Weight (lb/cu ft)
Aluminum (99.2% pure)	1250	2.7	0.097	168
Aluminum-copper (4.5% copper)	1250	2.8	0.101	175
Aluminum-bronze (10% alum)	1900	7.6	0.274	473
Brass (20% zinc)	2147	8.8	0.314	541
Copper	1981	8.9	0.323	560
Iron (gray, cast)	2200	7.2	0.26	450
Lead	620	11.3	0.41	708
Manganese-bronze	1630	8.5	0.308	532
Molybdenum	4760	10.2	0.369	638
Nickel	2651	8.9	0.322	556
Phosphor-bronze	1900	8.9	0.319	551
Steel (cast)	2800	7.8	0.28	489
Tin	449	7.2	0.26	450
Tungsten	6170	19.3	0.697	1204
Zinc	787	7.1	0.258	446

Table II. APPROXIMATE WEIGHT OF NONMETALLIC MATERIALS

Material	Average Weight (lb/cu ft)
Brick (common)	112
Brick (fire)	145
Clay (damp plastic)	110
Charcoal	26–33
Coal (anthracite)	97
Coke (piled)	23–32
Dolomite	181
Feldspar	159
Graphite	135
Gypsum	140
Limestone	155
Linseed oil	59
Magnesia (carbonate)	150
Mahogany	44
Mica	175
Molding sand (unrammed)	68
Molding sand (rammed)	85
Mortar	95
Mud	111
Pitch	70
Plaster of Paris	103
Talc	169
Vegetable oils	58
White pine	27

Table III. MELTING POINTS OF NONMETALLIC MATERIALS

Material	Melting Temperature (°F)
Alumina (Al_2O_3)	3722
Carbon	Infusible
Fire clay	2730–3150
Ganister (98% SiO_2)	2550
Magnesite (MgO)	3990–5070
Sand	2900–3100
Silica brick	3100
Silicon	2588
Sillimanite ($Al_2O_3 \cdot SiO_2$)	3290
Zircon ($ZrO_2 \cdot SiO_2$)	4532
Zirconium oxide	4892

Table IV. CONTROL SAND TEST DATA WHICH HAVE PROVED SATISFACTORY FOR VARIOUS TYPES OF CASTINGS

(Data obtained from *Tools for Control*, courtesy of Harry W. Dietert Co., Detroit)

	Moisture (%)	Permeability	Green Compression (psi)	Deformation (in.)	Clay (%)	Fineness Number	Sintering (°F)
Aluminum	6.5–8.5	7–13	6.5–7.5	0.018–0.024	12–18	225–160	2350
Brass and Bronze	6–8	13–20	7–8	0.014–0.020	12–14	150–140	2350
Cu-Ni	6–7.5	37–50	6.5–8	0.014–0.020	12–14	130–120	2400
Gray iron (stove plates)	6.5–8.5	10–15	6–7.5	0.018–0.022	10–12	200–180	2350
Light gray iron (squeeze molds)	6–7.5	18–25	6.2–7.5	0.019–0.022	12–14	120–87	2400
Medium gray iron (floor molds)	5.5–7	40–60	7.5–8	0.010–0.014	11–14	86–70	2400
Medium gray iron (synthetic sand)	4–6	50–80	7.5–8.5	0.012–0.017	4–10	75–55	2450
Heavy gray iron (green or dry)	4–6.5	80–120	5–7.5	0.012–0.016	8–13	61–50	2500
Light malleable	6–8	20–30	6.5–7.5	0.017–0.020	8–13	120–92	2500
Heavy malleable	5.5–7.5	40–60	6.5–7.5	0.012–0.018	8–13	85–70	2500
Light steel	2–4	125–200	6.5–7.5	0.020–0.030	4–10	56–45	2600
Heavy steel	2–4	130–300	6.5–7.5	0.020–0.030	4–10	62–38	2700
Steel (dry sand)	4–6	100–200	6.5–7.5	0.030–0.040	6–12	60–45	2600

SAND TESTING AND CONTROL PROCEDURE

Sand Sampling

1. Sand samples selected from a sand heap should be obtained at a depth of at least 6 in. below the surface of the heap.
2. Samples should be obtained from at least three different parts of the heap. For example, a long triangular heap should be sampled at both ends and in the center.
3. Obtain 1 qt of sand for each sample, and place each sample in an air-tight container without packing.
4. System sand samples may be obtained directly from the muller or aerator or anywhere along the conveyor line.
5. The sand should be riddled through a ¼-in. screen before it is tested.

