INTERNATIONAL TEXTBOOKS IN CIVIL ENGINEERING

A MANUAL IN THE TESTING OF MATERIALS

A Manual in
The Testing of Materials

By

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Preface

The curriculum in Civil Engineering in many of the technical schools includes a course in the Testing of Materials. Because of either lack of time or limited equipment, it is not possible, in many cases, to cover more than a few general tests in these courses.

With these conditions in mind, the author has worked out a method of laboratory instruction that has been used with success for ten years and has enabled the students to complete about thirty-five distinct experiments in eighteen periods of two hours each. The method consists, in brief, of utilizing the full two-hour period in the actual performance of experiments.

At the beginning of each term the student is given the assignments of experiments to be performed during each laboratory period. He is required to read the references given for each experiment before coming to the laboratory. The students work in pairs, and the necessary apparatus is assigned and placed on the tables before the beginning of the period. When the class convenes, it is only necessary to announce the samples to be used, and the different pairs of students can then proceed with the experiments.

A report is required to be written for each experiment. The reports are simplified as far as possible by using standard report forms. Neatness, accuracy, and clearness are required in these reports, though it is not believed that the preparation of them should be made a burden to the students.

While experiments should be performed with care and according to standard methods, the aim should not be to make expert laboratory technicians of the students. It should rather be to enable the students to become familiar with the different materials used in engineering, to determine their physical characteristics, and to learn the value of the particular test to the engineer.

It is becoming the practice in many of the technical schools to offer several options in the curriculum in Civil Engineering.

The list of experiments included in this Manual will enable the instructor to select those which will fit in more closely with the student's specialized work. Likewise, it will be found that the Manual will be valuable for use in courses in the testing of materials which are designed for other than Civil Engineering students.

Note to Second Printing

The necessity for a second printing of this manual has afforded the opportunity of correcting some errors that were in the first printing. It has also been possible to bring up-to-date the references to Standards of the American Society for Testing Materials, as well as references to other books, which, since the publication of this Manual, have been revised.

Numerous suggestions have been received for the inclusion of additional experiments in the Manual, especially certain routine tests on Soils. All of these suggestions have been carefully considered. It is believed that the increase in the size of the Manual, which would necessarily be the result of adding more experiments, would detract somewhat from the original purpose that prompted its publication. The decision, therefore, has been to leave the list of experiments unchanged. Some additional material has been added to certain experiments under "Remarks," and there are three new tables giving the specifications for cut-back asphalts and for tars.

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RALEIGH, N. C.
June 1941.

Table of Contents

A Manual in The Testing of Materials

INTRODUCTION

SCOPE OF COURSE

Aims.—Two general types of tests are usually made on materials—physical tests and chemical tests. The engineer is more interested in physical tests, for from the results of these he can determine whether or not certain materials are suitable for a particular construction project. The manufacturer is interested in chemical tests, by which the character of raw materials can be controlled, and also in physical tests, by which a check can be made on the qualities of the finished product. This Manual, being intended primarily for the use of engineers and students of engineering, contains only the methods for making the more common physical tests on many materials used in construction.

A course in the testing of materials may be given with the following aims:

1. To enable students to become adept in laboratory work so that they will be fitted for positions in commercial laboratories or in the testing departments of manufacturing companies.
2. To enable students to become familiar with materials and their physical qualities.
3. To supplement descriptive courses in materials of construction with actual demonstrations of the physical qualities of the materials.
4. To demonstrate the fundamental principles of mechanics of materials.

It is believed that one or all of the last three aims will be most common for students enrolled in many engineering curricula. It should be pointed out, however, that where time is available, thorough courses in the testing of materials, consistent with the first aim, should prove most desirable.

Standard Requirements and Tests.—Most of the materials tested in the laboratory must satisfy standard requirements. Many of these requirements have been established by the American Society for Testing Materials, abbreviated A.S.T.M. Some specifications have been fixed by other organizations, states, municipalities, private corporations, and individuals. The purpose of a specific test, in general, is to determine if the material meets a particular requirement.

There are standard specifications for each test. In general, these specifications have been adopted by the American Society for Testing Materials and are described in two volumes of Standards: *Part I. Metals;* and *Part II. Non-Metallic Materials.* These volumes are issued triennially. The specifications cover the following features: (1) physical and chemical qualities of the material; (2) standard apparatus to be used; (3) detailed methods of conducting the tests.

Reference Books and Note Books.—Unless the student has consulted reference sources prior to reporting for the laboratory period, it will be desirable for him to have with him a reference book giving a detailed explanation of the tests to be performed. He will also need a note book in which he will keep a record of work done in the laboratory. Detailed specifications for the experiments are given completely in the Standards of the American Society for Testing Materials and other reference books. It is unlikely, however, that each student will find it possible to bring a copy of these Standards to the laboratory.

As an alternative, the instructor would require that a textbook in the sampling and testing of materials be purchased by each student and be available. The difficulty with this plan is that few of the textbooks contain descriptions of *all* tests that might be performed in a laboratory course in materials. Furthermore, the descriptions of apparatus and tests in such a book are not always given in the detail necessary for conducting the experiments. In that case, a copy of the A.S.T.M. Standards would have to be available for general reference, and it would be necessary for each student to have in the laboratory both a textbook and a note book.

Use of This Manual.—The preparation and publication of this Manual have been undertaken in an effort to simplify the work of the student in the laboratory, and to reduce to a minimum the number of books and note books he must have available. The Manual not only gives for each test the essential steps in performing the experiment, but also provides space for recording all notes and for entering the results of the experiment. It is, therefore, a *textbook* and a *note book* combined. Where greater detail than that given in the Manual is needed for conducting an experiment, the A.S.T.M. Standards should be consulted. If copies of these Standards are available for occasional use, then the student will generally need only the Manual in the laboratory. To this extent, laboratory work is considerably simplified. The work of the student is further standardized by providing places for recording the date of the experiment, the samples, and the results, and also blank tables for recording certain test data. Suitable charts and graphs are included, in order that the student may become familiar with their use in the laboratory. It is assumed that only standard apparatus will be available. In the Appendix, the student will find a few typical requirements for the more common materials used in construction.

Selection of Tests.—A wide variety of materials are used in construction, and there are hundreds of specified tests from which physical qualities can be determined. Obviously, it would be impracticable, and well nigh impossible, to include all these tests in a laboratory course in the testing of materials. However, enough experiments should be given to familiarize the student with laboratory practice. Thereafter, he will be able, with specifications and standards such as those of the American Society for Testing Materials to guide him, to conduct satisfactorily any desired test on a particular material. The tests described in this Manual have been selected with the foregoing idea in mind. It will be found that there is enough variety in them to afford the student practical experience with the usual apparatus, machines, and methods that are more common in laboratories for physical testing of materials.

LAYOUT AND EQUIPMENT FOR TESTING-MATERIALS LABORATORY

Space Needed.—In order to conduct laboratory instruction most efficiently, sufficient space and equipment must be available. It is believed that a section unit of twelve students is large enough for one instructor, and the suggestions given for the space needed are based upon a unit of this size. Five rooms are desirable, and these should be arranged *en suite* so as to eliminate loss of time in going from room to room. There should be a main laboratory, a supply room, a second laboratory room for heavy machines, a room for the storage of test specimens, and a conference room.

Main Laboratory.—The main laboratory should contain approximately 2,000 square feet of floor space. There should be two or more chemical-type laboratory tables that are provided with stone tops and are equipped with gas, water, and sewer connections. Outlets for steam, hot water, and compressed air are desirable, and an ample number of plug-in electric sockets should be located conveniently in the room. In this main room would be located all apparatus and machines generally used in a majority of the tests.

Supply Room.—The supply room is used for the storage of miscellaneous materials and special apparatus. About 500 square feet of floor space will be needed, though this amount can be reduced greatly by having built-in cabinets. This room should open directly into the main laboratory.

Room for Heavy Machines.—There should be a separate laboratory room for heavy equipment, such as universal testing machines, core drills, abrasion machines, grinding laps, and a concrete mixer. This equipment should not be placed in the main laboratory room, because it is used occasionally rather than frequently and the use of some of the equipment is attended with considerable noise. The amount of space needed in the second laboratory room will depend on the variety and size of the equipment. It is suggested that the required area of floor space would be at least 2,000 square feet. Bins should be provided for the storage of heavy materials, such as concrete aggregate, brick, and cement. There should be an electric panel board from which suitable current can be obtained for operating the different machines. This room also should be equipped with outlets for water, gas, and compressed air.

Room for Storing Specimens.—Where tests are conducted on concrete, it is necessary to have a suitable place for the storage of test specimens. A small *humidity room* that is conveniently located with respect to both the main laboratory and the testing machines should be provided. A floor space of 100 square feet would be ample for most laboratories. The walls should be built of brick or building tile and should be heavily coated with asphalt. Suitable connections for water and other services should be provided so that constant humidity and temperature can be maintained in the room. It will generally be found that an atomizing fan is sufficient to maintain the proper humidity, and the temperature can be regulated by the use of radiation and refrigerating apparatus.

Conference Room.—A conference room, opening into the main laboratory, is not absolutely essential, but is desirable. In a room of this kind students may be met, prior to the beginning of experiments, for outlining the work to be done. Likewise, they can use the room for detail calculations. Blackboard space should be provided. It is believed that a room with approximately 400 square feet of floor space would be satisfactory for the section unit of twelve students.

Equipment.—There are certain items of equipment for a laboratory that might be classed as general, because they are of use in tests on a variety of materials, rather than in particular tests. A partial list of such general apparatus is as follows:

Balances, ranging from rough balances to analytical balances,
Hot plates for drying materials.
Drying ovens.
Electric or gas furnaces.
Electric constant-temperature ovens.
Boiling apparatus.
Moisture closets.
Mechanical shakers for sieving operations.
Constant-temperature water baths.

There will also be required in the laboratory a large variety of special apparatus and equipment that is needed for particular tests. The specifications for these are usually exact, and the aim should be to purchase and have available only such equipment as meets standard specifications.

A number of tests described in this Manual are to be conducted with universal testing machines. It is essential that two machines be available, one of them having a capacity of at least 150,000 pounds and the other a capacity of not more than 15,000 pounds. Both machines should be equipped with all accessories, so that specimens can be tested in tension, compression, shear, and bending.

Tests on concrete products should form an important part of a laboratory course in materials. A mechanical mixer will be needed. The mixer should have a capacity of 2 cubic feet and should be equipped with an electric drive; a loading skip is not necessary.

STUDENTS' WORK IN LABORATORY

HANDLING OF APPARATUS AND MATERIALS

Care of Apparatus.—The care of equipment and apparatus is of particular importance. Students should learn early in a laboratory course that certain delicate apparatus, as well as the various testing machines, may be ruined quickly through carelessness and thoughtlessness in using them. Likewise, expensive glassware will be destroyed unless students learn to handle apparatus in a careful manner. A student should be required to pay for any apparatus or equipment that has been broken or injured through his carelessness.

Orderliness.—Many different materials will be examined and tested in the laboratory. It is easy to become careless about storing materials in their proper places. Students should keep this in mind and assist the instructor in keeping the laboratory in order. A frequent source of trouble in a laboratory is stoppage of the drainage facilities. It will be found that waste products cannot be thrown promiscuously into the sinks. Buckets or garbage pails should be provided for this purpose.

Not only should students exercise care in the handling of apparatus, but all equipment and apparatus which one group of students has used should be cleaned and left in a suitable condition for use by another group.

Sampling Materials.—In connection with many of the experiments described in this Manual, it is essential that representative samples be obtained. For cement, sand, gravel, broken stone, and similar material, this can be done best by the *quartering method.* The correct procedure for obtaining representative samples is described in detail in the references given in this Manual.

Weighing Materials.—In conducting many of the experiments, it is necessary to obtain the weights of samples. Balances and scales vary in accuracy, as different types of scales are adapted to various purposes. The proper balance or scale should be employed for each weighing. It should be used with care, and each weighing should be checked carefully.

Analytical balances are used for the most accurate weight determinations. Before a student is permitted to use them in a laboratory course, he should be given detailed instructions regarding the care to be exercised. When conducting a test, he should use them only in the manner prescribed.

PREPARATION OF REPORTS

Necessity for Reports.—A report of each experiment performed should be required. The student should look upon this not as a burden, but as a most essential and valuable part of a laboratory course. Some results which are obtained through requiring reports on laboratory work are as follows:

1. The student is enabled to evaluate properly each step in the experiment.
2. Additional time is required for calculations, some of which could not be made in class, and a report of the results is essential.
3. The student secures a general training, which can only be obtained by writing out in one's own words the different steps carried out in an experiment.

4. Time is given in which tables, curves, and diagrams may be prepared in order to complete an experiment.
5. The student is enabled to study references and give in his own words the *reasons* for performing particular experiments.

Standard Form.—The burden of writing reports may be considerably lightened through the adoption of a standard form. It is suggested that each report be written in accordance with the outline used in describing the experiment in this Manual. Also, for convenience in filing reports, the students should be required to use standard size paper and folders. The following rules should be observed in preparing and handing in reports:

(1) The reports must be in ink and written in the third person. While it is desirable to use a typewriter in preparing these reports, this is not required. Only reports prepared as indicated will be accepted. Where tables, curves, and diagrams are required in the reports, particular care should be taken to prepare them neatly; otherwise, they will be returned to the student to be redrawn.

(2) Unless otherwise directed, all reports must be in promptly at the time indicated by the instructor. At least 10 per cent should be deducted from the normal grade where reports are handed in late.

(3) The aim in a laboratory course in the testing of materials should be not so much to make expert laboratory technicians, but to enable the student to become familiar with the more common materials used in engineering construction, to determine their physical properties and characteristics, and to understand the purposes of the ordinary requirements and tests of materials which are usually included in engineering specifications. Therefore, the most important part of the student's report is that included under the heading VALUE OF TEST. Under this head the student will explain the usual requirements in specifications applying to the particular experiment, the reasons for these requirements, and the use the engineer can make of the results of the tests. The student will be expected to acquire sufficient information for writing this part of his report from the instructor, from the results of the experiment, and from assigned references.

(4) When the report for the initial experiment is handed in, the cover sheet, properly filled out, is included. Thereafter, each report that is turned in is attached to those already handed in. Only one cover sheet per term is used, and the instructor keeps all the reports of any one student properly bound together. Upon completion of the course, the student may obtain his reports if he so desires.

(5) A definite number of experiments should be assigned each section to be completed during any one term. A student who is absent from any class period should be required to make up the work and he should be given the opportunity to do this. The responsibility for making up the work, however, should rest entirely upon the student. Unless all experiments have been completed by the end of the term, and the corresponding reports, in proper form, have been handed in, the student should not be given credit for the term's work.

Originality.—The student who desires to profit most from the course in the testing of materials should endeavor to be original in writing the report of each test. While the *form* of reports is standardized, the language is not. Many students will, in the report, be inclined to use the same wording as given under "Methods" and "Value of Test" in this Manual or to copy *verbatim* from references without using quotation marks or giving the authority. This practice should be discouraged, as reports should be wholly original. It should be emphasized again that the greatest benefit from a course in the testing of materials is obtained by performing each test and then writing out in one's own words, clearly and concisely, exactly what was done.

Sample Report.—A typical student's report for an experiment is given on pages 282 and 283 of this Manual. This should serve as a satisfactory guide to students in the preparation of their reports.

SUGGESTIONS TO INSTRUCTOR

Arrangements for Efficient Use of Time in Laboratory. Laboratory work in the testing of materials should be so planned that the student will be able to proceed systematically in the performance of a particular experiment. The necessity for this is due largely to the fact that the time available for laboratory work is generally limited, while many of the experiments require considerable time. It is important, therefore, that the students report promptly at the beginning of each class period and with a clear understanding of the general methods that will be followed in performing the particular experiment. The student is expected to study the general method given in this Manual for the work assigned, and also to consult the references for additional details, before coming to class. To allow ample time for this study, the assignment for a particular period should be announced at least one week ahead.

In order to save time, all necessary apparatus to be used in a particular experiment should be assembled before a class period. Thus, with apparatus and equipment in place, and with a clear understanding of the methods of procedure, the student will be able to proceed with the work in an orderly manner and with minimum loss of time.

Division of Section Into Groups.—With large sections, it is not always possible to provide each student with all the apparatus and equipment necessary to perform an experiment. In some cases, as in performing the experiments involving the determination of the strengths of structural materials, the entire section may work as a unit. For certain other experiments, a section will be divided into parties, each consisting of two or more students. This will lessen the work of the instructor and will enable him to supervise more closely the specific experiments being conducted by the students. In every case, each student will be required to keep separate notes and to perform all calculations independently.

Assignments to Students.—It is not likely that all the experiments given in this Manual will be performed by any one section. It is suggested that the instructor make a list of those tests that more nearly meet the specialized needs of the students.

This list should be given to each student at the beginning of the course. A schedule should likewise be prepared to show the dates on which each experiment will be performed.

Duties in Connection With Use of Equipment.—Students should be taught early in a laboratory course that delicate apparatus and equipment must be handled carefully and used in a certain prescribed way. For example, when it first becomes necessary to use analytical balances in the laboratory, the instructor should give the students a detailed explanation of the method of operation and the precautions to be taken. The same procedure applies in using other pieces of equipment. At the end of an experiment, the instructor should check over the apparatus assigned to the various students and should see that it was left in proper condition.

Grading Students' Work.—The following basis of grading has been found to be satisfactory for laboratory work in the testing of materials:

(*a*) 50 per cent for the work in the laboratory and 50 per cent for the report. The grade on the laboratory work should be based on the student's knowledge of the test, his technique in the experiment, and his use and care of the equipment.

(*b*) The 50 per cent allowed for the report should be divided as follows:

1. General appearance and completeness of the report, 10 per cent.
2. Method and results, 15 per cent.
3. Value of test, 25 per cent.

The instructor should insist that reports be wholly original.

LIST OF EXPERIMENTS

The numbers and titles of all experiments described in this Manual and also the pages on which their descriptions begin are given in the following list:

SELECTED EXPERIMENTS IN MATERIALS OF CONSTRUCTION

In many educational institutions it is the practice to include in one or more engineering curricula a descriptive course in Materials of Construction. Such a course covers the sources, methods of manufacture, physical qualities, and uses of the more important building materials. The value of such a course can be greatly increased if it is supplemented by laboratory demonstrations. The following list of experiments has therefore been made up in an attempt to indicate which tests of those described in this Manual might be used in a descriptive course in Materials of Construction. Also, it will be found that many of the experiments listed here might very well be included, both for illustration and as practical tests, in courses in the Mechanics of Materials.

LIST OF REFERENCES

Under each experiment described in this Manual, there are given a few references to several standard books or other publications. The student is expected to consult these for all the details which have not been covered completely in the methods described in the following pages. The books should be placed where they will be readily available, or they may be consulted in the Central Library. It would be well for each student to provide himself with one or more of these standard books.

It should be realized, too, that the references given are not the only ones to be used. There are numerous other books and publications, covering the testing of materials, from which additional information can be gained. The student should learn to search for references, and to list those which he finds particularly useful. The various references will be helpful when writing reports of the experiments performed, and especially when discussing the *Value of the Test*.

Wherever the words that are written in quotation marks in the following list of references occur elsewhere in this Manual, they refer to the publications here designated.

1. "A.A.S.H.O." *Standard Specifications for Highway Materials and Methods of Sampling and Testing.* 1938. The American Association of State Highway Officials.
2. "A.S.T.M." *Standards of American Society for Testing Materials.* Published by the Society. Philadelphia.
3. "Barton and Doane." *Sampling and Testing of Highway Materials.* 1925 Edition. McGraw-Hill Book Company.
4. "Bauer." *Highway Materials.* 1932 Edition. McGraw-Hill Book Company.
5. "Besson." *City Pavements.* 1923 Edition. McGraw-Hill Book Company.
6. "Boyd." *Strength of Materials.* 1935 Edition. McGraw-Hill Book Company.
7. "Johnson." *Materials of Construction.* 8th Edition. John Wiley and Sons.
8. "Mills." *Materials of Construction.* 1939 Edition. John Wiley and Sons.
9. "Moore." *Materials of Engineering.* 1936 Edition. McGraw-Hill Book Company.
10. "Murphy." *Properties of Engineering Materials.* 1939 Edition. International Textbook Company.
11. "Ross." *Waterproofing Engineering.* 1919 Edition. John Wiley and Sons.

EXPERIMENTS

EXP. No. 1
DATE: . . . .

GENERAL SUBJECT: Testing of Portland Cement.

SPECIFIC OBJECT: Determination of Specific Gravity.

SAMPLE:

APPARATUS: Le Chatelier Specific Gravity Flask, Balance, Funnel, Beaker, Pan, Thermometer.

METHOD: The sample to be used should be thoroughly dry. Lumps should be removed by sifting through a No. 10 sieve. For most portland cements a sample weighing 65 grams will be correct. The exact weight of the cement must be determined.

The Le Chatelier flask is filled with kerosene to the lower graduation mark, using the lower meniscus. The temperature of the kerosene must be maintained constant throughout the test. The cement is introduced into the flask by means of the funnel. If the cement balls in the neck, it can be loosened by gently tapping the sides of the flask. When all of the cement has been poured in, a stopper is inserted, and the flask is rolled while being held in an inclined position so that air bubbles will be released. The height of the liquid is then read, using the same meniscus as in the first reading.

$$\text{Specific gravity} = \frac{\text{Weight}}{\text{Volume}}$$

RESULTS: Give individual results and the average result obtained for a particular brand of cement.