Moisture Determination—Moisture Teller Method

1. Place counter weight on the left-hand side of the balance. Place the sample pan on the right-hand side. Have rider at zero.
2. Add sand to the pan until scales balance. This represents 50 grams of sand.
3. Place pan containing sand into Moisture Teller.
4. Set temperature adjustment to desired heat.
5. Start the motor of the Moisture Teller by turning the timer past three, then to the number of minutes previously found necessary to dry the sand.
6. When the Moisture Teller stops, remove the pan and place on balance.
7. Balance the scales by moving the rider to the right on the balance beam.
8. The original sample being 50 grams, the percentage moisture may be computed by multiplying the reading of the rider by 2.

9. Clean pan by brushing with a soft hair brush. The pan may be cleaned by blowing air through the back. Do not attempt to clean the pan by tapping it against the table. After being cleaned, the pan should be checked for weight.

Weighing Sand Sample to Be Rammed in Specimen Tube

1. Set specimen tube in cup pedestal, and place assembly on left side of balance. Place sufficient weights on right-hand pan to equal weights of pedestal and tube plus weight of sand desired. Because the density of different sands varies, this is obtained by experimentation. It may vary from 150 to 190 grams.
2. Add sand to specimen tube until scales are balanced.
3. Place cup pedestal on top of the specimen tube, and up-end the tube. Remove the top cup pedestal.

Ramming Standard Specimen

1. Place the specimen tube and cup containing the weighed sample under the rammer.
2. Allow the rammer to rest easily on the sand.
3. Ram the sand by turning the crank of the rammer through three revolutions at moderate speed.
4. Note whether the upper end of the rod corresponds with the center line on the tolerance marker. For routine control this may vary ± $1/32$ in.

Standard Permeability Test

1. Check water level in tank.
2. Turn air valve to "vent," and slowly raise drum until it is out of the water. Then turn valve to "closed" position, and release drum slowly into water.
3. Place specimen tube containing test specimen in position in mercury cup.
4. Turn air valve to "on" position.
5. With a stop watch, determine the time required for the drum to pass from 0 to 2000 cc. Note the pressure.

6. Compute the permeability as follows:

$$P = \frac{vh}{pat} \quad \text{or} \quad \frac{501.2}{pt}$$

where P = permeability number.
v = volume of air passing through the specimen (cubic centimeters).
h = height of specimen (centimeters).
p = pressure of the air (grams per square centimeter).
t = time (minutes).
a = cross-sectional area of specimen (square centimeters).

Routine Permeability Test

1. Prepare sand specimen for test.

2. Attach the correct standardized orifice plate to permeability machine. It is customary to use the small orifice plate for permeabilities below 90 and the large one for permeabilities above 90.

3. Rotate permeability dial so that the straight edge is vertical and the zero adjusting tip points down. The end of the zero adjusting tip should coincide with the level of the water in the glass tube. Turn adjusting screw at right of dial to bring the tip to the proper level.

4. Turn air valve to vent, raise drum, turn valve to "off," and lower drum.

5. Place specimen tube over orifice in mercury cup, and turn air valve to "on."

6. Rotate the permeability dial until the edge is just level with the height of the water in the glass tube. Read the permeability figure just above the point where the dial corresponds with the water level. If the small orifice is used, read the outer scale. If the large orifice is used, read the inner scale.

Base Permeability Test

1. Place special retaining screen in the specimen tube so that the screen surface fits down against the pedestal.

2. Weigh the proper amount of sand (which is dried and free of clay) to produce a specimen 2 in. in height. Place sand in specimen tube.

3. Place other screen on top of the sand in the specimen tube, with its flange facing down.

4. Ram three times.

5. Place tube in permeability meter, and test for permeability.

Dry Permeability Test

1. Place split specimen tube on pedestal, and insert steel ring in bottom of tube.

2. Tighten clamp on split specimen tube.

3. Weigh out sufficient sand to produce a test specimen of standard dimension, and ram according to standard procedure.

4. Release clamp on specimen container, remove the tube, and place specimen on a drier. If the specimen tube is split on one side only, the rammed specimen is up-ended over a stripping post. The clamp is then released, and the core is stripped.

5. Place core in an oven and dry at 221° to 230° F for 1 hr or until dry.

6. Remove specimen from oven, and place it in a desiccator to cool.

7. When cool, place specimen in a core permeability tube. Clamp the specimen firmly in position, and fill space between specimen and container with mercury.

8. Place permeability tube in position in permeability meter, and determine permeability in usual way.

Baked Permeability Test

1. Prepare specimen in same manner as described for dry permeability. A steel ring may not be needed if specimen has sufficient strength.

2. Bake specimen in an oven at a temperature above 230° F. Record temperature.

3. Allow specimen to cool until it can be handled. Then place in a desiccator.

4. Proceed with experiment as described for dry permeability.

Green Sand Compressive Strength Test

1. Prepare standard test specimen.

2. Strip test specimen from specimen tube.

3. Place specimen in testing machine so that the face that was uppermost in the ramming operation is facing the right-hand test head of the machine.

4. Set magnetic rider against pendulum arm on scale.

5. Apply load to the specimen by turning hand wheel at a uniform rate to secure a compression reading of 7.5 lb in 15 sec. Continue load application until failure takes place.

6. Return pusher arm and pendulum to zero, and read compressive strength on scale indicated by magnetic rider.

Green Sand Shear Test

1. Replace compressive test heads with shear heads.

2. Continue with test as described for compressive testing.

3. Read shear strength on scale indicating "Shear Strength."

Dry Sand Compressive Test

1. Prepare test specimen as described for dry permeability test.

2. Place specimen in testing machine, and proceed with test as described for green sand compressive test.

3. If the sand specimen breaks above 15 psi, remove test heads from lower position and place them in upper position of testing machine. This increases the breaking force five times. Repeat the test. Read the scale indicating "Dry Compression."

Dry Sand Shear Test

1. Prepare test specimen as described for dry permeability test.

2. Place specimen in testing machine, and proceed with test as described for green sand shear testing.

3. If the sand specimen breaks above 15 psi, repeat test with shear heads in upper position of testing machine.

Baked Tensile Strength of Cores

1. Attach the core box plunger to the rammer plunger head.
2. Assemble the tensile core box, and fill with a weighed sample of core sand.
3. Place the core box under the rammer, and ram three times.
4. Loosen screw, and lift off the hopper. The core specimen is to be within $\frac{1}{16}$ of the standard 1-in. thickness. If thickness of core does not come up to specifications, discard core and make a new one.
5. Open core box carefully by rapping the box a few times to loosen specimen.
6. Bake core, and cool to room temperature.
7. Place core specimen in testing machine, and break specimen.
8. Record reading from "Dry Shear Scale." Multiply this reading by 4 or 5 (depending on style of brackets in use) (see instructor).

Percentage of Clay and Fineness Number

1. Obtain a pint of the sand to be tested.
2. Place sand in a pan, and dry in an oven at 212° to 230° F for 1 hr; or dry in a moisture teller until dry.
3. Weigh out 50 grams of dried sample.
4. Place sample in a wash bottle.
5. Add 475 ml distilled water and 25 cc of 3 per cent solution of caustic soda.
6. Stir for 5 min with rapid sand washer, or 1 hr in a rotating sand washer.
7. Add distilled water to fill receptacle to the 1 liter marker.
8. Allow to settle 10 min.
9. Syphon the water out of the bottle to 1 in. above bottom.
10. Repeat items 7, 8, and 9.
11. Repeat items 7, 8, and 9, but allow to stand only 5 min before syphoning.

12. Repeat item 11 until water becomes clear to a depth of 5 in. in 5 min.

13. Loosen the two screws of wash bottle, and remove the base.

14. Allow solution to settle 5 min; then pour off water, being careful not to disturb sand grains.

15. Dry the sand that remains in the base.

16. Weigh the dried sand.

17. Subtract weight from original weight of sample to obtain weight of clay.

18. Compute percentage of clay.

19. Place sand grains in top sieve and turn on the sieve shaker (Ro-tap or Combs Sifter) for 15 min.

20. Weigh the sand that was retained on each sieve. Multiply each weight by 2 to obtain percentage retained on the basis of original sand sample.

21. Compute grain fineness number as described in Chapter 3.

Sintering Test

1. Place a standard dried sand specimen into sintering apparatus, and lower platinum ribbon holder over cylindrical surface of the specimen.

2. Close instrument cabinet, and adjust current rheostat to obtain 2300° F for a period of 4 min. Observe temperature with optical pyrometer attachment.

3. Raise ribbon, and determine if sand has fused to ribbon.

4. Increase temperature, and repeat items 2 and 3 at 4-min intervals until fusion is observed.

5. Record the temperature and correct for emissivity of ribbon.

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