VALUE OF TEST: This is no longer a standard test on portland cement. It is given here because the method described is used with other materials, such as sand. Portland cement that has been manufactured properly should have a specific gravity of 3.1 or higher. A low specific gravity indicates age, adulteration, or underburning.

QUESTIONS AND PROBLEMS:

1. Why is kerosene, rather than water, used in this experiment?
2. Explain the necessity for maintaining the same temperature when the initial and final readings for the height of the liquid are made.

3. Consult Experiments Nos. 21 and 22 for the reason why it is necessary to obtain the specific gravity of portland cement.

REFERENCES:

Barton and Doane: Pages 74-76
Bauer: Pages 43, 176-178
Besson: Pages 146-147
Johnson: Pages 330-331, 378-379
Mills: Page 311
A.S.T.M. Serial Designation C 77-39

NOTES

EXP. No. 2

DATE: ....

GENERAL SUBJECT: Testing of Portland Cement.

SPECIFIC OBJECT: Determination of Fineness.

SAMPLE:

APPARATUS: Standard 200-Mesh Sieve with Pan and Cover, Balance, Watch, Trowel, Spatula.

METHOD: This test is extremely simple in principle, but must be carried out with strict attention to details if uniform results are to be obtained. A sample of 50 grams of cement that is dry and free from large lumps is weighed out. The sample is placed on the 200-mesh sieve and, with top and pan in position, is shaken for about 10 minutes.

The cement in the pan is then discarded, the pan is replaced, and the sieve is shaken for 1 minute as follows: The sieve is held in an inclined position in the right hand and is struck against the left hand, which is held stationary. The rate is 150 strokes per minute, and the sieve is turned through one-sixth of a revolution after each 25 strokes. At the end of 1 minute the cement in the pan is weighed. The sieving should be continued until not more than 0.05 gram of cement passes in 1 minute of continuous sieving.

When the sieving has been completed, the sieve is turned over on a clean sheet of paper and brushed with a stiff brush. The cement that was retained is then carefully weighed. The fineness is expressed as a percentage and is determined from the following formula:

$$\text{Fineness} = 100 - \frac{\text{weight retained}}{50} \times 100$$

If there is any doubt about the accuracy of the sieves, they should be standardized with cement samples of known fineness. These may be obtained from the Bureau of Standards.

RESULTS: Give individual results and the average result for each brand of cement tested.

VALUE OF TEST: The standard requirement is that at least 78 per cent of the cement must pass a 200-mesh sieve. Fineness is an important physical quality of portland cement. The finer the cement is ground, the quicker it will set, and the greater will be its strength. On the other hand, it may be necessary with finely-ground cements to use more retarder in order to delay the setting. There would seem, therefore, to be a practical limit to the fineness of portland cement.

QUESTIONS AND PROBLEMS:

1. Explain the purpose of turning the sieve during the final minute of sifting.
2. Why is it necessary that a limitation be placed on the amount of material passing the sieve during the last minute of shaking?
3. How can 0.05 gram of cement be obtained, using balances sensitive to 0.1 gram?

REMARKS:

Requirements for fineness, as determined with the No. 200 sieve, seem to have been eliminated from the standard specifications for portland cement. See A.S.T.M. Serial Designation C 9-38. The method that must be followed in performing it, however, is covered in A.S.T.M. Serial Designation C 77-39. There has come into use since 1930 the method of determining fineness with the turbidimeter. The procedure is described in detail in A.S.T.M. Serial Designation C 115-38T. The method necessitates special apparatus; its use involves too many technical details for it to be given in this Manual.

REFERENCES:

Barton and Doane: Pages 76-78
Bauer: Pages 41, 179-181
Besson: Pages 147-149
Johnson: Pages 320-331, 379-382
Mills: Pages 312-313, 320
A.S.T.M. Serial Designation C 77-39

NOTES

Exp. No. 3
Date: ....

General Subject: Testing of Portland Cement.

Specific Object: Determination of Normal Consistency.

Sample:

Apparatus: Vicat Apparatus, Stop-Watch, Hard Rubber Mold, Glass Plate 4″ × 4″, Graduate, Burette, Trowel, Spatula.

Method: This test is for the purpose of determining the amount of water to use in subsequent tests on portland cement. The amount of water is found by trial. With most portland cements, normal consistency is obtained with from 120 to 130 cc. of water to 500 grams of cement. The proper mixing of the mortar is of the greatest importance. Rubber gloves are used and the mixing is done on an impervious plane surface.

The cement—500 grams—is formed on the table into a mound. With the handle of the trowel a crater is made in the cement, and the water is poured in all at once. It is allowed to soak in for 30 seconds, during which time the cement from the outside of the mound is turned into the crater. The material is then mixed vigorously with the hands for 1 minute, the mixing being a combination of kneading and squeezing. The process may be likened to that employed in mixing dough. At the end of the mixing period the mortar is formed into a ball and is thrown from hand to hand six times, the hands being kept 6 inches apart. Students performing this experiment for the first time will require somewhat more than 1 minute for the mixing operation.

The mold is then taken in the cupped left hand, the ball of mortar is forced into the large end of the mold, and the excess mortar is cut off with the heel of the right hand. The glass plate is put on, the mold is turned over, and the excess mortar is cut off with one stroke of the trowel. The mold is then put under the plunger of the Vicat apparatus and the penetration during 30 seconds is obtained. The total time required from the instant water is added to the

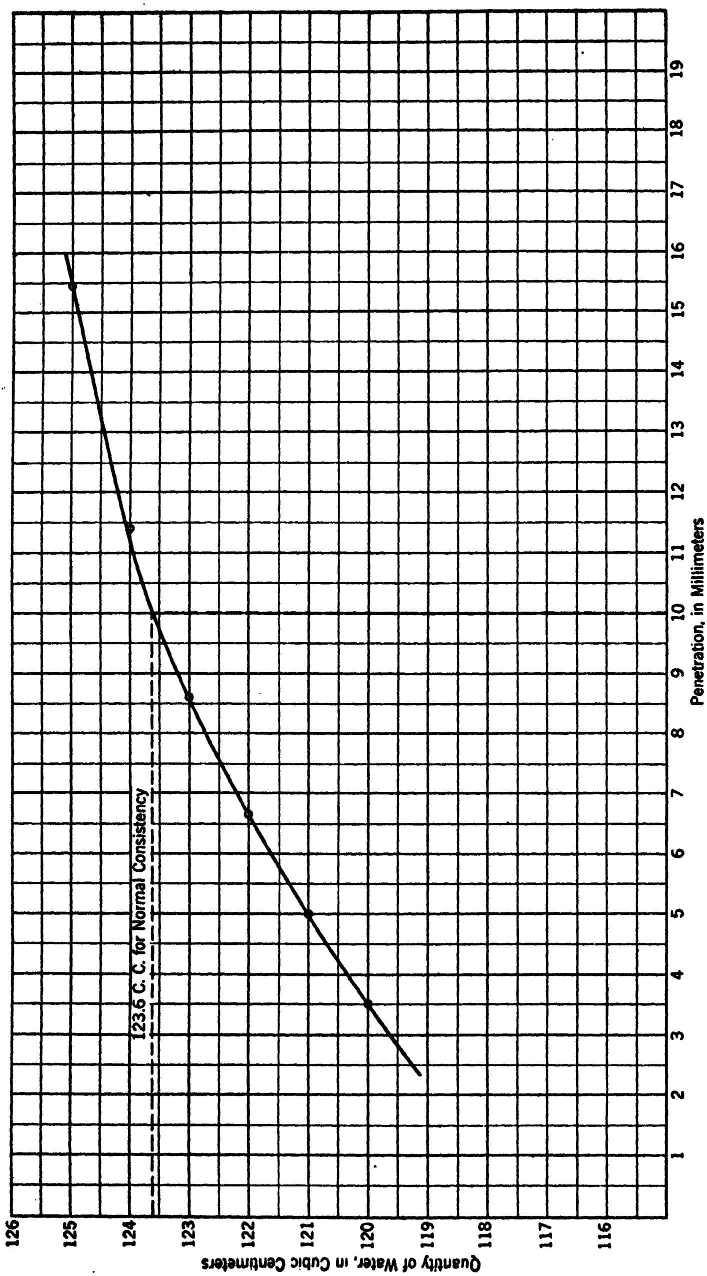

FIG. 1. CURVE SHOWING RELATION BETWEEN AMOUNT OF MIXING WATER AND PENETRATION (VICAT APPARATUS). 500 GRAMS OF CEMENT USED WITH EACH MIX.

cement until the penetration is obtained is exactly $2\frac{1}{2}$ minutes. The right amount of water has been used when the penetration is 10 mm. in 30 seconds. Varying quantities of water are used until normal consistency is obtained. This is expressed as a percentage as follows:

$$\text{Normal consistency} = \frac{\text{Amount of water}}{500} \times 100$$

It will be found helpful to plot the penetrations obtained against quantities of water used, as in Fig. 1 on page 26. This will serve to indicate the uniformity with which the mixing operations are performed.

RESULTS: Give the results for each trial, and the amount of water determined for normal consistency.

VALUE OF TEST: The standard requirement is that the plunger sink into the mortar 10 mm. in 30 seconds of time. The quantity of water used with a given amount of cement materially affects the behavior of the mortar in certain tests. It is therefore important, in order to standardize tests, that the same amount of water be used with the same cement in all laboratories. This is done by using the amount of water that produces normal consistency. The determination of normal consistency has no reference to mortars used in construction.

QUESTIONS AND PROBLEMS:

1. Why are rubber gloves used in this experiment?
2. Is there any relation between "normal consistency" and the consistency of a concrete mixture?

REFERENCES:

Barton and Doane: Pages 78-81
Bauer: Pages 182-185
Besson: Pages 149-151
Johnson: Pages 320-331, 382-385
A.S.T.M. Serial Designation C 77-39

NOTES

EXP. NO. 4
DATE: ....

GENERAL SUBJECT: Testing of Portland Cement.

SPECIFIC OBJECT: Determination of Time of Set.

SAMPLE:

APPARATUS: Vicat Apparatus with Needle or Gillmore Needles with Supports, Hard Rubber Mold, Glass Plate 4″ × 4″, Balance, Burette, Graduate, Trowel, Moist Closet.

METHOD: *Vicat Needle.*—A mix of normal consistency is prepared as in Experiment No. 3. The time of adding the water is recorded. The rubber mold filled with cement is stored in the moist closet and the following test is made at intervals: The needle is allowed to rest on the glass plate on which the rubber mold is placed. The reading is recorded. The needle is then brought in contact with the surface of the paste and released for 30 seconds. Initial set is said to have taken place when the needle sinks into the paste to within 5 mm. of the bottom in 30 seconds of time. The test is repeated from time to time until the initial set has taken place. Final set has taken place when the needle makes no indentation on the surface of the mortar. From the readings made for initial set, the exact time of set can be determined by interpolation.

Gillmore Needles.—A pat from a cement paste of normal consistency is formed on the 4″ × 4″ glass plate. The pat has the size and shape required for the *soundness test* of Experiment No. 5. The pat is stored in a moist closet maintained at a temperature of 21° C. and at a relative humidity of 90 per cent, and is tested at frequent intervals. The cement is said to have taken its initial set when the pat will bear, without appreciable indentation, the Gillmore needle that is $\frac{1}{12}$ inch in diameter and is loaded to weigh $\frac{1}{4}$ pound. The final set has taken place when the pat will bear, without appreciable indentation, the Gillmore needle that is $\frac{1}{24}$ inch in diameter and is loaded to weigh 1 pound.

RESULTS: Give the time when mixing water was added to the cement, the times when the initial and final sets took place, and also the time intervals in hours and minutes.

VALUE OF TEST: The standard requirements for portland cement are: initial set, not less than 45 minutes when the Vicat needle is used or 60 minutes when the Gillmore needle is used; final set, not over 10 hours. These requirements are necessary in order that the portland cement may be used satisfactorily in construction. Time of set is affected by fine grinding, amount of retarder, amount of mixing water used, storage conditions, and other factors.

QUESTIONS AND PROBLEMS:

1. Consult standard specifications for the maximum amount of retarder permitted in portland cement.
2. What would be an ideal cement with reference to initial and final sets?
3. What material is used for controlling the time of set of portland cement?

REFERENCES:

Barton and Doane: Pages 84-85
Bauer: Pages 189-191
Besson: Pages 154-155
Johnson: Pages 320-331, 390-391
Mills: Page 313
A.S.T.M. Serial Designation C 77-39

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EXP. No. 5
DATE: . . . .

GENERAL SUBJECT: Testing of Portland Cement.

SPECIFIC OBJECT: Determination of Soundness.

SAMPLE:

APPARATUS: Glass Plate 4″ × 4″, Balance, Burette, Graduate, Pan, Trowel, Moist Closet, Steaming Apparatus.

METHOD: A mortar of neat cement is prepared by using the percentage of water determined in the *normal consistency test.* An amount equal in size to a walnut is placed on the glass plate and is troweled until it has the shape of a cone with diameter of base 3 inches and height ½ inch. This is then placed in the moist closet for 24 hours.

At the end of the storage period the pat is boiled. The water in the boiling apparatus is brought to about 100° C., and the pat is placed on the wire shelf, which should be 1 inch above the water. The pat is then boiled for 5 hours. At the end of the test, the pat is examined for changes in volume or discoloration which may have taken place during the boiling.

RESULTS: Report appearance of pat, particularly any cracks, checking, warping, or discoloration.

VALUE OF TEST: The requirements are that the pat under this test should show no change in volume and no discoloration. This is an accelerated test, by which it is possible to determine in a short period whether the cement will be sound when used in actual construction. Soundness is affected by the presence of free lime or adulterants, or by underburning of the cement.

QUESTIONS AND PROBLEMS:

1. Consult the references and compare the effect of the accelerated test for soundness with the effect of storage of the specimens in dry air.
2. If unsoundness is due to underburning of the cement, how can this be determined definitely?
3. Why is it necessary that a cement retain a constant volume when used in construction?

REFERENCES:

Barton and Doane: Pages 81-83
Bauer: Pages 186-188
Besson: Pages 151-154
Johnson: Pages 320-331, 385-389
Mills: Pages 315-317
A.S.T.M. Serial Designation C 77-39

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Exp. No. 6
Date: ....

General Subject: Testing of Portland Cement.

Specific Object: Determination of Tensile and Compressive Strengths of Cement Mortars—Preparing Specimens.

Sample:

Apparatus:

1 4-Gang Mold	1 Beaker
2 Cylindrical Molds	1 Tamping Rod
2 Glass Plates (3″ × 14″)	Balance, Graduate, Trowel
4 Glass Plates (4″×4″)	Flow Table
1 Pan	Brass Mold

Method: A mortar is prepared, in the manner described in the *normal consistency test*, by using 250 grams of cement, 750 grams of Ottawa sand, and the amount of water indicated in the following table:

(1)	(2)	(1)	(2)
20	9.8	24	10.5
21	10.0	25	10.7
22	10.2	26	10.8
23	10.3	27	11.0

In column (1) is the per cent of water found for neat-cement paste in the *normal consistency test*; in column (2) is the corresponding per cent of water to be used for 1 part of cement and 3 parts of Ottawa sand.

The molds are assembled and greased. The gang molds are filled heaping full of the mortar, and this is pressed in with the thumbs, a pressure of about 15 pounds being exerted. The excess mortar is struck off, the molds are turned over, and the process of heaping and thumbing is repeated. The cylindrical molds are filled in layers 1 inch thick, each layer being tamped. The molds are tagged to identify them, and are stored in the moist closet for 24 hours. At the end of 1 day the molds are removed, and for the balance of the storage period they are kept in clean water maintained at 21° C. Half of the specimens are tested at the end of 7 days, and the remainder at the end of 28 days.

Since in Experiment No. 13 a mortar will be prepared having the same consistency as that of Ottawa sand mortar, it will be desirable to obtain the *flow* of the sample prepared in this Experiment. This is done by using the 10-inch flow table and the brass mold or *cone*. Immediately after the mortar is mixed, it should be placed in the cone, which is carefully centered on the flow table. The mortar is rodded twenty-five times with a $\frac{3}{8}$-inch rod, the surplus is struck off, the flow-table plate is wiped clean, the cone is removed, and then the table is given thirty drops in 30 seconds. The per cent of increase in the diameter of base of the pat, measured on two diameters at right angles to each other, is known as the flow.

RESULTS: The results of the tensile and compressive tests will be given in Experiment No. 7. Report the average flow obtained.

VALUE OF TEST: The standard requirements for 1 : 3 Ottawa sand mortar are:

	7 Days	28 Days
Tensile Test	275 lbs./in.^{2}	350 lbs./in.^{2}
Compressive Test	1,200 lbs./in.^{2}	2,000 lbs./in.^{2}

The compressive strength requirements are tentative. The tensile test affords a real determination of the physical quality of the cement, even though cement is rarely used in tension. The strength of the cement is affected by fineness of grinding, amount of water used, storage conditions, and manner of testing. Cements which fail to pass this test are definitely rejected.

QUESTIONS AND PROBLEMS:

1. Why is a 1 to 3 mortar used in this test rather than neat-cement paste?
2. Why do standard specifications require the "tensile test" rather than the "compressive test"?
3. Why is a standard sand, such as Ottawa, specified in this experiment?
4. Why are the samples stored in water?

REMARKS:

The tentative requirements for the compressive strength of cement mortars have varied from year to year. There is a definite optional requirement for high early strength portland cement. See A.S.T.M. Serial Designation C 74-39. The method of performing the test is given in A.S.T.M. Serial Designation C 109-37T. It should be noted that, for this method, 2-inch cubes are used, the sand is a *fine* Ottawa sand, the proportions of cement to sand is 1:2.77, and the water-cement ratio is 0.8 by volume.

REFERENCES:

Barton and Doane: Pages 85-91
Bauer: Pages 192-200
Besson: Pages 155-159
Johnson: Pages 320-331, 392-398
Mills: Pages 310-322
A.S.T.M. Serial Designation C 77-39

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EXP. No. 7
DATE: ....

GENERAL SUBJECT: Testing of Portland Cement.

SPECIFIC OBJECT: Determination of Tensile and Compressive Strengths of Cement Mortars—Testing Specimens.

SAMPLE:

APPARATUS: Standard Briquette Testing Machine, Universal Testing Machine (15,000-pound model), Universal Bearing Block.

METHOD: In making the tensile test, the machine should first be tested for adjustments. Without load the beam should be horizontal, and the spring-balance scales should read ZERO. The rate of flow of the shot should be adjusted so that the load will be applied at the rate of 600 pounds per minute. The specimen is then inserted in the clips, care being taken that it is firm against the backstops. The shot is released and the beam kept balanced by means of the hand crank. The breaking load is recorded from the weight of the shot. Since the minimum cross-section of the specimen is 1 square inch, the breaking load gives the tensile strength in pounds per square inch.

In making the compressive test, the machine is adjusted for balance without load. The specimen is centered between the bearing block and the head, which is run down with the high speed. Then the low speed is used, the beam being kept balanced by the movable weight until the specimen breaks. The breaking load, divided by the cross-sectional

	TENSILE STRENGTH		COMPRESSIVE STRENGTH	
	7 DAYS	28 DAYS	7 DAYS	28 DAYS
Individual Specimens				
Average				
Class Average				

area, gives the compressive strength in pounds per square inch.

RESULTS: The results should be given in a table similar to that on the preceding page.

VALUE OF TEST: This was given in Experiment No. 6 and may be omitted in this Experiment.

QUESTIONS AND PROBLEMS:

1. Why is it necessary that the rate of application of the load be specified?
2. If the diameter of the compressive specimen actually measures $1\frac{7}{8}$ inches instead of 2 inches, what per cent of error would be made in the compressive strength?

REFERENCES:

See Experiment No. 6

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Exp. No. 8
Date: ....

General Subject: Testing of Fine Aggregate.

Specific Object: Determination of Specific Gravity, Unit Weight, and Per Cent of Voids.

Sample:

Apparatus: Le Chatelier Specific Gravity Flask, Balance, Pan, Thermometer, $\frac{1}{10}$-Cubic Foot Measure, Tamping Rod, Trowel.

Method: The specific gravity of the sand is first determined by using the Le Chatelier flask as in Experiment No. 1. The sand should be thoroughly dry and should be sifted through a No. 10 sieve. The quantity to use will vary, but for most sands 55 grams will be a satisfactory amount. Water is used instead of kerosene.

The unit weight is next determined by using the $\frac{1}{10}$-cubic foot measure. This is weighed when empty and is then filled with the sand in three equal layers, each layer being tamped 25 times. The top layer is struck off with the rod, and the measure and contents are weighed. The weight of $\frac{1}{10}$ cubic foot of the sand being found, the weight of 1 cubic foot becomes known.

From the specific gravity and unit weight, the per cent of voids can be calculated readily.

Results: Report individual results and the averages obtained for all tests on a particular sample. It will be well to show the results and the calculations on an attached sheet.

Value of Test: Specific gravity is useful in determining the per cent of voids and in calculating the absolute volume of aggregate. The per cent of voids in an aggregate is helpful in designing concrete and other mixtures. Unit weight is useful in proportioning the ingredients of concrete by weight instead of by volume.

Questions and Problems:

1. Why may water be used for determining the specific gravity of the sand, when kerosene is used in determining the specific gravity of portland cement?

2. Is it necessary to control the temperature of the water within close limits in this experiment?
3. Deduce a formula for determining the per cent of voids in sand where the weight of a cubic foot of dry sand and its specific gravity are known.
4. Consult Experiments Nos. 21 and 22 to obtain illustrations of the use of specific gravities and unit weights of aggregates in designing concrete mixtures.

REMARKS:

The specific gravity obtained in the method that is outlined in this experiment is the *apparent* specific gravity. If the *bulk* specific gravity is desired, the method outlined in A.S.T.M. Serial Designation C 128-39 should be followed. For a description of terms relating to specific gravity, consult A.S.T.M. Serial Designation E 12-27.

REFERENCES:

Barton and Doane: Pages 74-76, 124-127
Bauer: Pages 271-279
Besson: Pages 185-187
Johnson: Pages 413-420
Mills: Pages 333-347
A.S.T.M. Serial Designations C 128-39, C 29-39 and C 30-37

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EXP. No. 9
DATE: . . . .

GENERAL SUBJECT: Testing of Fine Aggregate.

SPECIFIC OBJECT: Determination of Per Cent of Clay.

SAMPLE:

APPARATUS: Pan, Trowel, Stirring Rod, Balance, Evaporating Dish, Desiccator.

METHOD: It is essential that a representative sample be obtained. This is accomplished by careful quartering of the sand. A flat-bottomed pan is used, and a sample of at least 250 grams is weighed out. This is put in the pan and covered with water. It is thoroughly agitated for 15 seconds and then allowed to settle for 15 seconds. The water is then poured off, and the process repeated until the wash water is clear.

The washed sample is next put in the evaporating dish, which has been weighed while empty, and dried. The dish, with sample, is then placed in the desiccator to cool, and, after cooling, it is weighed. The per cent of clay content is obtained from the following formula:

$$\text{Per cent of clay} = \frac{\text{Original weight} - \text{Final weight}}{\text{Original weight}} \times 100$$

A check can be obtained by saving the wash water and evaporating it to dryness.

RESULTS: Report separate results and the average result obtained for a particular sample.

VALUE OF TEST: Small percentages of clay in the sand are not considered to be injurious, especially if the sand be coarse. Large percentages tend to retard the set, and to reduce the strength, of concrete. The limiting per cent is 5, and most specifications for a sand to be used in concrete require that the clay content be not in excess of 3 per cent. It should be noted that other foreign materials, such as mica and organic matter, are removed in this test.

QUESTIONS AND PROBLEMS:

1. Why is it necessary that a minimum period of time be specified for the water to settle after it has been thoroughly agitated?

2. Under what conditions would a small percentage of clay actually be advantageous in concrete mixtures?
3. In what ways are large percentages of clay injurious in concrete mixtures?

REFERENCES:

Barton and Doane: Pages 127-131 and 259
Bauer: Pages 318-319
Besson: Pages 163-164
Johnson: Pages 413-420
Mills: Pages 330-331
A.S.T.M. Serial Designation C 117-37

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EXP. NO. 10
DATE: ....

GENERAL SUBJECT: Testing of Fine Aggregate.

SPECIFIC OBJECT: Determination of Organic Impurities (Colorimetric Test).

SAMPLE:

APPARATUS: 100-cc. Graduate, Stirring Rod, 3-Per Cent Solution *NaOH*, Standard Color Solution.

METHOD: The 100-cc. graduate is used instead of the 12-oz. prescription bottle specified in the usual methods. A 3-per cent stock solution of sodium hydroxide is prepared. A representative sample of the sand is secured. The graduate is then filled with the sand to the 37-cc. mark. Enough sodium hydroxide is added to bring the height to the 58-cc. mark. The contents of the graduate are stirred and it is then set aside for 24 hours, at which time the color of the supernatant liquid is compared with the standard color solution.

A reference standard color solution shall be prepared by adding 2.5 ml. of a 2 per cent solution of tannic acid in 10 per cent alcohol to 97.5 ml. of a 3 per cent sodium hydroxide solution. This shall be placed in a graduate or bottle, stoppered, shaken vigorously, and allowed to stand for 24 hr.

RESULTS: Report if the color of the supernatant liquid is lighter or darker than the standard color solution. See A.S.T.M. Standards, 1939, Part II, Plate II, opposite page 294.

VALUE OF TEST: Organic matter in sand retards the set of concrete and lowers the strength. If the sand fails to pass this test, mortar briquettes should be made up and tested.

The method given here does not enable a determination of the *quantity* of organic matter to be made, but only indicates its presence in an injurious amount.

QUESTIONS AND PROBLEMS:

1. What organic materials are most commonly encountered in sands?

2. By consulting the references, determine the actual limiting amount of organic matter that would ordinarily be injurious in sands.
3. Assume that a sand is subjected to this test and the color of the supernatant liquid is darker than the standard color. What further tests should be made to determine if it would be safe to use the sand?

REFERENCES:

Barton and Doane: Pages 131-132
Bauer: Pages 285-286
Besson: Pages 164-165
Johnson: Pages 413-420
Mills: Pages 330-331
A.S.T.M. Serial Designation C 40-33

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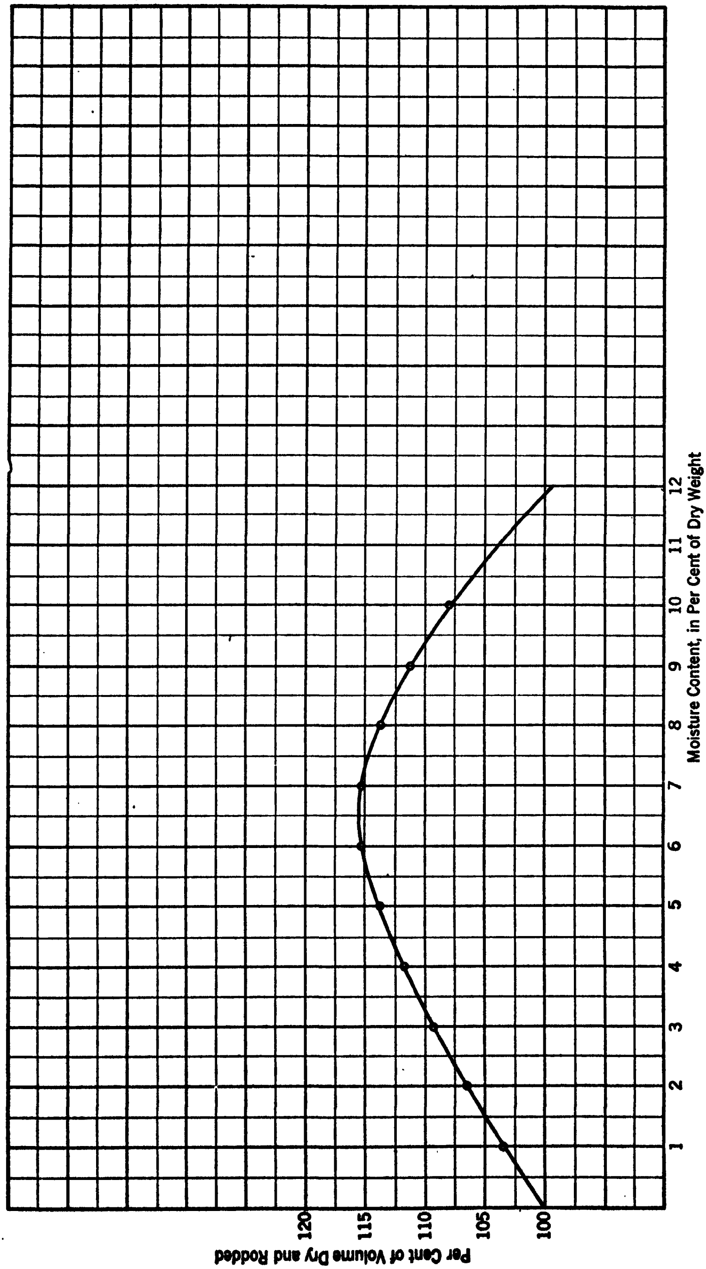

FIG. 2. RELATION BETWEEN MOISTURE CONTENT AND BULKING FOR BONSAL SAND.

Exp. No. 11
Date: ....

General Subject: Testing of Fine Aggregate.

Specific Object: Determination of Moisture Content and Effect of Moisture.

Sample:

Apparatus: Balances, Trowel, Evaporating Dish, Desiccator, 500-cc. Graduate, 50-cc. Graduate, Pan.

Method: A sample of damp sand is obtained. A definite amount is weighed out, and placed in the evaporating dish. After the sample is dried, it is put in the desiccator to cool. It is then reweighed, and the per cent of moisture is calculated on the basis of the dry weight, as follows:

$$\text{Per cent of moisture} = \frac{\text{Original weight} - \text{Final weight}}{\text{Final weight}} \times 100$$

The effect of moisture in causing bulking of the sand is next determined. The 500-cc. graduate is filled with dry sand to the 200-cc. mark. The weight of this volume of sand is then obtained. The sand is next placed in the pan and 1 per cent by weight of water is added. The sand is stirred until the mixture is homogeneous. The dampened sand is then put in the graduate, which is jarred on the palm of the hand to settle the material, and the volume is read. The process is repeated, an additional 1 per cent of water being added each time, until the volume ceases to increase. Finally, enough water is added to completely inundate the sand, when it will be noted that the volume of sand is the same as that of the original dry sample.

Results: Prepare a table giving the per cent of increase in volume with increase in moisture content. Prepare a diagram similar to that shown in Fig. 2, using the average values obtained.

Value of Test: A small percentage of moisture causes a large per cent increase in the volume of sand. Concrete mixtures are proportioned in the laboratory on the basis of dry ingredients. If the sand on the job is damp, a very appreciable error in measuring the materials by volume will result. If the ingredients are proportioned by *weight* rather than by volume, it is seen that the error will be small. Better still, if the sand is measured in an inundator, the effect of moisture in proportioning the materials is entirely eliminated.

QUESTIONS AND PROBLEMS:

1. The following are the quantities of materials for a batch of concrete:

   Cement — 1 sack
   Water — 0.90 cu. ft.
   Sand — 2.00 cu. ft.
   Stone — 4.00 cu. ft.

   The dry sand weighs 97½ pounds per cubic foot. The sand as actually used contains 4 per cent of moisture. Assuming the results of *bulking* as determined from this experiment, calculate:

   (*a*) The volume of loose, damp sand for each batch.
   (*b*) The actual quantity of water for each batch, taking into account the moisture present in the sand.

2. If sand be measured in the loose, damp state instead of *dry* and *rodded,* will the resulting concrete be *leaner* or *richer?*

REFERENCE:

Mills: Pages 347-349

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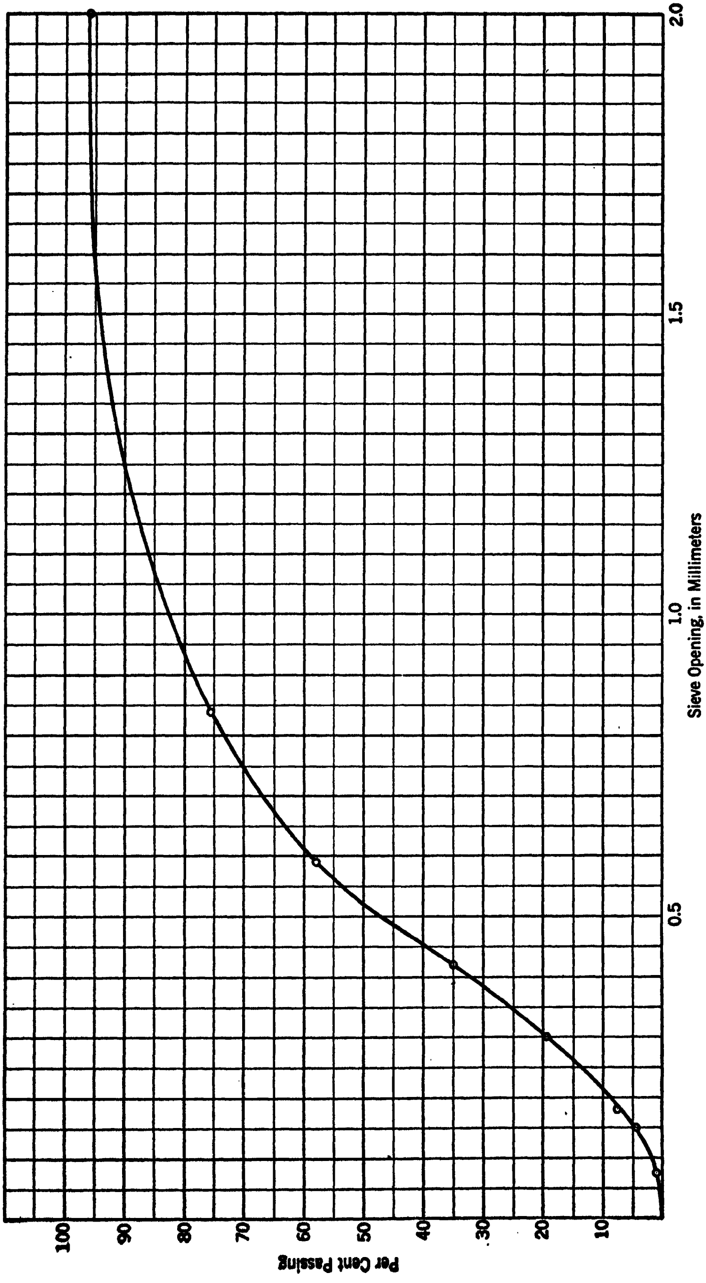

FIG. 3. SIEVE ANALYSIS CURVE FOR WATEREE SAND.

EXP. No. 12
DATE: ....

GENERAL SUBJECT: Testing of Fine Aggregate.

SPECIFIC OBJECT: Mechanical Analysis of Sand.

SAMPLE:

APPARATUS: Ro-Tap Mechanical Shaker, Trowel, Balance, Pan and Standard Sieves Nos. 10, 20, 30, 40, 50, 80, 100, and 200.

METHOD: This is a simple test in principle, but one where considerable care must be exercised if uniform results are to be obtained. It is first essential that a uniform sample be obtained by quartering. The amount of the sample will depend upon the maximum size of the material being tested, but 200 grams will be sufficient for average sands. The sieves must be of substantial construction and so woven that the openings will meet standard specifications. The larger sieves should be shaken for 10 minutes; the smaller sieves for 15 minutes. After being shaken each sieve is turned over on a large sheet of paper and cleaned with a stiff brush. The material retained on each sieve and held in the pan is weighed. If the total weights do not equal the weight of the sample, these are adjusted proportionately, provided there has been no appreciable error in weighing. The per cents retained by the sieves are then calculated, and the results are reported in the desired manner.

RESULTS: The results should be given in the form of a table on a second sheet attached to the report. Draw a sieve analysis curve similar to the one shown in Fig. 3. Openings corresponding to sieve numbers are given in Table 11, page 276.

VALUE OF TEST: This is one of the most important tests made on sands and other fine aggregates. Whenever sand is used in construction, the grading is generally specified. For concrete, a fine sand usually permits a smooth finish to be obtained, but coarser sands give greater strength. For sheet-asphalt pavements, a fine sand is to be preferred. The student should consult references and give the common specifications covering the gradation of sand for concrete.

Questions and Problems:

1. Consult A. S. T. M. specifications for requirements as to the completeness of the sieving operation.
2. What are the openings between wires for U. S. standard sieves Nos. 14 and 100? Note the ratio for the openings of the two sieves.
3. Consult the references, and compare the ideal grading for a good concrete sand with the results obtained for the sand tested in this experiment.
4. What is the grading of standard Ottawa sand used in the testing of portland cement?

References:

Barton and Doane: Pages 119-123, 258-261
Bauer: Pages 279-283
Besson: Pages 161-163, 166-168
Johnson: Pages 413-420
Mills: Pages 329-330, 334-335
A.S.T.M. Serial Designations C 136-39 and C 33-39

Table For Experiment No. 12

Sieve No.	Weight Retained	Per Cent Retained	Per Cent Passing	Class Average
10				
20				
30				
40				
50				
80				
100				
200				
Pan				
Total				

Methods of Reporting the Results of Sieve Analyses:

There are several different ways of reporting the gradation of sands and other aggregates as determined by mechanical analyses. It is the usual practice to determine the weight retained on each separate sieve and to express this as a per cent of the total material used in the analysis. These per cents will enable the results to be expressed in any desired manner. Some of the methods of reporting results are as follows:

(1) *Per Cent Retained.* As used in this Manual, this means the per cent of the material caught on each individual sieve.

(2) *Per Cent Coarser Than.* This is obtained by taking the accumulated per cents retained on the several sieves above and including the sieve considered. This method is used in obtaining the *fineness modulus* of an aggregate. For definition of fineness modulus, see page 258.

(3) *Per Cent Passing.* For the largest sieve, this is obtained by subtracting the per cent retained on that sieve from 100. For each of the other sieves, it is found by subtracting the per cent retained on that sieve from the total per cent passing the next larger sieve.

(4) *Passing and Retained.* This method utilizes the per cents obtained in method (1), but the results are expressed as follows:

Passing No. ..., retained on No. ..., ... per cent

Several methods of reporting the results of sieve analyses will be found in the Appendix in the specifications for sand and other aggregates.

For standard specifications for aggregates, including sand, for portland cement concrete, see A.S.T.M. Serial Designation C 33-39. It should be noted that in determining the grading of a sand to be used for mortars and concretes, combinations of sieves, different from that given on page 56, are used. The method of performing the test, however, is the same with any combination of sieves.

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EXP. No. 13
DATE: ....

GENERAL SUBJECT: Testing of Fine Aggregate.

SPECIFIC OBJECT: Determination of Tensile and Compressive Strengths of Sand in Comparison with Ottawa Sand.

SAMPLE:

APPARATUS: Same as for Experiment No. 6.

METHOD: The flow of a normal 1:3 Ottawa sand mortar should first be determined. The method of doing this has been outlined in Experiment No. 6. The sand to be tested should be sifted through a No. 4 sieve. The amount of water to give a mortar the same consistency as that of Ottawa sand mortar is determined by trial. Mixes of 1 part of cement and 3 parts of sand are prepared, 250 grams of cement and varying amounts of water being used, and the flow of each mix is obtained. These data are plotted on cross-section paper, a smooth curve is drawn, and the amount of water for the desired consistency is read from the diagram. The curve shown in Fig. 4 illustrates the method. It has been found that varying the water content by 5 cc. will give sufficiently accurate results. After a little experience, the operator will be able to determine the correct quantity of water without having to use a great number of trial mixes.

The object of this experiment is to determine the strengths of sand in comparison with Ottawa sand. Therefore, it will be necessary either to prepare test specimens of Ottawa sand mortars or to use the results of this test in comparison with those obtained in Experiment No. 6, both experiments being run at the same time.

The preparation, storage, and testing of the specimens are in every detail the same as for Experiments Nos. 6 and 7.

RESULTS: The student should give all data found in determining with the flow table the correct quantity of water to use. Also a flow diagram, similar to the one shown in Fig. 4, should be prepared in ink and attached to the report. The results of the strength tests may be shown in the tables on page 61.

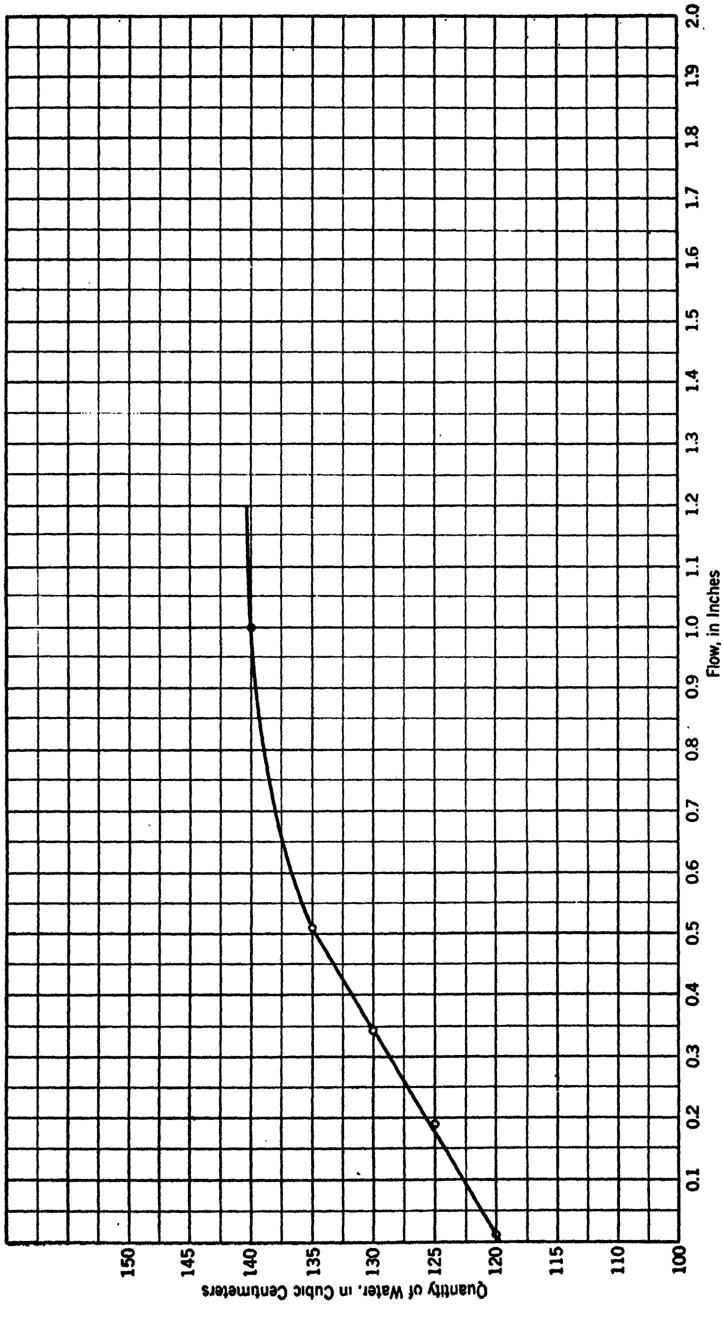

Fig. 4. Typical Flow Diagram for Wateree Sand.

POUNDS PER SQUARE INCH

SAND	TENSILE STRENGTH		COMPRESSIVE STRENGTH	
	7 Days	28 Days	7 Days	28 Days
Ottawa				
Local				

RATIO OF COMPRESSIVE TO TENSILE STRENGTH

SAND	7 Days	28 Days
Ottawa		
Local		

VALUE OF TEST: An important specification for sand is that it shall show the same mortar strength as, or a definite per cent of the strength of, a standard Ottawa sand mortar with the same mix, same cement, and same consistency, and stored and tested in the same manner. By using the flow table and following the procedure outlined in this test, the same consistency of mortar can be obtained. All of the other required conditions can be easily met. This is one of the most important tests made on sands to be used in concrete.

QUESTIONS AND PROBLEMS:

1. Why is it essential that the consistency of the sand mortar be the same as that of an Ottawa sand mortar?
2. Instead of obtaining the same consistency by the *flow table,* would it be equally as satisfactory to use the same *quantity* of water in each mix?
3. Explain why more water is usually required with a *graded*-sand mortar to give the same consistency as an Ottawa-sand mortar.
4. In general, will a mortar containing good, clean, graded sand have a *higher* or *lower* strength than that obtained with Ottawa sand for the same proportions and conditions of testing?

REFERENCES:

Barton and Doane: Pages 98-100 and 261
Bauer: Pages 295-296
Besson: Pages 168-170, 174-177
Johnson: Pages 413-420
Mills: Pages 329-333

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EXP. No. 14
DATE: ....

GENERAL SUBJECT: Testing of Fine Aggregate.

SPECIFIC OBJECT: Tests for Structural Strengths of Fine Aggregates in Mortars with a Constant Water-Cement Ratio.

SAMPLE:

APPARATUS: Same as for Experiment No. 6, with the addition of Mixing Pan and Kitchen Spoon.

METHOD: A constant water-cement ratio of 0.6 by weight shall be used. First, 600 grams of cement and 360 cc. of water are placed in the mixing pan, and the cement is permitted to absorb water for 1 minute. The materials are then mixed with a kitchen spoon so as to form a smooth paste. Saturated and surface-dried sand from a sample of known weight is then beaten into the mixture until the material appears to be of the desired consistency (flow 100 ± 5). The mixing shall be continued for 30 seconds, and a determination of the flow then made in accordance with the method outlined in Experiment No. 6.

Should the flow be too great, the mortar may be returned to the mixing vessel, additional sand added, and another determination of flow made. If the mortar is too dry, the batch shall be discarded. A record should be made of the quantity of sand used in each mix.

The 2″ × 4″ cylindrical molds are filled in three layers, each layer being rodded in place with 25 strokes of the tamping rod and the mold being filled to overflowing. The specimens are placed in the moist closet for curing. Between 3 and 4 hours after the molding, the specimens are struck off to a smooth surface; and 20 to 24 hours after molding, they are removed from the molds and stored in water until tested.

Cylindrical specimens should be carefully capped with plaster of Paris before they are tested. The methods of testing are the same as those given in Experiment No. 7.

RESULTS: Report quantities of materials used in each mix, the proportions used for correct flow, and the results of compressive tests.

Value of Test: See Experiment No. 13.

Questions and Problems:

1. Determine the water-cement ratio by volume corresponding to the water-cement ratio of 0.6 by weight.
2. Why is it necessary to discard the trial batch if the mortar is too dry, as indicated by the flow?
3. Give the essential differences in the methods of obtaining the strengths of the sand by Experiment No. 13 and by this experiment.

Remarks:

The structural strength of sand as obtained in this experiment is generally compared with the strength of mortars made in the same manner but using a graded Ottawa sand with a Fineness Modulus of 2.40 ± 10. The proper grading can be obtained approximately by using equal parts by weight of standard Ottawa sand and run-of-mine Ottawa sand. See A.S.T.M. Serial Designation C 33-39.

References:

See Experiment No. 13
A.S.T.M. Serial Designation C 87-39

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EXP. NO. 15
DATE: ....

GENERAL SUBJECT: Testing of Coarse Aggregate.

SPECIFIC OBJECT: Determination of Specific Gravity, Unit Weight, and Per Cent of Voids.

SAMPLE:

APPARATUS: Beaker, Silk Thread, Thermometer, Bridge, Analytical Balances, ½-Cubic Foot Measure, ⅝-Inch Tamping Rod, Platform Balance.

METHOD: The sample must be dried to constant weight at a temperature between 100° C. and 110° C. The apparent specific gravity of the aggregate must first be determined. The displacement method is used. This is described in A.S.T.M. Serial Designation C 127-39.

For large and homogeneous aggregate the apparent specific gravity may be found from a single piece of the stone. A small bridge is fitted over the pan of the analytical balances, care being taken that it does not touch the pan at any point. The stone is suspended from the hook of the balances by means of the silk thread. Its weight in air is then determined and recorded as weight *A*. The sample is next immersed in water for 24 hours, at the end of which time it is taken out, the surface water is blotted or wiped off, and the sample is reweighed while suspended by the silk thread. This will be weight *B*. A beaker of distilled water at 25° C. is placed on the bridge, and the sample is immersed in it. The weight of the sample immersed in water is obtained and recorded as weight *C*. Then:

$$\text{Apparent specific gravity} = \frac{A}{B-C}$$

The unit weight is then obtained just as in Experiment No. 8, but the ½-cubic foot measure is used. From the specific gravity and the unit weight, the per cent of voids can be calculated readily.

RESULTS: Report individual results and the average of the class. If the student prefers, the results, as well as the detailed calculations, may be shown on an attached sheet.

VALUE OF TEST: The value of this test is substantially the same as that for Experiment No. 8. The results of these tests for the physical qualities of the stone are essential in an exact proportioning of the ingredients of concrete mixtures.

QUESTIONS AND PROBLEMS:

1. How would the absolute specific gravity of a stone be obtained?
2. Explain the reason for using distilled water in this experiment and maintaining the temperature at 25° C.
3. The unit weight of a crushed granite is 95 pounds per cubic foot and the voids are 42 per cent of the volume of the stone. Calculate the specific gravity of the stone.

REFERENCES:

Barton and Doane: Pages 141-143, 145-148
Bauer: Pages 274-279
Besson: Pages 165-166, 185-187, 305-306
Mills: Pages 333-347
A.S.T.M. Serial Designations C 29-39, C 30-37 and C 127-39

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EXP. No. 16
DATE: ....

GENERAL SUBJECT: Testing of Aggregates.

SPECIFIC OBJECT: Sieve Analysis of Aggregates.

SAMPLE:

APPARATUS: Ro-Tap Machine, Standard Sieves, Balances, Pan, Brush, Trowel.

METHOD: The method here used is substantially the same as that used in Experiment No. 12, though this method applies specifically to aggregates for concrete. This method is applicable to samples of fine and coarse aggregates tested separately, or to a combination of them.

The size of sample for fine aggregate is 500 grams. For coarse aggregate the weight of the sample in grams is equal to 3,000 times the size of the largest required sieve opening in inches. The materials are dried to constant weight, and a representative sample is obtained by quartering. The sieving is continued until not more than 1 per cent by weight of the residue passes any sieve during one minute of sieving. The procedure thereafter is the same as outlined in Experiment No. 12. The per cent, by weight, of the total sample which is finer than each of the sieves shall be computed.

RESULTS: The results should be given in the form of a table on a second sheet attached to the report. A sieve analysis curve, similar to the one shown in Fig. 3, should be plotted.

VALUE OF TEST: Careful proportioning of the ingredients of concrete results in both better and more economical mixtures. In order to obtain the most satisfactory mixture, it is necessary to know the grading of all the aggregates used. Specifications generally limit the maximum and minimum sizes of the coarse aggregate. For the fine aggregate, the limits are usually specified for the percentages passing the No. 50 and No. 100 sieves.

QUESTIONS AND PROBLEMS:

1. Consult the references and note how closely the grading of the aggregate used in this experiment approximates Fuller's curve.

2. Compare the grading for the aggregate tested in this experiment with the grading for crushed stone as given on page 260.
3. What determines the maximum size of aggregate permitted in a concrete mix? In general, if the maximum size of aggregate has been specified, what determines the grading from coarse to fine?

REFERENCES:

Barton and Doane: Pages 138-141, 266-271
Bauer: Pages 279-283
Besson: Pages 161-163, 166-168
Johnson: Pages 420-426
Mills: Pages 334-335
A.S.T.M. Serial Designation C 136-39 and C 33-39

TABLE FOR EXPERIMENT NO. 16

SIEVE	WEIGHT RETAINED	PER CENT RETAINED	PER CENT PASSING	CLASS AVERAGE
3″				
2″				
1½″				
1″				
¾″				
⅜″				
No. 4				
No. 8				
No. 14				
No. 28				
No. 48				
No. 100				
Pan				
Totals				

NOTES

Exp. No. 17
Date: ....

General Subject: Testing of Aggregates.

Specific Object: Determination of Mixture of Aggregates for Maximum Density.

Samples:

Apparatus: ½-Cubic Foot Measure, Platform Balance, Tamping Rod, Scoop, Trowel.

Method: The general procedure consists in determining the unit weights of mixtures of sand and stone of varying proportions. That mixture, the unit weight of which is the greatest, will be the combination giving maximum density. The ½ cubic foot of coarse aggregate obtained in Experiment No. 15 can be used. Sand is added so as to give the percentages of sand and stone desired. The method is illustrated in the following tabulation:

Sand	Stone	Sand Pounds	Stone Pounds	Unit Weight Pounds
0%	100%	0.0	47.0	94.0
10%	90%	5.22	47.0	....
20%	80%	11.75	47.0	....
....	....	....	....	....
....	....	....	....	....
100%	0%	48.0	0.0	96.0

This method will not apply where there is any great difference in the unit weights of the two materials. It is usually only necessary to add sand until the weight ceases to increase. The results are then plotted on cross-section paper and a curve of density is drawn as illustrated in Fig. 5. From the curve the exact mixture to give maximum density can be determined.

Results: Report results in the form of a table like the one shown under "Method". Prepare a diagram similar to the one in Fig. 5. Report the per cents of fine and coarse aggregates which give maximum density.

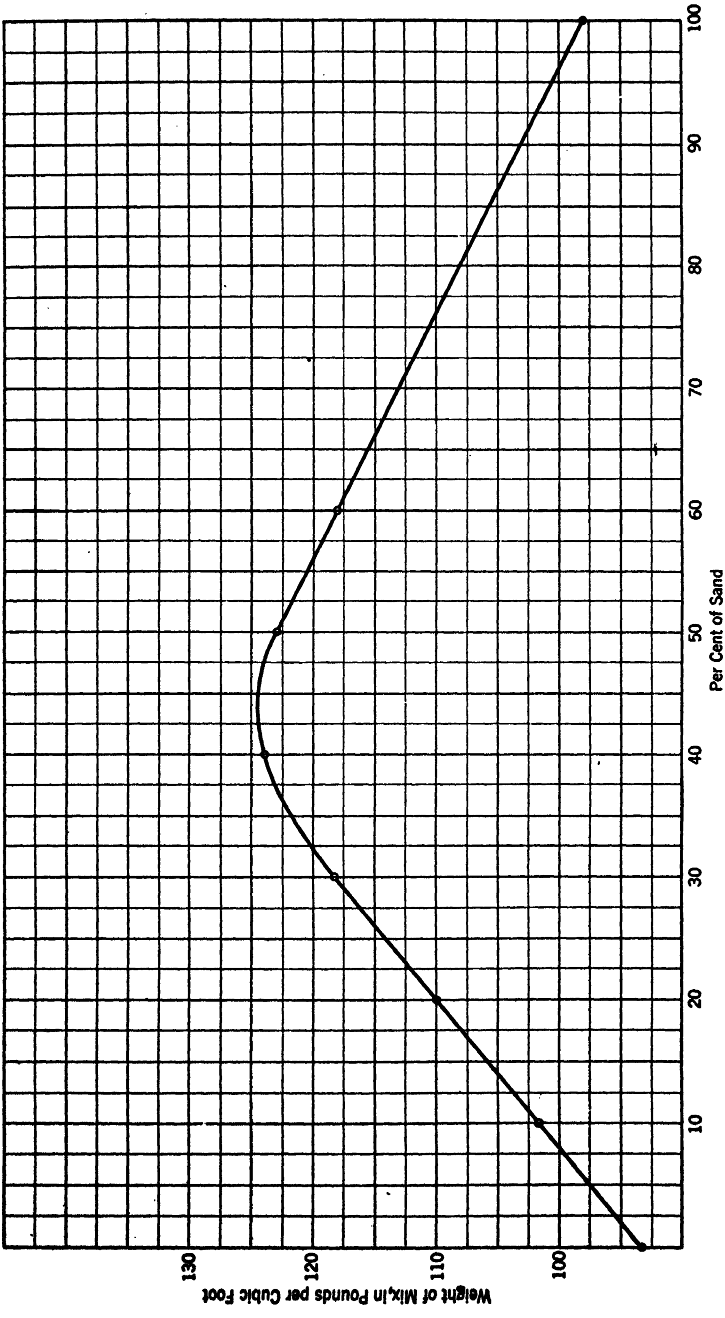

Fig. 5. Density Curve for Goldsboro Sand and Crushed Stone.

VALUE OF TEST: Maximum density is useful in proportioning the ingredients of concrete. The theory is that the best mixture of coarse and fine aggregates is the one which has the greatest unit weight, or maximum density. In practice, the use of this method provides a starting point for proportioning the ingredients. The quantities of sand and stone should then be varied by a few per cent, and the concrete mixture that gives the best yield for the strength desired should be used.

QUESTIONS AND PROBLEMS:

1. Under what conditions is the method used in this experiment not applicable?
2. Explain why a cubic foot of a mixture of sand and broken stone generally weighs more than a cubic foot of either material alone.

REFERENCES:

Barton and Doane: Pages 141-142
Besson: Pages 193-195
Mills: Pages 333-335

NOTES

NOTES

PROPORTIONING THE INGREDIENTS OF CONCRETE

Methods of Proportioning.—The careful proportioning of the ingredients is considered to be of primary importance in obtaining concrete that will be both of good quality and economical. The desired qualities of the concrete are strength, durability, appearance, and (frequently) imperviousness to water. Also, the consistency of the concrete mixture should be such as to produce the desired workability. The purpose and object in designing a concrete mixture is to produce with available materials a concrete that will combine the desired physical characteristics with reasonable economy.

The engineer can obtain a suitable mixture by preparing various combinations of aggregates with different proportions of cement, testing these combinations under similar conditions, plotting the results in the form of charts, and adopting the combination that gives the desired strength (usually the criterion) with the greatest yield (maximum economy). However, this procedure, being essentially a "cut and try" method, is laborious and wasteful of time. It is therefore desirable to narrow the range of possible combinations of ingredients. This has been attempted by numerous investigators, with the result that by utilizing certain principles it is now possible to design a concrete of predetermined qualities and of suitable economy without using a great number of trial mixes.

Various methods have been proposed for designing concrete mixes, but only the *water-cement-ratio method* and the *cement-space method* are used in this Manual. They are not considered entirely superior to other methods. Their use, however, illustrates the general procedure in proportioning the ingredients for concrete and in making the detailed calculations that are so necessary in laboratory control.

Water-Cement-Ratio Method.—The water-cement-ratio method depends on a law formulated by the Portland Cement Association some years ago. According to this law, concrete of the same strength is obtained with all combinations of aggregates and with a constant water-cement ratio, *provided* the mixture is workable. The water-cement ratio is the ratio of the volume of mixing water, in cubic feet, to the volume of a sack of cement,

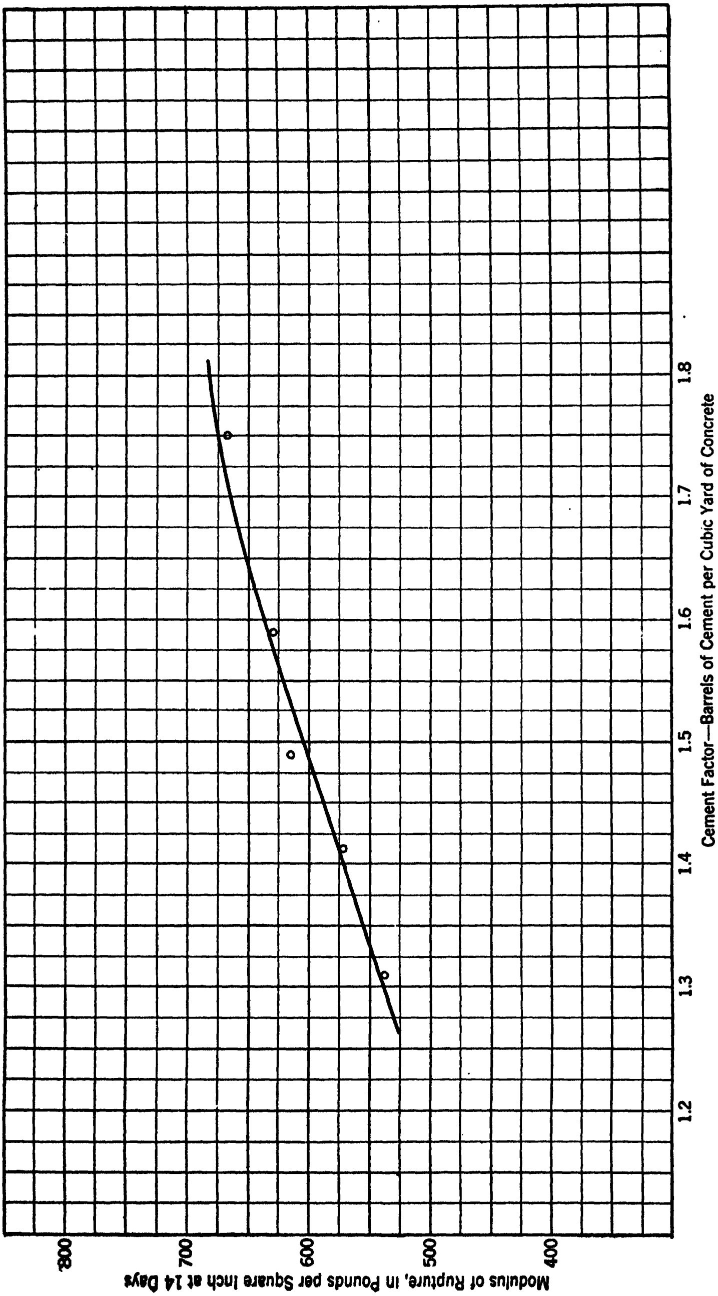

Fig. 6. Relation between Modulus of Rupture and Cement Factor for Concrete at Age of 14 Days. Based on Tests using North Carolina Sands and Gravel of Good Quality.

which is taken as 1 cubic foot. This ratio is frequently expressed as the number of gallons of water per sack of cement. In the application of this law, it is assumed that the aggregates are structurally sound and of good quality. The use of this method is shown in detail in Experiment No. 21.

Cement-Space Method.—The cement-space method depends on the general assumption that there is a relation between the strength of concrete and the volume of the space occupied by the cement paste. The general law may be stated as follows: The greater the number of pounds of cement per cubic foot of space occupied by the cement paste, the higher will be the strength of the resulting concrete. In practice, a number of trial mixes must be prepared with varying cement contents. For each mix the number of pounds of cement per cubic foot of space occupied by the cement paste must be calculated. Test cylinders are prepared, stored, and tested for strength. The strength is then plotted against cement space, and a curve showing the relationship is drawn.

With a standard strength-cement-space curve, the procedure is fairly simple. The desired strength being known, the corresponding number of pounds of cement per cubic foot of space occupied by the cement paste is read from the chart. However, a mix with the correct amount of cement cannot be readily obtained, since the space occupied by the cement paste varies with the volume of wet concrete. In practice, several trial mixes are prepared by using varying quantities of cement. From the actual volumes of wet concrete, the number of pounds of cement per cubic foot of space occupied by the cement paste will be determined. It is then easy to obtain by interpolation the exact amount of cement to use. The detailed procedure is explained and illustrated in Experiment No. 22.

The student is cautioned against confusing the *amount of cement used in proportion to the aggregates* with the *pounds of cement per cubic foot of space occupied by the cement paste.* They are quite different. The first is measured out and is known; the second is calculated from the absolute volumes of the aggregates and the known volume of the wet concrete.

Variable Factors in Design of Concrete Mixtures.—It is well to point out that a number of variable factors are encountered in designing concrete mixtures. Some of these factors are as follows:

Maximum size of aggregate
Gradation of coarse aggregate
Gradation of fine aggregate
Proportion of fine aggregate to coarse aggregate
Cement content
Water content

Practical Procedure.—The number of combinations of materials that might be used to produce the desired quality of concrete is almost infinite. However, the quality of concrete will vary with variations in the factors mentioned in the preceding article. It is necessary, therefore, for the investigator or engineer to eliminate as many of the variables as possible. This can be done by fixing the maximum size of aggregate, by standardizing the grading of the fine and coarse aggregate, and by selecting the ratio of fine aggregate to coarse aggregate. The range of possible combinations can be narrowed further by selecting the workability or the consistency for the mixture.

There are then left only two major variables, namely, the amount of mixing water and the cement content. These may be varied in trial mixes until a suitable strength has been obtained.

If the problem in the laboratory is to obtain a desired strength, this may be accomplished by preparing trial mixes with varying cement contents, molding cylinders, testing these, and preparing a diagram in which the strength is plotted against the cement used. The cement content for the desired strength can then be read from the chart. A chart of this kind is shown in Fig. 6, where the modulus of rupture is plotted against the cement factor. The quantities of cement used in concrete mixtures are expressed in various ways. The term *cement factor,* meaning the number of barrels of cement per cubic yard of wet concrete, is frequently used.

Exp. No. 18
Date: . . . .

General Subject: Testing of Concrete Mixtures.

Specific Object: Determination of Consistency by the Slump Cone and the Flow Table.

Samples:

Apparatus: Slump Cone, ⅝-Inch Rod, Flow Table with Mold, Mixing Pan, Measuring Devices, Balances.

Method: A concrete mixture is prepared, an accurate record being kept of the weights of all the ingredients. A trial mix can be obtained as follows: The proportions of sand and stone are determined by the *maximum density method* described in Experiment No. 17. The ratio of water to cement, by volume, is taken from a water-cement-ratio curve. Definite quantities of aggregates (totaling about 40 pounds) are put in the mixing pan, and water and cement in the proper ratio are added. The materials are thoroughly mixed with the trowel. If the mixture appears too dry, more water and cement are added; if too wet, more aggregates are added. When it appears that the desired consistency has been obtained, the mixture is tested as follows:

Slump Cone: The slump cone is placed on a firm non-absorbent surface. The concrete mixture is put into the mold in three layers, each approximately one-third the volume of the mold. Each layer is rodded 25 times. The strokes shall be distributed in a uniform manner over the cross-section of the mold and shall penetrate into the underlying layer. The bottom layer shall be rodded throughout its depth. When the mold has been filled and rodded, the top layer is struck off and the mold is slowly removed. The height of the mound of concrete is measured, and the "slump" is taken as 12 inches minus this height. While filling the mold, care must be taken to hold it down firmly.

Flow Table: The flow-table mold is filled in two layers, each layer being puddled by 25 strokes with the ⅝-inch rod. The top is struck off and the mold is removed immediately. The crank is then turned 15 times in 6 seconds. The average diameter of the mass of concrete on the table is obtained. This will give the flow of the mixture. The flow may also be expressed as a per cent as follows:

$$\text{Flow} = \frac{\text{New diameter} - \text{Old diameter}}{\text{Old diameter}} \times 100$$

RESULTS: Report quantities of materials used, and the slump and flow obtained. If more than one mixture is used, report results for all combinations tested.

VALUE OF TEST: It is important, both on the job and in the laboratory, that the consistency or workability of a concrete mixture be controlled. The consistency can be determined by either of the methods here described, though the slump cone is more convenient for use in the field. Where the "slump" is specified on a particular job, frequent tests of the mixtures and adjustment of the quantities will enable uniform workability to be obtained. The following slumps are usual in construction work:

For puddled concrete	1 – 2 inches
For pavement	2 – 4 inches
For reinforced concrete	4 – 6 inches

QUESTIONS AND PROBLEMS:

1. What are the limitations in the use of the slump cone for measuring the consistency of concrete?
2. What methods, rather than the slump cone and flow table, are in common use for determining the workability of concrete mixtures?
3. Give several reasons why the flow table is a more accurate means of measuring the consistency of concrete than the slump cone.

REFERENCES:

Barton and Doane: Pages 94-100
Besson: Pages 173-177
Mills: Page 336
A.S.T.M. Serial Designation C 124-39 and C 143-39

NOTES

Exp. No. 19
Date: ....

General Subject: Testing of Concrete Mixtures.

Specific Object: Preparation of Concrete Cylinders and Beams.

Samples:

Apparatus: Measuring and Weighing Devices, Mixing Pan, Trowel, 6″ × 12″ Cylindrical Molds, ⅝-Inch Tamping Rod, 6″ × 6″ × 30″ Beam Molds.

Method: This experiment is run in connection with the design of a concrete mix in Experiments Nos. 21 and 22. The proportions of the ingredients will have been determined. The larger mixing pan is used and enough material is weighed out to fill two cylindrical molds and two beam molds. A square-pointed shovel may be used to mix the materials instead of the mason's trowel. Mixing may be accomplished with a power machine, though this will not be satisfactory for small batches.

The cylindrical molds are cleaned thoroughly, greased, and assembled. The base plates should likewise be cleaned and greased. Immediately after the mixing has been completed, the molds are filled. The concrete is put in the molds in layers 3 to 4 inches in thickness, each layer being tamped 25 times. After the top layer is puddled, it is struck off with the trowel and the mold is covered with a glass plate. Within 2 to 4 hours after molding, the cylinders are capped with a thin layer of neat-cement paste. The surface of this is worked down by means of a piece of plate glass.

The beam molds are assembled, cleaned, and greased. The concrete is put in the molds in layers about 2 inches in thickness, each layer being puddled about 50 times with the tamping rod. When the mold is full, the top is struck off with the tamping rod.

The filled molds are placed in the humidity room. The humidity should be maintained between 95 and 100 per cent, and the temperature between 60° F. and 75° F. The molds are removed at the end of 24 hours, and the test specimens are marked for identification and left in the humidity room until tested.

RESULTS: The method of making the compressive and transverse tests on concrete will be described in Experiment No. 20. Therefore, no results are given in this experiment.

VALUE OF TEST: Concrete is used largely in compression. From the results of crushing-strength tests, therefore, the safe load for concrete structures can be determined. Then, too, it is possible by these tests, and by using various mixtures in the laboratory, to select that mixture which will give the desired strength and will be the most economical. When strength requirements are specified on the job, it is necessary that frequent test cylinders be molded to determine if the concrete is of the proper quality.

The transverse test is made for the purpose of determining the modulus of rupture of concrete. This information is useful in designing concrete roads, culverts, and certain other concrete structures.

QUESTIONS AND PROBLEMS:

1. Why is it necessary to cap the cylinders within 4 hours after they are molded?
2. Explain the necessity for rodding the wet concrete into the molds.
3. Why is it necessary to maintain both humidity and temperature within close limits in the humidity room? What satisfactory methods of storage may be used in the absence of a humidity room?

REFERENCES:

Barton and Doane: Pages 100-112
Besson: Pages 177-180
Johnson: Pages 458-476
Mills: Pages 369-381
A.S.T.M. Serial Designations C 31-39, C 39-39 and C 78-39

NOTES

EXP. No. 20
DATE: ....

GENERAL SUBJECT: Testing of Concrete Mixtures.

SPECIFIC OBJECT: Determination of Crushing Strength and Transverse Strength.

SAMPLES: See Experiment No. 19.

APPARATUS: Universal Testing Machine, Spherical Bearing Block, Knife Edges and Base.

METHOD: The specimens must be tested immediately upon being removed from the humidity room. The spherical bearing block is attached to the upper movable head of the testing machine. The beam should be balanced at ZERO when there is no load on the machine. The load is applied at a rate which will cause the head to move 0.05 inch per minute. The setting of the rheostat arm for this speed should be determined before starting the test.

The cylinder is placed on the lower bearing block and centered relative to the upper spherical bearing block. By using the high speed, the head is run down until just on the point of making contact with the top of the cylinder. The slow speed is then used, and the rheostat arm is set at the point previously determined. The beam is kept balanced either mechanically or by hand. In general, only the ultimate crushing load needs to be observed. This will usually be indicated when the beam drops. For 6-inch cylinders the ultimate compressive unit stress S_c, in pounds per square inch, will be:

$$S_c = \frac{P}{\pi r^2} = \frac{P}{28.2744}$$

where P = ultimate crushing load, in pounds.

For the transverse test, two knife edges are spaced on the bed plate of the testing machine so that the span will be exactly 24 inches. The third knife edge is affixed to the movable head of the machine. The lower knife edges and the concrete beam are then centered under the upper knife edge. The 15,000-pound counterpoise should be used. The remainder of the test is carried out as described for the compression test. The modulus of rupture R, in pounds per square inch, is calculated from the following formula:

$$R = \frac{1.5\,Pl}{bd^2}$$

where
P = breaking load, in pounds;
l = span, in inches;
b = width, in inches;
d = depth, in inches.

For a span of 24 inches, and $b = d = 6$ inches, the formula becomes

$$R = P/6$$

In many laboratories the modulus of rupture is determined by testing the concrete beam as a cantilever. A portion of the beam is clamped rigidly in the machine and an extended arm is fitted onto the free end of the beam. The load is applied to the end of the arm by a shot loading device or by a dynamometer. With a lever arm of 54 inches and a 6″ × 6″ beam, the modulus of rupture would be given by the formula

$$R = 1.5\,P + K$$

where K is the initial stress due to the weight of the extended arm and the dynamometer.

RESULTS: Report all loads for individual specimens, the ultimate stresses in pounds per square inch, and the averages for each series of tests.

VALUE OF TESTS: This has been discussed in Experiment No. 19. It should be noted that extreme care must be exercised in making these tests if uniform results are to be secured.

QUESTIONS AND PROBLEMS:

1. Deduce the last two formulas given under "Method".
2. Deduce a formula for the modulus of rupture if the loading is at the third-points of the beam.
3. Why is it essential that the load, for the compressive test, be applied uniformly and at a specified rate?
4. Observe the fractured ends of the beam and note whether the aggregate broke or was pulled from the mortar.

5. Note the surfaces along which the cylinders failed. For a homogeneous material similar to concrete, what should be the typical shapes of the broken portions of the cylinders?

REFERENCES:

See Experiment No. 19, and
Murphy: Pages 16-28

NOTES

EXP. No. 21
DATE: ....

GENERAL SUBJECT: Testing of Concrete Mixtures.

SPECIFIC OBJECT: Design of a concrete mixture of predetermined strength, by using the Maximum-Density Theory for determining the proportions of sand and stone, the Water-Cement-Ratio Theory for fixing the quantity of water, and the Slump for determining the proportions of aggregates and cement.

SAMPLES:

APPARATUS: All the apparatus used in Experiments Nos. 18 and 19.

METHOD: In order that the student may understand the method to be followed in designing a concrete mixture of predetermined strength, the different steps are worked out in detail for an assumed case. The students will be expected to obtain their own data and the proper results for the materials which are being tested.

The separate materials to be used in this experiment have been previously tested and their physical characteristics determined. They will be combined into concrete, molded into cylinders and beams, cured in a humidity room, and finally tested, all of which will be done in accordance with uniform methods and by using standard apparatus.

1. PRELIMINARY ASSUMPTIONS:
   a. Desired strength at 28 days ....2,000 lbs./in.^{2}
   b. Water-cement ratio 0.96
   (See diagram, page 263)
   c. Slump ....4 inches

2. DATA ON AGGREGATES:

The following data on the aggregates used have been determined:

MATERIAL	SPECIFIC GRAVITY	PER CENT VOIDS	UNIT WEIGHT LBS./CU. FT.
Sand	2.63	37.69	102.2
Broken stone	2.65	42.40	95.25

3. Determination of Proportions of Sand and Stone for Maximum Density:

The maximum-density method of proportioning the fine and coarse aggregates is described in detail in Experiment No. 17.

For the illustrative problem used here, it was found that the proportions, by weight, of sand and stone in the mixture which gave maximum density were:

Sand	38 per cent
Stone	62 per cent

4. Preparation of Mixture for Desired Slump:

Any quantity of cement may be taken. It is convenient to use 9.4 lbs., as that quantity is exactly one-tenth of a cubic foot. The weight of water for this quantity of cement will then be:

$$0.96 \times \frac{1}{10} \times 62.4 = 6.0 \text{ lbs.}$$

A flat-bottom pan about 2 feet square and 3 inches deep is used, and the water and cement are mixed to a paste in this pan. Sand and stone, in the proportions of 38 per cent of sand and 62 per cent of stone, are added to the paste and the whole is thoroughly mixed. The addition of sand and stone to the mix is continued until the desired consistency is reached, as measured by the slump of the concrete. A detailed description of the method of determining the slump of a concrete mix is given in Experiment No. 18.

With the materials used in this problem, it was found that the following quantities gave a concrete mixture of the desired consistency:

Cement	9.4 lbs.
Water	6.0 lbs.
Sand	20.3 lbs.
Stone	33.2 lbs.

5. Preparation of Test Cylinders:
(See Experiment No. 19.)

6. Storage of Test Cylinders:
(See Experiment No. 19.)

7. Testing of Cylinders:
(See Experiment No. 20.)

8. Proportions Used by Weight and Volume:

The proportions of materials used by *weight* will be:

Cement		Sand		Stone	
9.4	:	20.3	:	33.2	; or, dividing by 9.4,
1	:	2.16	:	3.53	

The volumes used will be:

Cement: 9.4/94 = 0.100 cu. ft.
Sand: 20.3/102.2 = 0.199 cu. ft.
Stone: 33.2/95.25 = 0.349 cu. ft.

The proportions by *volume* will be:

Cement		Sand		Stone	
0.10	:	0.199	:	0.349	; or, dividing by 0.10,
1	:	1.99	:	3.49	

9. Comparison with Method of Voids:

A combination of 38 per cent of sand and 62 per cent of stone actually weighs 124 pounds per cubic foot. The weight of sand and stone in each cubic foot is as follows:

$$\text{Sand} \ldots\ldots\ldots \frac{38}{100} \times 124 = 47.12 \text{ lbs.}$$

$$\text{Stone} \ldots\ldots\ldots \frac{62}{100} \times 124 = 76.88 \text{ lbs.}$$

Volume of Sand: 47.12/102.2 = 0.461 cu. ft.
Volume of Stone: 76.88/ 95.25 = 0.807 cu. ft.

Ratio of sand to stone by volume = 0.461/0.807 = 0.571

If the method of voids were used in proportioning the sand and stone, the ratio of sand to stone would be 0.424, since the per cent of voids in the stone is actually 42.4. It is seen, therefore, that the maximum-density method gives a considerably greater ratio of sand to stone.

10. Yield:

The yield may be measured or calculated. In general, the calculated yield should be slightly less than the measured yield.

Measured Yield: The mixture of concrete having been prepared with the proper quantities of materials, it is carefully rodded into one of the unit measures, and its volume is measured. This volume is then used for determining the yield per sack of cement and the cement factor, as follows:

Measured volume of concrete = 0.472 cu. ft.

Concrete per sack of cement = $10 \times 0.472 = 4.72$ cu. ft.

Sacks of cement per cubic yard of concrete $= \frac{27}{4.72} = 5.72$

Barrels of cement per cubic yard of concrete $= \frac{5.72}{4} = 1.43$

The measured yield of the concrete can be obtained more easily and, perhaps, more accurately by weighing a unit volume of the wet concrete. The volume of the mix would then be:

$$\text{Total volume} = \frac{\text{Total weight of all materials}}{\text{Weight of unit volume}}$$

Calculated Yield. The absolute volumes of the ingredients are determined as follows:

Absolute volume of water $= \frac{6.0}{62.4} = 0.096$ cu. ft.

" " " cement $= \frac{9.4}{3.1 \times 62.4} = 0.049$ " "

" " " sand $= \frac{20.3}{2.63 \times 62.4} = 0.124$ " "

" " " stone $= \frac{33.2}{2.65 \times 62.4} = 0.201$ " "

Total absolute volume.............. = 0.470 cu. ft.

11. Conclusions:

The foreging methods enable one to design for any given materials a concrete mixture of a predetermined strength. With different aggregates, but the same water-cement ratio, different combinations of sand and stone will be obtained. One should take that combination which gives not only the desired strength but the maximum yield of concrete per sack of cement.

VALUE OF TEST: The strength of concrete is the important physical quality to be known in stuctures where this material is used. By employing the principles and methods described here, it is possible to design a concrete mix which will have a desired strength. The water-cement-ratio curve, however, must not be used blindly. At best it offers a means whereby a mix approximating a desired strength may be obtained. Thereafter, by varying the proportions of sand to stone as well as the amounts of cement and water, it is possible to design a mixture that will have not only the desired strength but maximum economy.

QUESTIONS AND PROBLEMS:

1. Consult the references and prepare a list of the more common methods of proportioning the ingredients of concrete.
2. If the coarse aggregate used in the illustrative mix of this experiment absorbs 0.50 per cent of water, by weight, what additional amount of water would have to be added to the mix to preserve the same water-cement ratio?
3. A 1/10-cubic foot measure is filled with the wet concrete, the process being the same as for obtaining the unit weight of an aggregate. This quantity of concrete weighs 14.69 pounds. Using the quantities given for the illustrative mix, determine the measured yield of the wet batch of concrete.
4. Why is the *calculated* yield generally less than the *measured* yield?
5. A batch of wet concrete weighs 146.9 pounds per cubic foot. A 6″ × 12″ cylinder made from this concrete, when thoroughly hardened and dry, weighs 28.49 pounds. What accounts for the loss of weight?

REFERENCES:

Besson: Pages 181-218
Johnson: Pages 426-450
Mills: Pages 333-349
A.S.T.M. Serial Designations C 31-39, C 39-39, C 78-39 and C 138-39.

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EXP. No. 22
DATE: ....

GENERAL SUBJECT: Testing of Concrete Mixtures.

SPECIFIC OBJECT: Design of a concrete mixture of predetermined strength by the use of the Cement-Space Method.

SAMPLES:

APPARATUS: All the apparatus used in Experiments Nos. 18 and 19.

METHOD: This method is similar in many respects to the water-cement-ratio method of designing concrete mixtures, which has been outlined in Experiment No. 21. The aggregates may be proportioned by any method, but it is suggested that the principle of maximum density be used to give a starting point for determining the correct proportions of the sand and coarse aggregate.

It is important that the consistency of the concrete mixtures be uniform, if proper relative results are to be obtained. The amount of water should, therefore, be regulated by use of the slump cone or flow table, the proper slump or flow having been previously selected.

The general method of procedure will vary, depending on whether it is desired to design a concrete of predetermined strength or to determine the relation between the number of pounds of cement per cubic foot of space occupied and the compressive strength obtained at the end of 28 days.

In order to design a concrete of predetermined strength by the use of the cement-space method, a strength-cement-space curve must be used. A typical curve may be found on page 192 of Besson's *City Pavements*. Suppose the strength desired is 2,000 lbs./sq. in. From the curve it is found that the number of pounds of cement used per cubic foot of space occupied by the cement paste should be 71.

Trial mixes are now prepared as follows:

(1) The proportion of sand to coarse aggregate is kept constant, the proper proportion having been determined by the maximum-density method.

(2) The consistency is kept constant by use of the slump cone or flow table.

(3) A different quantity of cement is used with each trial mix.

(4) That mix is correct which gives the desired number of pounds of cement per cubic foot of space occupied by the cement paste.

(5) When the proper mix is obtained, test cylinders will be poured, stored in the humidity room, and crushed at 28 days. This will afford a check on the practicability of the method.

In case it is desired to obtain the relation between the number of pounds of cement per cubic foot of space occupied by the cement paste and the resultant strength of the concrete, the procedure just outlined will be followed, except that test cylinders will be poured from each of the trial mixes and tested at 28 days.

If the data on aggregates given in Experiment No. 21 are used, the calculations for a trial mix would be as follows:

Quantities of materials used:

Cement	9.4 lbs.
Sand	20.3 lbs.
Stone	33.2 lbs.

The specific gravities of the aggregates are as follows:

Sand	2.63
Stone	2.65

$$\text{Absolute volume of sand} = \frac{20.4}{2.63 \times 62.4} = 0.124 \text{ cu. ft.}$$

$$\text{Absolute volume of stone} = \frac{33.2}{2.65 \times 62.4} = 0.201 \text{ cu. ft.}$$

Total absolute volume of aggregates = 0.325 cu. ft.

The mixed concrete is puddled into a measure and the volume is determined. Thus,

Volume of mixed concrete............ = 0.472 cu. ft.

Therefore,

Space occupied by cement paste......... = 0.147 cu. ft.

The cement used per cubic foot of such space is, hence,

$$\frac{9.4}{0.147} = 64 \text{ lbs.}$$

By referring to the strength-cement-space curve on page 192 of Besson's *City Pavements,* it is found that this corresponds to a strength of 1,700 lbs./sq. in.

A new trial mix, in which the same quantities of sand and stone are used with 10.5 pounds of cement, gives a puddled volume of concrete of 0.473 cu. ft.

The space occupied by the cement paste would be, for this mix, 0.148 cu. ft.

Therefore, the cement used per cubic foot of space would be

$$\frac{10.5}{0.148} = 71 \text{ lbs.}$$

This last mix would be the correct one for the conditions which have been assumed.

It should be pointed out that additional cement should not be added to a trial mix already prepared. The reason for this is that the introduction of additional cement in the mix would change its consistency. It should, likewise, be noted that the volume of a new trial mix is not necessarily increased by the absolute volume of additional cement used. The amount of mixing water must usually be varied in order to give the desired consistency.

Results: Calculations and results for all trial mixes should be given. In case test cylinders are made and tested, the results should be given in tabular form. A curve should be plotted similar to the one on page 192 of Besson's *City Pavements.*

Value of Test: The value of this test is substantially the same as that of Experiment No. 21. This particular method is useful in enabling the engineer to design a concrete of predetermined strength. While positive and exact results cannot always be obtained, it nevertheless affords a basis for determining the amount of cement to use with various concrete mixtures. When it is used in connection with strength curves and tables of yields, the engineer will be enabled to select that mix which gives the desired strength with maximum economy.

Questions and Problems:

1. Assume that, in the mix first used in this experiment, the measured volume was 0.470 cubic foot instead of 0.472 cubic foot. What would have been the amount of cement per cubic foot of space occupied by the cement paste?
2. Assume that the specific gravities of both the sand and broken stone were 2.62, and the yield was 0.472 cubic foot. What would then be the amount of cement per cubic foot of space occupied by the cement paste?
3. Explain the difficulties involved in proportioning the ingredients of concrete by the cement-space method, in the light of the results obtained for questions 1 and 2.

References:

Besson: Pages 181-218
Johnson: Pages 426-450
Mills: Pages 333-349
A.S.T.M. Serial Designations C 31-39, C 39-39, C 78-39 and C 138-39

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EXP. No. 23
DATE: ....

GENERAL SUBJECT: Testing of Rock and Aggregates.

SPECIFIC OBJECT: Abrasion Test on Rock or Gravel.

SAMPLE:

APPARATUS: Deval Abrasion Machine or Los Angeles Rattler, $\frac{1}{16}$-Inch Sieve, Pan, Balances.

METHOD: *Deval Machine.*—If rock is to be tested, it shall be in pieces that are as nearly uniform in size as possible, and 50 pieces shall constitute the test sample. The total weight of the sample shall be within 10 grams of 5 kilograms. The sample is washed and thoroughly dried before weighing. The material is then placed in the cylinder of the Deval machine. With this machine, 10,000 revolutions at a rate of from 30 to 33 revolutions per minute shall constitute a test.

At the end of the required number of revolutions, the material is removed from the cylinder and poured through a $\frac{1}{16}$-inch sieve. Only the material passing the sieve is considered in determining the per cent of wear. This may be expressed either as a per cent or as the French coefficient of wear. Thus:

$$\text{Per cent of wear} = \frac{w}{1{,}000} \times 100 \qquad (1)$$

$$\text{French coefficient of wear} = \frac{400}{w} \qquad (2)$$

in which w is the weight, in grams, of the detritus under $\frac{1}{16}$ inch in size per kilogram of rock used.

The same procedure is followed with gravel, except that the material is first separated by sieves with circular openings and the sample is made up as follows:

Passing 2 inch, retained on 1½ inch......	1,250 grams
Passing 1½ inch, retained on 1 inch......	1,250 grams
Passing 1 inch, retained on ¾ inch......	1,250 grams
Passing ¾ inch, retained on ½ inch......	1,250 grams
Total	5,000 grams

Six cast-iron spheres, each 1.875 inches in diameter and weighing 0.95 pound, shall be placed in the cylinder with the gravel as an abrasion charge. These spheres are the same as those used in the standard rattler test for paving brick.

If the gravel contains more than 10 per cent of crushed pieces, it shall, for the purpose of this test, be considered as crushed gravel. In such a case, the abrasion test shall be made on a representative sample that includes the crushed pieces, and shall be run in substantially the same manner as described for rock. The per cent by weight of the crushed pieces shall be determined, and the permissible per cent of wear calculated from the following formula:

$$W = \frac{AL + (100 - A)L'}{100}$$

in which W = permissible per cent of wear;
A = per cent of uncrushed pieces;
$100 - A$ = per cent of crushed pieces;
L = maximum per cent of wear permitted by the specifications for gravel containing no crushed pieces;
L' = maximum per cent of wear permitted by the specifications for gravel consisting entirely of crushed pieces.

Los Angeles Rattler.—Since the method of running the abrasion test with the Deval machine is different for crushed stone and gravel, there is difficulty in comparing the qualities of different kinds of materials from the results of this test. For that reason, the Los Angeles rattler has been devised. Where this machine is used, the test is run in the same manner on all materials, including crushed stone and either crushed or uncrushed gravel. The procedure is as follows:

One of the two gradings tabulated on page 103 is used for the sample. Grading A is for material to be used as an aggregate in concrete pavements; grading B is for material to be used in the construction of bituminous surfaces.

The abrasive charge for grading A is twelve $1\frac{7}{8}$-inch cast-iron balls which have a total weight of 5,000 grams;

the abrasive charge for grading *B* is eleven 1⅞-inch cast-iron balls weighing 4,583 grams.

The prepared sample and the abrasive charge are placed in the machine, which is run at a rate of 30 to 33 revolutions per minute for 100 revolutions. The material is then removed, and the loss, or the amount passing through a 10-mesh (No. 12 U. S. standard) sieve, is determined. All of the material is then replaced in the machine, and it is run for an additional 400 revolutions. The final loss is then determined.

Screen Size	Total Per Cent Retained	
	Grading A	Grading B
1½ inches	0	0
1 inch	25	0
¾ inch	50	0
½ inch	75	50
⅜ inch	100	100

Results: Report all results in accordance with the method used in running the test. Consult the specifications of several State Highway Departments and compare the results obtained in this experiment with the per cents of wear permitted for several types of road surfaces.

Value of Test: This test serves as an indication of the rapidity with which the rock or gravel will wear when used in a pavement. It is usually required for all coarse material used in macadam and surface-treated roads. It is likewise frequently required on the material to be used in surfaces of portland-cement concrete. A usual limitation for crushed stone is that the per cent of wear shall not exceed 7. This corresponds to a French coefficient of wear of 6. For gravel, the per cent of wear should not exceed 25. Where the Los Angeles rattler is used, the per cent of wear should not exceed 50. Engineers are not in complete agreement as to the value to be assigned to this test in determining the qualities of materials to be used in constructing concrete roads.

QUESTIONS AND PROBLEMS:

1. Why are cast-iron balls used in determining the abrasion of gravel and not with crushed stone?
2. Why is it necessary to specify the grading of the charge used in running the abrasive test?
3. Is there any relation between the abrasion of crushed stone and that of gravel as determined with the Deval machine?
4. Is it practicable to compare crushed stone and gravel on the basis of the results of abrasion obtained with the Los Angeles rattler?
5. Consult specifications of several State Highway Departments and obtain maximum loss permitted for gravel and crushed stone in the abrasion test, when the material is to be used for concrete road construction.

REFERENCES:

Barton and Doane: Pages 148-151, 159-160, 266-270
Bauer: Pages 54-55, 301-303
Johnson: Pages 258-261
Mills: Pages 399-401
A.S.T.M. Serial Designations C 131-39, D 2-33 and D 289-37T

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EXP. No. 24
DATE: ....

GENERAL SUBJECT: Testing of Rock.

SPECIFIC OBJECT: Determination of Toughness.

SAMPLE:

APPARATUS: Page Impact Machine, Diamond Core Drill, Diamond Saw, Grinding Lap.

METHOD: The test specimens are cylinders each 25 mm. in diameter and 25 mm. high. One set of specimens shall be drilled perpendicularly to the plane of structural weakness and one set drilled parallel to the plane. The test specimens are sawed to the approximate height and then the ends are finished on the grinding lap.

A specimen is centered on the anvil of the impact machine. The first blow is struck from a height of 1 cm., the second from a height of 2 cm., and so on. The number of blows, which is also the height, necessary to rupture the specimen is recorded. The same procedure is followed with each of the specimens.

RESULTS: Report results of individual specimens, and also the average for those perpendicular to the plane of weakness and the average for those parallel to the plane.

VALUE OF TEST: This test serves as an indication of the quality of rock used in road construction. It is particularly important for rock used for macadam and bituminous road surfaces. A value of toughness of 20 or over is *high;* 13 or under is *low.* A usual requirement for rock for macadam surfaces is that the toughness shall not be less than 6.

QUESTIONS AND PROBLEMS:

1. Why is it necessary that the height of every specimen be exactly 25 mm.?
2. Consult specifications of several State Highway Departments and determine if there are any requirements for "toughness" of rock to be used in the construction of bituminous-macadam road surfaces.

REFERENCES:

Barton and Doane: Pages 153-156, 269-270
Bauer: Pages 54-55, 304-307
Johnson: Pages 258-261
Mills: Pages 399-401
A.S.T.M. Serial Designation D 3-18

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EXP. No. 25
DATE: ....

GENERAL SUBJECT: Testing of Rock.

SPECIFIC OBJECT: Determination of Hardness.

SAMPLE:

APPARATUS: Dorry Hardness Machine, Diamond Core Drill, Diamond Saw, Balances.

METHOD: The specimen to be tested should be 1 inch in diameter. A core about 4 inches long is drilled perpendicularly to the bedding plane. The ends are sawed square and the specimen is thoroughly dried. It is then inserted in the grip of the Dorry machine so that about 1 inch projects from the lower end. The grip is put in the machine and the funnels are filled with sand. Standard No. 2½ quartz sand is used, not more than 5 per cent being retained on a No. 30 sieve and not more than 25 per cent passing a No. 40 sieve.

The machine is run for a few minutes so that the specimen will seat thoroughly on the grinding disc. The grip and specimen are then removed and weighed. They are put back in the machine and the weight is adjusted to 1,250 grams. The machine is then run for 1,000 revolutions at a speed of 30 revolutions per minute. At the end of the run the loss in weight of the test specimen is accurately determined. The hardness coefficient is expressed as follows:

$$\text{Hardness} = 20 - \frac{W}{3}.$$

in which W is the loss of weight, in grams.

RESULTS: Report the results of individual tests and the average of all tests.

VALUE OF TEST: This test was developed to determine the quality of stone to be used in the construction of macadam road surfaces. It is not considered to be so valuable as the abrasion test. Values of the hardness coefficient below 14 are considered *low*, and values above 17 are *high*. The test measures the ability of a rock to resist abrasion by foreign materials.

QUESTIONS AND PROBLEMS:

1. Why is it necessary to specify the size of the sand used as an abrasive?
2. Would the same results be obtained if the weight of the holder and specimen was 1,500 grams instead of 1,250 grams?
3. Is there any relation between the *toughness* and the *hardness* of a particular specimen of rock?
4. Consult the specifications of several State Highway Departments and find if there are any requirements for *hardness* of the crushed stone used for bituminous-macadam road surfaces.

REFERENCES:

Barton and Doane: Pages 151-153
Bauer: Pages 307-309
Mills: Pages 399-401

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EXP. No. 26
DATE: ....

GENERAL SUBJECT: Testing of Rock.

SPECIFIC OBJECT: Determination of Crushing Strength.

SAMPLE:

APPARATUS: Diamond Core Drill, Diamond Saw, Grinding Lap, Universal Testing Machine.

METHOD: A core is taken from the specimen of rock with the diamond drill. The diameter of the core should be 2.5 cm. The core is sawed into lengths which will finish 1½ inches. The ends of each of these are ground down smooth on the grinding lap, care being taken to have the end planes at right angles to the axis of the core.

The test specimens, after being prepared, are tested in the universal testing machine. The load in pounds when the specimen crushes is obtained, and this, divided by the cross-sectional area, gives the ultimate strength in pounds per square inch.

RESULTS: Report the results for individual specimens and the average of all tests.

VALUE OF TEST: When stone is used in masonry construction, it is generally subjected to direct compression. This test is, therefore, of great practical value. In addition, the quality of the stone in other respects may be indicated from the results of this test. The crushing strengths of stones vary widely, depending on the kind of stone and the manner of testing. Values for crushing strength may range from 15,000 to 45,000 pounds per square inch.

QUESTIONS AND PROBLEMS:

1. The specific gravity of a stone is approximately 2.63, and its crushing strength 24,000 pounds per square inch. What would be the height of a column of the stone in which the bottom layer would crush under the weight of the material?
2. Observe the surfaces of rupture of the cylinders tested in this experiment, and compare them with those of the cylinders of concrete tested in Experiment No. 20.

3. Consult Mills and Johnson (see References) and classify the more common building stones according to their crushing strengths.

REMARKS:

Tentative A.S.T.M. Specifications permit the use of either a 2.5 inch cube or a cylinder 2.5 inches in diameter and 2.5 inches in height. The cubes are cut from the natural stone with suitable saws; the cylinders are obtained with diamond core drills. See A.S.T.M. Serial Designation C 98-30T.

REFERENCES:

Barton and Doane: Pages 156-157
Johnson: Pages 254-261
Mills: Pages 397-398
Murphy: Pages 16-28
A.S.T.M. Serial Designation C 98-30T

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EXP. No. 27
DATE: ....

GENERAL SUBJECT: Testing of Rock.

SPECIFIC OBJECT: Determination of Modulus of Rupture.

SAMPLE:

APPARATUS: Stone-Cutting Saw, 15,000-Pound Testing Machine, Knife Edges.

METHOD: A slab of the material to be tested is obtained with the stone-cutting saw. The test specimens are cut out to a size of 12″ × 4″ × 1″. Three or more specimens shall be prepared for each required combination of load application and bedding- or rift-plane direction.

Two knife edges of the testing machine are fixed on a suitable base that will permit self-adjustment of the bearing surfaces of the knife edges. The third knife edge is fixed in the head of the machine. The specimen is tested with the load at right angles to the 12″ × 4″ faces. The span is exactly 10 inches. By means of the crank the upper knife edge is brought to bear on the upper plane of the specimen, and at a point exactly in the middle of the span. The load is then applied by means of the slow motion at the rate of 100 pounds per minute until the specimen ruptures.

The modulus of rupture R, in pounds per square inch, is calculated from the following formula:

$$R = \frac{1.5\ Pl}{bd^2}$$

where P = load, in pounds, at rupture;
l = span, in inches;
b = width, in inches;
d = depth, in inches.

RESULTS: Report results for individual specimens and the average of all tests on the same variety of stone.

VALUE OF TEST: Stone is rarely used where it will be subjected to transverse stresses. However, the determination of modulus of rupture serves as an indication of the general quality of the stone. Tests of North Carolina marbles give average values for the modulus of rupture of from 718 to 3,133 pounds per square inch.

QUESTIONS AND PROBLEMS:

1. Deduce the formula for modulus of rupture given under "Method".
2. A marble stair tread is 18″ × 2″ in cross-section and 8 feet long. Because of imperfect setting, it is supported only at the ends. A person stepping on it causes an equivalent static load of 300 pounds in the center. If the modulus of rupture of the marble is 1,200 pounds per square inch, will the tread break?
3. Consult Mills and Johnson (see References) and classify the more common building stones according to their moduli of rupture.

REFERENCES:

Johnson: Pages 254-261
Mills: Pages 397-398
A.S.T.M. Serial Designation C 99-36

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EXP. No. 28
DATE: ....

GENERAL SUBJECT: Testing of Rock.

SPECIFIC OBJECT: Determination of Absorption.

SAMPLE:

APPARATUS: Balances, Pan, Thermometer, Drying Oven.

METHOD: The sample to be tested is dried to constant weight in the drying oven at a temperature of between 110° and 120° C. for a period of at least 24 hours. The specimen is then immersed in distilled water in the pan for a period of 14 days, the water being maintained at a temperature of 20° C. At the end of the period the sample is removed, and, after the water is wiped off with a towel, the sample is weighed. The absorption is calculated on the basis of dry weight as follows:

$$\text{Absorption, per cent} = \frac{b - a}{a} \times 100$$

where a = the dry weight of the specimen;
b = the saturated weight of the specimen.

RESULTS: Report results for individual specimens and the average of all tests on the same variety of stone.

VALUE OF TEST: This is a direct usability test. The per cent of absorption gives an indication of the ability of a rock to resist weathering. For this reason, hard, dense rocks with low absorption are very durable. North Carolina marbles have an absorption not exceeding 0.05 per cent. The absorption for certain sandstones may be as high as 5 per cent.

QUESTIONS AND PROBLEMS:

1. Consult Johnson, pages 246-249, for a description of freezing and thawing tests to determine the durability of building stone exposed to the weather.
2. What other tests are applicable to building stones to determine their durability under adverse conditions?
3. Consult Johnson, page 245, for the comparative life of several stones under weathering conditions.

REFERENCES:

Johnson: Pages 251-254
Mills: Page 395
A.S.T.M. Serial Designation C 97-36

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EXP. NO. 29
DATE: . . . .

GENERAL SUBJECT: Testing of Brick.

SPECIFIC OBJECT: Absorption Test on Building Brick.

SAMPLE:

APPARATUS: Sand Box, Chisel, Hammer, Balance, Drying Oven, Steaming Apparatus, Hack Saw.

METHOD: Five representative bricks are selected from a lot to be tested. The ends of these bricks are labeled for identification, and a line is marked about the middle of the long dimension of each brick. The bricks are cut along the marked lines. This should be done with a hack saw, or it may be done with a chisel on a sand bed, if great care is exercised. In the latter method, the brick is bedded on a ridge of sand in the sand box. It is then cut with the chisel, this being accomplished by using a great number of light blows and by repeatedly turning the brick. When done properly, a clean fracture should result.

The absorption is determined by two methods: (*a*) absorption based on 24 hours of submergence in cold water; (*b*) absorption based on 5 hours of submergence in boiling water.

The half-brick, obtained from the whole brick in the manner just described, is weighed and placed in a drying oven, where a temperature of 110° to 115° C. is maintained. After a suitable interval, the brick is taken out and re-weighed. If weight is lost, the process is repeated until the samples have constant weight.

The dry specimen shall then be immediately submerged in clear, soft water at a temperature of 15.5° to 30° C., and left for 24 hours. The brick shall then be removed, the surface water wiped off, and the brick again weighed. The absorption shall be calculated on the basis of the following formula:

$$\text{Absorption, per cent} = \frac{b - a}{a} \times 100 \qquad (C)$$

where a = the dry weight of the specimen;
b = the saturated weight of the specimen.

The same specimen shall again be submerged in clear, soft water at a temperature of 15.5° to 30° C., and the water shall be heated to boiling within 1 hour, and boiled continuously for 5 hours. The water is allowed to cool to the initial temperature during a period of not less than 16 nor more than 18 hours. The specimen is then removed, the surface water is wiped off, and the specimen is again weighed. The absorption is calculated on the basis of the following formula:

$$\text{Absorption, per cent} = \frac{b' - a}{a} \times 100 \qquad (B)$$

where a = the dry weight of the specimen;
b' = the saturated weight of the specimen.

Specifications require that the absorption ratio be obtained. This is determined by the following formula:

$$\text{Absorption ratio } (C/B) = \frac{b - a}{b' - a}$$

where a = the dry weight of the specimen;
b = the saturated weight of the specimen after 24-hr. submersion in cold water;
b' = the saturated weight of the specimen after 5-hr. submersion in boiling water.

Instead of cutting brick to obtain the specimens for this test, half-brick obtained from the transverse tests may be used. See Experiment No. 31.

RESULTS: Give results for individual bricks, and the average for the five bricks. Also give the classification of the brick on the basis of Table 1 on page 267.

VALUE OF TEST: The per cent of absorption of bricks gives an indication of the quality of the bricks, as well as their resistance to weathering. This test also serves to classify bricks. There is considerable doubt among engineers as to the value of this test.

QUESTIONS AND PROBLEMS:

1. Consult A. S. T. M. Tentative Standards for 1939 for any changes that may have been made in the specifications for clay or shale building brick.

2. Why do building codes prohibit the use of brick of high absorption in the foundations (below the ground line) of structures?
3. In general, should brick show a higher absorption when subjected to the boiling test than when stored in cold water?

REFERENCES:

Barton and Doane: Pages 188-190
Johnson: Pages 279-288
Mills: Pages 419-422
A.S.T.M. Serial Designations C 62-39T and C 67-39

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EXP. No. 30
DATE: ....

GENERAL SUBJECT: Testing of Brick.

SPECIFIC OBJECT: Determination of Compressive Strength.

SAMPLE:

APPARATUS: Sand Box, Chisel, Hammer, Glass Plates, Scale, Trowel, Universal Testing Machine with Spherical Bearing Block.

METHOD: The other halves of the bricks used in Experiment No. 29 are taken as the samples for this test. The compressive strength is determined with the brick tested on the larger cross-sectional dimension. Plaster of Paris is used to obtain a smooth bed. The faces of the bricks should first be given a coating of shellac. The plaster of Paris is mixed with water by hand to the consistency of thick cream. A pat is placed on an oiled glass plate. The brick is worked down into the plaster of Paris. After a few minutes the excess plaster of Paris is cut off with the trowel or a knife. The brick should be left undisturbed for at least 1 hour. It is then removed from the glass plate and the other side is bedded in a similar manner. The plaster of Paris should be allowed to set thoroughly before the bricks are tested.

The least horizontal cross-sectional dimensions of the bricks are determined prior to testing. The bricks are then tested to failure with the universal testing machine, the procedure being exactly the same as that described in Experiment No. 20. The ultimate crushing strength S_c, in pounds per square inch, is determined from the following formula:

$$S_c = \frac{P}{bl}$$

where P = total load at failure, in pounds;
b = width, in inches;
l = length, in inches.

RESULTS: Report individual results, and the average for the five bricks. Also give the classification of the brick on the basis of Table 1 on page 267.

VALUE OF TEST: Brick masonry is generally subjected to compressive loads. This test is, therefore, a direct measure of the ability of the bricks to resist the stresses which result from usual loads in practice. However, it has been found that the mortar in brick masonry generally fails before the bricks. This test thus serves primarily to give an indication of the *quality* of the brick. Bricks are usually classified on the basis of the results of this test.

QUESTIONS AND PROBLEMS:

1. Why are the bedding faces of the brick given a coating of shellac previous to bedding with plaster of Paris?
2. A brick pier is 2 ft. × 3 ft. in cross-section and 20 feet high. It supports one end of a beam that carries a total load of 84,000 pounds. The brick masonry weighs 140 pounds per cubic foot. What will be the compressive unit stress in the brick in the bottom of the pier?
3. Consult Johnson, pages 285-287, and compare the crushing strength of brick piers with the crushing strength of individual bricks as obtained in this experiment.
4. Examine the surfaces along which the bricks failed. Compare the shapes of the broken fragments with those obtained in the testing of building stone, Experiment No. 26.

REFERENCES:

Barton and Doane: Pages 190-192
Johnson: Pages 279-288
Mills: Pages 419-422
A.S.T.M. Serial Designations C 62-39T and C 67-39

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EXP. No. 31
DATE: ....

GENERAL SUBJECT: Testing of Brick.

SPECIFIC OBJECT: Determination of Transverse Strength.

SAMPLE:

APPARATUS: Scale, Universal Testing Machine of 15,000-Pound Capacity, Knife Edges, and Supports.

METHOD: Five bricks constitute the test specimens of a particular lot of brick. They are tested flatwise. The dimensions of the bricks are carefully obtained. The lower knife edges are spaced 7 inches apart, and a brick is centered on them. By using the high speed, the upper knife edge is brought into contact with the upper surface of the brick and it is centered between the two lower knife edges. The low speed is then used, and the load is applied to failure. The modulus of rupture R, in pounds per square inch, is calculated from the following formula:

$$R = \frac{1.5\,Pl}{bd^2}$$

where P = breaking load, in pounds;
l = span = 7 inches;
b = width of brick, in inches;
d = depth of brick, in inches.

RESULTS: Report individual results, and the average for the five bricks. Also give the classification of the brick on the basis of Table 1 on page 267.

VALUE OF TEST: Bricks are rarely used under conditions where they will be subjected to transverse stresses. However, this test gives an indication of the quality of the brick. The results of this test, together with those of Experiments Nos. 29 and 30, enable a classification of the brick to be made.

QUESTIONS AND PROBLEMS:

1. Deduce the formula given under "Method".
2. Consult Johnson, page 285, for an example of the transverse failure of an individual brick.

3. Consult Johnson, pages 280-284, for a very complete tabulation of the results of tests made on building brick.

REFERENCES:

Barton and Doane: Pages 192-194
Johnson: Pages 279-288
Mills: Pages 419-422
A.S.T.M. Serial Designations C 62-39T and C 67-39

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Exp. No. 32
Date: ....

General Subject: Testing of Paving Brick.

Specific Object: Determination of Per Cent of Wear (The Rattler Test).

Sample:

Apparatus: Standard Rattler with Cast-Iron Shot, Balances.

Method: Ten paving bricks are selected for the test. These are weighed and placed in the machine. A charge of shot is put in with the bricks, this being made up as follows:

Ten shot, 3.75 inches in diameter and weighing 7.5 pounds each, and between 245 and 260 shot, 1.875 inches in diameter and weighing 0.95 pound each.

The number of smaller shot shall be adjusted until the total weight of the charge of shot is 300 pounds.

After the machine is charged, it is closed, the switch is thrown, and the barrel is revolved for 1,800 revolutions at a rate between 29.5 and 30.5 revolutions per minute. The number of revolutions is ascertained by means of a counter attached to the barrel shaft.

When the run is completed, the bricks are removed and weighed. In weighing the brick, any piece less than 1 pound in weight is rejected. The wear is calculated as follows:

$$\text{Per cent of wear} = \frac{\text{Original weight} - \text{Final weight}}{\text{Original weight}} \times 100$$

Results: Report the per cent of wear.

Value of Test: This is the most important test made on paving brick. It gives a direct indication of the probable life of the brick in actual service. It also serves as a measure of the general quality of the brick. Specifications usually require that the wear in this test shall not exceed 22 per cent for brick pavements subjected to heavy traffic, nor more than 28 per cent for pavements designed for light traffic.

Questions and Problems:

1. From the references, determine the quality of raw materials from which paving brick is manufactured.

2. What are the essential differences between paving brick and common building brick?
3. Consult specifications of several State Highway Departments and determine the maximum loss permitted for brick to be used in road surfaces.
4. What tests, other than the one specified in this experiment, could be used to determine the quality of paving brick?

REFERENCES:

Barton and Doane: Pages 112-115, 271-274
Bauer: Pages 319-327
Besson: Pages 378-389
Johnson: Pages 289-291
Mills: Page 422
A.S.T.M. Serial Designation C 7-38T

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Exp. No. 33
Date: ....

General Subject: Testing of Reinforcing Steel.

Specific Object: Determination of Yield Point, Tensile Strength, Per Cent of Elongation, and Modulus of Elasticity.

Sample:

Apparatus: Universal Testing Machine, Steel Scale, Prick Punch, Hammer, Micrometer Calipers, Strain Gage, V-Block, Dividers.

Method: A piece of reinforcing rod about 18 inches long is used. This is turned down for the middle 11 inches in the machine shop. Two small prick marks exactly 8 inches apart are made on the turned-down portion of the test specimen, and the diameter of the rod is determined at 1-inch intervals along its length.

The grips are put in the testing machine and the ends of the rod are inserted in them, enough steel wedges being used to form the proper connection. The strain gage is attached to the rod, the machine is run until all slack is taken up, and then the gage is adjusted to ZERO. The machine is then started at the proper speed. With the strain gage, it is possible to obtain simultaneous readings of the load and the elongation. These are usually recorded for increments of load of 2,000 pounds. The yield point is indicated by the drop of the beam. When this point is reached, the strain gage is removed, and the elongations are thereafter measured with dividers.

If necessary, gears are shifted to obtain a higher speed. The maximum load is obtained when the beam again drops. The beam is then balanced by moving the counterpoise backward, and the run is continued until the specimen breaks. The final load is recorded as "the breaking load."

The ends of the broken specimen are fitted together in the V-block, and the total elongation is measured. From the data obtained, the following results can be calculated:

Unit stress at yield point
Maximum unit stress

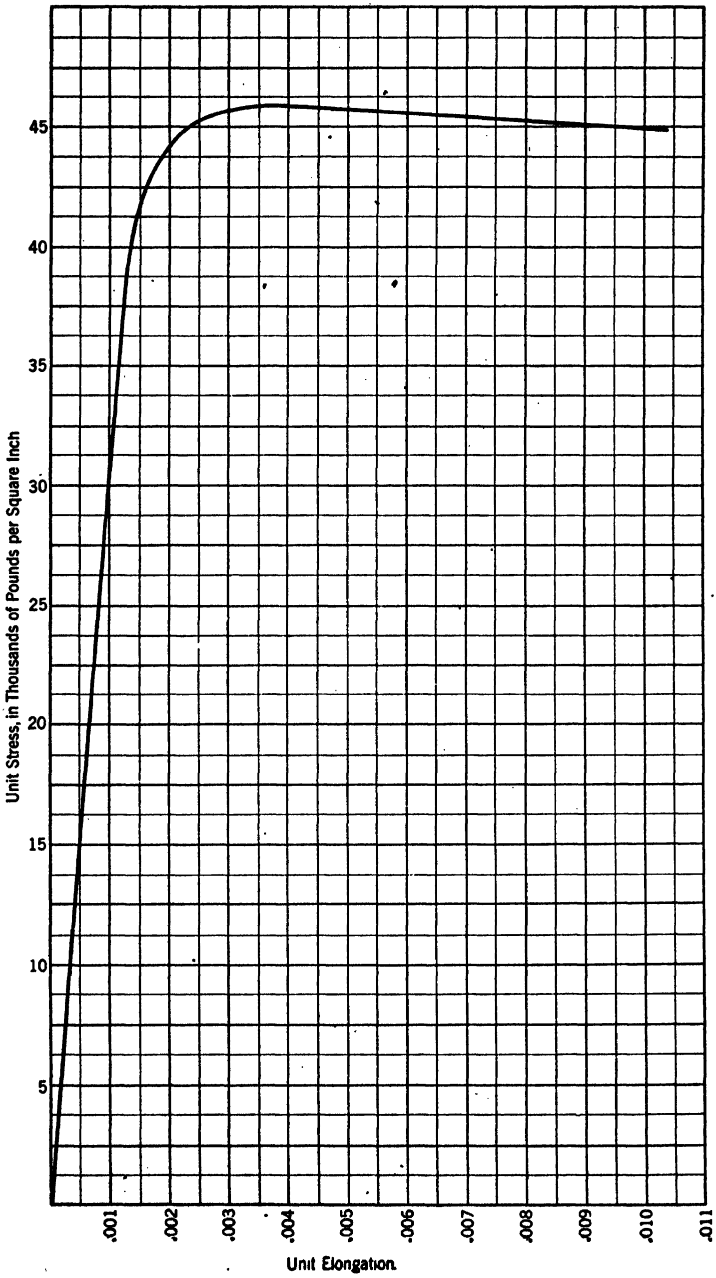

FIG. 7. TYPICAL STRESS-STRAIN DIAGRAM FOR MACHINE STEEL.

Per cent of elongation
Modulus of elasticity

RESULTS: The test data should be recorded in the table on page 136, and the columns for unit stresses and unit elongations should be completed. A curve similar to that shown in Fig. 7 should be drawn, the data obtained in this test being used. The modulus of elasticity should be calculated. It would be well to attach a separate sheet to the report, showing all calculations in detail.

VALUE OF TEST: All the data determined in this experiment are of great practical value. The safe stresses to be used in the design of reinforced-concrete structures are based on the behavior of steel when subjected to increasing loads under tests. Likewise, the modulus of elasticity of the material, which is of such great importance in the theory and design of structures, can best be determined experimentally as has been done in this test.

QUESTIONS AND PROBLEMS:

1. Consult Boyd (see References) for a discussion of "yield point" and "elastic limit".
2. From the measurement of the final diameter of the bar at the point of rupture, calculate the maximum unit stress in the steel.
3. What is the purpose of determining the diameter of the rod at 1-inch intervals in the gage length?
4. Consult Mills and Johnson (see References) for the relation between the carbon content of the steel and its ultimate tensile strength.
5. Explain how the strain gage can be used to measure the actual stress in a piece of steel under a given load, if the modulus of elasticity is known.

REFERENCES:

Barton and Doane: Pages 178-179; Boyd: Pages 58-78; Johnson: Pages 609-621; Mills: Pages 1-20, 99-104; Murphy: Pages 16-28

A.S.T.M. Serial Designations A 15-39, A 16-35, E 6-36 and E 8-36

TABLE FOR EXPERIMENT No. 33

LOAD POUNDS	UNIT STRESS LBS./SQ. IN.	TOTAL ELONGATION INCH	UNIT ELONGATION	REMARKS

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Exp. No. 34
Date: ....

General Subject: Testing of Reinforcing Steel.

Specific Object: Determination of Ductility (The Cold-Bend Test).

Sample:

Apparatus: Universal Testing Machine, Cold-Bend Apparatus, Scale.

Method: A sample of the reinforcing bar about 18 inches long is needed. The cold-bend apparatus is assembled on the bed of the testing machine. The pin holder is attached to the head of the machine. The size of the pin to be used, as well as the angle through which the bar is to be bent, is given in the A.S.T.M. Specifications, and depends on the grade of the steel as determined from the tensile test, Experiment No. 33. (See table No. 6, page 271.) The two rollers on the cold-bend apparatus are spaced a distance apart equal to the total of the following:

The diameter of the pin.

Twice the diameter of the test specimen.

A clearance of about ¼ inch on each side.

The bar is laid across the rollers, the machine is thrown into high gear, and the pin is brought into contact with the center of the bar. The machine is run until the bar is bent through the desired angle. No load is recorded. After the test, the bend is examined carefully for any signs of fracture.

Results: Report the appearance of the bend, and whether there were any signs of fractures.

Value of Test: It is necessary to bend reinforcing bars in order that they may be placed in the proper position in concrete. The bending is done with the rod cold. It is important, therefore, that a grade of steel be used for reinforcing bars which will successfully pass this test. As a general rule, the higher the carbon content of the steel, the less will be its ductility.

Questions and Problems:

1. Explain why the size of the pin about which the specimen is bent varies with the diameter of the test bar.

2. Why is the angle through which the bar is bent 90° for some materials and 180° for others?
3. Consult Johnson and Mills (see References) for the relation between the carbon content and the ductility of steel.

REFERENCES:

Barton and Doane: Pages 179-180
Boyd: Pages 67-73
Johnson: Pages 609-621
Mills: Pages 1-20, 99-104
A.S.T.M. Serial Designations A 15-39, A 16-35, and E 16-39

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EXP. NO. 35
DATE: ....

GENERAL SUBJECT: Testing of Steel.

SPECIFIC OBJECT: Determination of Hardness (The Brinell Test).

SAMPLE:

APPARATUS: Universal Testing Machine of 15,000-Pound Capacity, Brinell Hardness Tester, Microscope.

METHOD: The standard apparatus for the Brinell hardness test consists of an anvil on which the specimen rests, a hardened steel ball 10 millimeters in diameter, and a suitable means of applying a pressure of 3,000 kilograms. A description of the tester is given on pages 68 and 69 of Johnson's *Materials of Construction.* The Brinell hardness can be determined satisfactorily with a universal testing machine, to the head of which is fixed an attachment carrying the hardened steel ball. The method of conducting the test with this type of apparatus is as follows:

The surface of the metal to be tested is first smoothed so that the edge of the impression will be clearly defined. This can be done by filing, grinding, or machining it, and finally finishing it with emery cloth. The hardened steel ball in the Brinell tester is intended to be 10 mm. in diameter, and this dimension should be checked frequently between tests. The steel to be tested is placed on an anvil set firmly on the bed of the testing machine. The Brinell tester is attached to the head of the machine. The ball is brought in contact with the polished surface of the metal and a load of 3,000 kg. (6,615 pounds) is applied for 10 seconds. The head of the machine is then run up, the test specimen is removed, and the diameter of the indentation is determined with the aid of the microscope. The reading will be in millimeters. This must be converted to area of indentation by use of suitable tables, one being on pages 738 and 739, A.S.T.M. Standards, 1939, Part I.

RESULTS: Where several tests are made on the same specimen, it is well to make a diagram showing the location of the places where readings were taken, as well as the results obtained. Individual results for the several tests should be reported as well as the average for all tests on the same specimen.

VALUE OF TEST: The hardness of steel is a measure of certain other physical characteristics. The hardness varies with the carbon content and the form in which the carbon is present, as well as with the amounts of other constituents that may be in the steel. Tests of hardness are of particular value in the heat treatment of steels, and in certain investigations of failures of steel due to fatigue.

QUESTIONS AND PROBLEMS:

1. Determine the spherical area of indentation from the measurements of the diameter of indentation.
2. Dividing the load by the spherical area of indentation, determine the Brinell hardness number.
3. What other methods are in common use for measuring the hardness of metals?
4. What factors determine the degree of hardness of steel?
5. Consult the References and convert the Brinell hardness, as obtained, into hardness as determined by the Shore scleroscope.

REFERENCES:

Mills: Pages 1-20, 99-104
Johnson: Pages 68-70, 625-651
A.S.T.M. Serial Designation E 10-27

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EXP. NO. 36
DATE: ....

GENERAL SUBJECT: Testing of Cast Iron.

SPECIFIC OBJECT: Determination of Transverse Strength and Modulus of Elasticity.

SAMPLE:

APPARATUS: Universal Testing Machine of 15,000-Pound Capacity with Knife Edges and Bed Plate, Deflectometer, Scales.

METHOD: The "arbitration bar" is used. This is 1.2 inches in diameter and 21 inches in length. It is cast from the ladle of iron to be tested. Detail methods of molding and pouring the bars are given in A.S.T.M. Serial Designation A 48-36. The bars are cleaned by brushing, and only skin machining is permitted. In case there is a variation in the diameter from the 1.2 inches specified, a correction factor may be applied to the breaking load and deflection. A table of factors is given on page 485 of A.S.T.M. Standards, 1939, Part I.

The transverse test on the bar is run in substantially the same manner as the static bending test on timber, described in Experiment No. 39. However, the rate of application of the load shall be such that fracture will be produced in not less than 20 seconds for the 1.2-inch bar.

If deflections corresponding to increments of load are desired, they can be obtained with the deflectometer. A tensile test on the broken bar is frequently desired. In this case, a portion of the bar is turned down in accordance with specifications given on page 484 of A.S.T.M. Standards, 1939, Part I., and the ends are threaded for the standard grips. The test is then conducted substantially in the manner specified for steel in Experiment No. 33.

In the Appendix on page 262 there is given a tabulation of the physical properties of gray-iron castings according to several classes. If the modulus of rupture of the test bar is desired, it can be calculated from the formula

$$\text{Modulus or rupture} = \frac{2.546\,Pl}{D^3}$$

where P = breaking load, in pounds;
l = span length or distance between supports, in inches;
D = diameter of the test bar, in inches.

For a diameter of 1.2 inches and a span of 18 inches, the preceding formula becomes

$$\text{Modulus of rupture} = 26.524\,P$$

The transverse test can be utilized for determining the modulus of elasticity. The general formula is

$$y = \frac{Pl^3}{48\,EI}$$

where y = deflection, in inches;
I = moment of inertia, in inches^4;
E = modulus of elasticity, in pounds per square inch.

For the test bar with a diameter of 1.2 inches and a span of 18 inches, this formula becomes

$$y = 1{,}193.6\frac{P}{E}$$

from which

$$E = 1{,}193.6\frac{P}{y}$$

RESULTS: Give breaking load and modulus of rupture. If deflections were taken, plot a load-deflection curve. Calculate the modulus of elasticity for several deflections and loads.

VALUE OF TEST: The transverse test on cast iron has come into rather general use by foundrymen. It is a test that does not require elaborate or expensive equipment and one that can be quickly made. And it has been proved that the results give a fairly close indication of the quality of the material. In case the transverse test leaves any uncertainty as to the character of the material, a tensile test should be made on a portion of the test "arbitration bar".

QUESTIONS AND PROBLEMS:

1. Deduce the several formulas under "Method."
2. What would be the behavior of a bar of cast iron if subjected to a tensile test similar to that for steel (see Experiment No. 33)?
3. After reading the References, compare the physical qualities of cast iron with those of steel.
4. What are the chief differences, metallurgically, between cast iron and steel?

REFERENCES:

Boyd: Pages 83-87
Johnson: Pages 712-715
Mills: Pages 144-154
A.S.T.M. Serial Designation A 48-36

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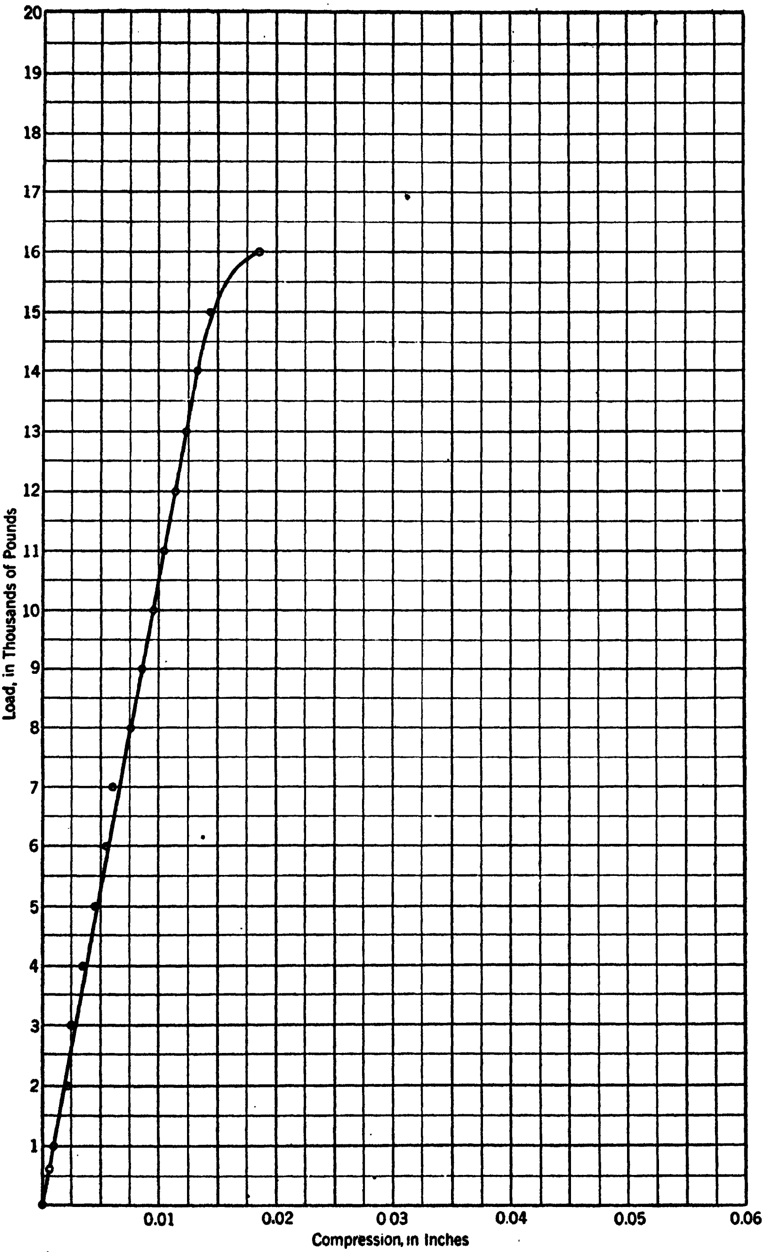

FIG. 8. LOAD-COMPRESSION DIAGRAM FOR WOOD TESTED PARALLEL TO THE GRAIN.

Exp. No. 37
Date: ....

General Subject: Testing of Timber.

Specific Object: Compression Parallel to the Grain.

Sample:

Apparatus: Universal Testing Machine, Spherical Bearing Block, Compressometer, Scale.

Method: Two or more test specimens of each species are selected from well-seasoned, straight-grained timber, which is free from defects. The blocks are 2″ × 2″ × 8″, and they are carefully measured to verify the correctness of the dimensions. The ends of each block should be true planes and exactly parallel. A test specimen is placed on the bed of the testing machine so that it is centered with respect to the upper spherical bearing block. The compressometer is fastened in position on the sample. The head of the testing machine is run down until contact is made with the test specimen. The rate of application of the load is then set at 0.024 inch per minute.

The deformation is read for every 2,000-pound increment of the load. The readings are taken to the nearest 0.0005 inch. A load-compression curve should be plotted as the test proceeds. When the elastic limit of the wood has been passed, as indicated by the curve, the compressometer must be removed. The test can then be continued until the specimen fails. This test will enable the following determinations to be made for each specimen:

Elastic limit
Ultimate strength
Modulus of elasticity

Results: A record of each test should be kept in the form shown on page 150. In addition, a load-compression curve similar to the one in Fig. 8 should be drawn. The elastic limit, ultimate strength, and modulus of elasticity will be calculated and reported for each specimen and variety of wood.

Value of Test: Timber is used largely where it is subjected to direct compression parallel to the grain. This test, therefore, is of great practical importance. The results that are obtained for different varieties of wood furnish information to be used in the design of timber structures. The elastic limit, ultimate strength, and modulus of elasticity can be determined only by tests similar to this one.

Table for Experiment No. 37

Load Pounds	Unit Stress Lbs./Sq. In.	Total Deformation Inch	Unit Deformation	Remarks

QUESTIONS AND PROBLEMS:

1. Examine the test specimen after failure, and note the angle the plane of rupture makes with the horizontal.
2. Consult the tables in the references and compare the more common varieties of wood on the basis of their compressive strengths parallel to the grain.
3. Why is a higher factor of safety used with wood than with steel?

REFERENCES:

Boyd: Pages 5-6
Johnson: Pages 195-233
Mills: Pages 455-465
Murphy: Pages 234-235
A.S.T.M. Serial Designation D 143-27

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EXP. NO. 38
DATE: . . . .

GENERAL SUBJECT: Testing of Timber.

SPECIFIC OBJECT: Compression Perpendicular to the Grain.

SAMPLE:

APPARATUS: Universal Testing Machine, Rigid Bearing Block, 2″ × 4″ × ½″ Metal Bearing Plate, Deflectometer, Scale.

METHOD: Two or more test specimens of each species are selected from straight-grained, well-seasoned timbers. The test specimens should be 2″ × 2″ × 6″, and the dimensions are verified by careful measurements. A sample is placed under the rigid bearing block with the longest dimension horizontal, and so that the load will be applied to a radial (quarter-sawn) surface. The metal bearing plate is placed across the upper surface of the specimen, so as to be equally distant from the ends and at right angles to the length of the specimen. The cross-head of the machine is lowered until the bearing block just touches the bearing plate.

The deflectometer is now placed so that the point of the adjusting screw is under the projecting end of the bearing plate. By means of the adjusting screw the arm of the deflectometer is set to read ZERO. The counterpoise is placed near ZERO and the load is applied continuously at the rate of approximately 0.024 inch per minute. The test is continued until the plate has been pressed into the specimen 0.1 inch. Readings of the deflectometer are taken to 0.001 inch at load intervals of 1,000 pounds or 2,000 pounds, depending on the hardness of the wood.

RESULTS: Tabulate the readings of compression and load according to species and specimen number. Make a load-compression curve with load as ordinate and compression as abscissa.

VALUE OF TEST: This test is of practical importance, since it serves to indicate the behavior of timber when a load is applied perpendicular to the grain. Timber is strongest in compression parallel to the grain, but there are numerous instances in actual construction where the strength perpendicular to the grain must be known.

QUESTIONS AND PROBLEMS:

1. Under what conditions is timber used where it will be subjected to compression perpendicular to the grain?
2. Give an explanation as to why the compressive strength of wood perpendicular to the grain is so much less than its compressive strength parallel to the grain.

REFERENCES:

Boyd: Pages 5-6
Johnson: Pages 195-233
Mills: Pages 455-465
A.S.T.M. Serial Designation D 143-27

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EXP. No. 39
DATE: 23/7/...

GENERAL SUBJECT: Testing of Timber.

SPECIFIC OBJECT: Static Bending Test.

SAMPLES:

APPARATUS: Universal Testing Machine, Knife Edges and Bed Plates, Special Hard Maple Bearing Block, Scale, Special Deflectometer.

METHOD: The test specimens should be selected from straight-grained wood which is free from defects. The size is $2'' \times 2'' \times 30''$. Center loading with a span of 28 inches is used. Bearing plates $1\frac{1}{2}'' \times \frac{1}{4}''$ are used between the knife edges and wood. The deflectometer is attached in position under the center of the beam. The special bearing block is attached to the cross-head of the testing machine and, by using the high speed, is brought into contact with the test specimen at its center. The speed is then changed so as to apply the load at the rate of 0.10 inch per minute.

The deflection should be read for every 200-pound increment of load. The test should continue until failure occurs. The relation between the load and the deflection is given by the formula:

$$y = \frac{Pl^3}{48EI}$$

where y = deflection, in inches;
P = load, in pounds;
l = span, in inches;
I = moment of inertia, in inches^4;
E = modulus of elasticity, in pounds per square inch.

For the dimensions used,

$$y = \frac{343P}{E}$$

It is thus seen that the modulus of elasticity can be determined from the results of this test by the use of the above formula.

The modulus of rupture R, in pounds per square inch, will be given by the following formula:

$$R = \frac{1.5\,Pl}{bd^2}$$

where b = width of timber, in inches;
d = depth of timber, in inches.

For the dimensions used in this test, the formula becomes

$$R = 5.25\,P$$

RESULTS: The loads and corresponding deflections should be tabulated for all test specimens. Load-deflection curves should also be plotted. For each test piece the modulus of elasticity and the modulus of rupture are to be calculated and tabulated. Detail calculations may be given on a separate sheet attached to the report.

VALUE OF TEST: Timber is widely used in beams for the support of transverse loads. This test, therefore, is of great practical value, as it enables the modulus of rupture to be determined. It likewise affords an easy and fairly exact method of determining the modulus of elasticity of timber experimentally.

QUESTIONS AND PROBLEMS:

1. Deduce the formulas given under "Method".
2. Assume that the load P is divided equally and applied at the third-points of the span. Deduce the formula from which the modulus of elasticity can be calculated.
3. Note whether the beam failed first at the upper fibres or at the lower fibres; that is, whether the initial failure was in compression or in tension.
4. Is timber commonly used where it will be subjected to transverse stresses?
5. Give the safe unit stress to be used in designing a floor joist of short-leaf yellow pine.

REFERENCES:

Boyd: Pages 5-6, 177-178, 216-217
Johnson: Pages 195-233
Mills: Pages 455-465; Murphy: Pages 234-235
A.S.T.M. Serial Designation D 143-27

NOTES

EXP. No. 40
DATE: . . . .

GENERAL SUBJECT: Testing of Timber.

SPECIFIC OBJECT: Determination of Tensile Strength Parallel to the Grain.

SAMPLE:

APPARATUS: Universal Testing Machine, Scale, Special Grips.

METHOD: The test specimen is shaped from a piece of timber 2″ × 2″ × 30″. The middle portion is square in cross-section, each side being $\frac{5}{8}$ inch wide. The details of the shape of the specimen are given on page 530, of A.S.T.M. Standards, 1939, Part II.

Special grips must be inserted in the testing machine so that the test piece will be held securely, and yet will not be crushed. It is well to use the 15,000-pound counterpoise, since the total load will not be great. The specimen is inserted in the grips and the machine is run until all lost motion is taken up. The speed is then set at a rate of 0.05 inch per minute, and the test is continued until failure occurs. The total load at failure is recorded. The ultimate unit stress S, in pounds per square inch, will be given by the formula

$$S = \frac{P}{a}$$

where P = ultimate load, in pounds;
a = cross-sectional area, in square inches.

RESULTS: Report the breaking load and the ultimate tensile strength for each test specimen, and the average of all tests on a particular variety of wood.

VALUE OF TEST: Timber is widely used under conditions where it will be subjected to tensile stresses parallel to the grain. It is usually strongest in tension. This test determines the ultimate tensile strength of each of various kinds of wood, and therefore furnishes information necessary for the design of timber structures.

QUESTIONS AND PROBLEMS:

1. Explain why the modulus of elasticity of timber is not generally determined from a tensile test, as in the case of steel.
2. Consult the references and prepare a tabulation of the ultimate tensile strengths parallel to the grain of several of the more common varieties of wood.
3. Is timber ordinarily stronger in tension than in compression?

REFERENCES:

Boyd: Pages 5-6
Johnson: Pages 195-233
Mills: Pages 455-465
A.S.T.M. Serial Designation D 143-27

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Exp. No. 41
Date: ....

General Subject: Testing of Timber.

Specific Object: Determination of Tensile Strength Perpendicular to the Grain.

Sample:

Apparatus: Universal Testing Machine, Scale, Special Grips.

Method: The dimensions of the test specimen shall conform to those given on page 529, A.S.T.M. Standards, 1939, Part II. The least cross-sectional dimensions are 1″×2″. Special cast-iron machined grips are used for this test. These are attached to the testing machine, and the specimen is inserted. Since the load will be small, the 15,000-pound counterpoise should be used. The load is applied at the rate of 0.25 inch per minute. The test is continued until the specimen fails. The ultimate unit stress is determined from the formula

$$S = \frac{P}{a}$$

where P = ultimate load, in pounds;
a = cross-sectional area, in square inches.

Results: Report the breaking load and ultimate tensile strength for each test specimen, and the average of all tests on a particular variety of wood.

Value of Test: Timber is rarely used where it will be subjected to *tensile stresses* perpendicular to the grain. This test, therefore, is not of so much importance as certain other tests on timber.

Questions and Problems:

1. List a few cases in which timber would be subjected to tensile forces perpendicular to the grain.

References:

A.S.T.M. Serial Designation D 143-27

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EXP. No. 42
DATE: ....

GENERAL SUBJECT: Testing of Timber.

SPECIFIC OBJECT: Determination of Shearing Strength Parallel to the Grain.

SAMPLE:

APPARATUS: Universal Testing Machine, Special Shear Tool, Scale.

METHOD: The size and shape of the specimens are given on page 529, A.S.T.M. Standards, 1939, Part II. The block is 2″ × 2″ × 2½″, and is notched so that the cross-section in shear will be 2″ × 2″. The shear tool is assembled in the machine and the test specimen is clamped in position. The 15,000-pound counterpoise is used. The load is applied continuously at the rate of 0.015 inch per minute until failure occurs. The maximum load at failure is recorded. The ultimate shearing unit stress S, in pounds per square inch, is found from the following formula:

$$S = \frac{P}{a}$$

where P = maximum load, in pounds;
a = area in shear, in square inches.

RESULTS: Give maximum load and ultimate shearing unit stress for each test specimen. The average of all tests on a particular variety of timber should be given.

VALUE OF TEST: A knowledge of the ultimate shearing strength of timber is essential in the design of structures in which this material is used. Unless proper precautions are taken, such structures may fail at joints by shearing along a plane parallel to the grain.

QUESTIONS AND PROBLEMS:

1. Why is the shearing strength parallel to the grain for timber so much less than the shearing strength perpendicular to the grain?
2. List a few uses for which it would be necessary to know the shearing strength of timber parallel to the grain.

3. List the safe shearing stresses parallel to the grain for a few of the more common varieties of timber.

REFERENCES:

Boyd: Pages 5-6, 26-29
Johnson: Pages 195-233
Mills: Pages 455-465
Murphy: Pages 234-235
A.S.T.M. Serial Designation D 143-27

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Exp. No. 43
Date: ....

General Subject: Testing of Timber.

Specific Object: Determination of Hardness.

Sample:

Apparatus: Universal Testing Machine, Hardness Tester.

Method: The hardness test is made on a block that is 2″ × 2″ × 6″ and is laid with the long dimension horizontal. The ball used in the hardness tester has a diameter of 0.444 inch. It is fitted into a collar in such a way that penetration of the ball for a depth of one-half its diameter will be indicated.

The 15,000-pound counterpoise is used, and the load is applied at the rate of 0.25 inch per minute. The load is taken when the ball has penetrated into the timber a depth equal to one-half its diameter. This load will be a measure of the hardness of the test specimen.

Results: Report the hardness of all specimens, and the average of all tests on a particular variety of timber.

Value of Test: There are certain uses of timber where its hardness is of value. This test is important for these cases. It is rare that the hardness of timber is an important consideration in the use of timber in structures.

Questions and Problems:

1. Compare the method of testing the hardness of timber with the Brinell hardness test for steel (see Experiment No. 35).
2. List a few uses for which it would be necessary to know the hardness of the timber.

References:

A.S.T.M. Serial Designation D 143-27

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EXP. NO. 44
DATE: ....

GENERAL SUBJECT: Testing of Hollow Building Tile.

SPECIFIC OBJECT: Determination of Crushing Strength.

SAMPLE:

APPARATUS: Universal Testing Machine with Spherical Bearing Block, Glass Plates, Pans, and Trowel.

METHOD: At least five full-size dry tiles are used. These are to be tested so that the load will be applied at right angles to the bearing plane of the tile as used in the wall. The bearing surfaces must be bedded in order to secure true planes. A mixture of one part of plaster of Paris and three parts of portland cement, gaged with enough water to render the mixture plastic, is used. The surfaces to be capped are first given a coat of shellac. After this has dried, the capping mixture is spread evenly on an oiled glass plate and the tile is pressed firmly onto the mortar. It is allowed to remain until the mortar has set up.

The tiles are tested not less than 2 days after they are capped. The procedure in testing is the same as outlined in Experiment No. 20 for determining the crushing strength of concrete cylinders. The ultimate compressive strength is determined as follows:

$$S = \frac{P}{a}$$

where P = ultimate crushing load, in pounds;
a = gross cross-sectional area, in square inches.

RESULTS: Report results for individual specimens and average for all specimens. Detail calculations may be shown on a separate sheet attached to the report.

VALUE OF TEST: Load-bearing tile must meet standard specifications as .to physical qualities. Of these the crushing strength requirement is of considerable importance. This test not only serves as a measure of the safe load which the tile will bear, but also as an indication of the quality of the tile.

QUESTIONS AND PROBLEMS:

1. The crushing strength of hollow building tile is based on the gross cross-sectional area. Explain the necessity for doing this.
2. Determine the *net* cross-sectional area of the tile tested, and the compressive strength in terms of the net area.
3. Compare the crushing strengths of the tile, determined from both the gross and net cross-sectional areas, with the compressive strength of the brick tested in Experiment No. 30.
4. List the main reasons why, under certain conditions, hollow building tile is used in construction in preference to common brick.

REFERENCES:

Johnson: Pages 293-294
Mills: Pages 416-418, 423-424
A.S.T.M. Serial Designations C 34-39 and C 112-36

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EXP. No. 45
DATE: . . . .

GENERAL SUBJECT: Testing of Hollow Building Tile.

SPECIFIC OBJECT: Determination of Per Cent of Absorption.

SAMPLE:

APPARATUS: Boiling Apparatus, Drying Oven, Balances.

METHOD: The specimens for this test shall consist of five tiles or three representative pieces from each of the tiles selected for the test. If small pieces are used, two pieces shall be taken from the shell and one from an interior web; the weight of each piece is to be not less than 0.5 pound (227 grams). Rough edges or loose particles shall be removed from the specimen pieces, preferably by grinding. Pieces may be taken from tiles that have already been subjected to the compression test.

The selected specimens or pieces are weighed on a balance sensitive to within 0.2 per cent of the weight of the smallest piece used. They are then dried to constant weight in an oven at a temperature not less than 100° C.

After being dried to constant weight, the samples are immersed in soft distilled or rain water in the boiling apparatus, the temperature is raised to the boiling point, and the water is boiled continuously for 1 hour. The specimens are then allowed to cool in the water to room temperature.

The specimens are removed from the water and allowed to drain for 1 minute. The superficial water is then removed with a damp cloth and the specimens are weighed immediately. The absorption is calculated as a per cent of the initial dry weight.

RESULTS: Report results for each tile, and the average for the five tiles.

VALUE OF TEST: The results of the absorption test give an indication of the quality of the tile and its possible resistance to weathering action. It should be remembered, however, that tile is seldom used where it will be subjected to very severe weathering action. The results of this test and the compression test (see Experiment No. 44) enable one to classify the tile, as shown in Table 2, page 268.

QUESTIONS AND PROBLEMS:

1. In determining the absorption of hollow building tile, why are the specimens subjected to boiling in water, rather than to storage in cold water?
2. Why is the use of soft, distilled or rain water required to be used in the boiling apparatus in obtaining the absorption of the tile?
3. Why should the specimens remain in the water until cool, rather than taken out immediately and weighed?

REFERENCES:

Johnson: Pages 293 and 294
Mills: Pages 416-418, 423-424
A.S.T.M. Serial Designations C 34-39 and C 112-36

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Exp. No. 46
Date: ....

General Subject: Testing of Concrete Blocks.

Specific Object: Compressive Test on Load-Bearing Concrete Masonry Units.

Sample:

Apparatus: Universal Testing Machine, Pan, Glass Plate, Trowel.

Method: Five full-size units shall be used and these must be in an air-dry condition. The specimens are tested in the same position they will occupy when actually used in construction. The units must be suitably bedded so as to give a smooth bearing surface. The surfaces to be bedded must be coated with shellac, if there is possibility of their absorbing water used in gaging the capping material.

A mixture (by volume) of one part of portland cement and one part of unretarded plaster of Paris is gaged with sufficient water to spread evenly. The mortar is spread on a previously oiled glass plate and the concrete unit is placed on it and is given a single firm pressure. The average thickness of the cap shall not exceed $\frac{1}{8}$ inch. If the surfaces are so uneven that a cap of greater thickness is necessary, the units are first roughly capped with a 1:2 portland-cement mortar.

The caps are allowed to age at least 6 hours before the specimens are tested. The testing is then carried out exactly as specified for the crushing test on concrete cylinders, which is described in Experiment No. 20. The ultimate crushing strength is obtained by dividing the ultimate load by the gross cross-sectional area of the block.

Results: Give dimensions of block, ultimate load in pounds, and crushing strength in pounds per square inch for each of the units, and the average results for the five blocks.

Value of Test: This is a most important and practical test. Such units are generally used under conditions where they will be subjected to direct compression. The results of this test, therefore, will enable the engineer or builder to determine the safe loads such units will carry. Most generally, however, compressive tests serve as an indication of the quality of the units. See A.S.T.M. specifications in the References that follow for standard requirements for such building units.

QUESTIONS AND PROBLEMS:

1. Why must the caps be permitted to age for at least 6 hours before the specimens are tested?
2. The compressive strength is determined from the gross cross-sectional area of the specimen. Why is this provision necessary?
3. Compute the net cross-sectional area of the specimens tested and determine the crushing strength in pounds per square inch of net area.
4. Give the reasons why concrete building units are generally made hollow.

REFERENCES:

Johnson: Pages 513-517
A.S.T.M. Serial Designation C 90-39

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EXP. No. 47
DATE: ....

GENERAL SUBJECT: Testing of Concrete Blocks.

SPECIFIC OBJECT: Determination of Absorption of Load-Bearing Concrete Masonry Units.

SAMPLE:

APPARATUS: Balances, Drying Oven, Immersion Tank.

METHOD: Five blocks shall be used or pieces from each of the the five units. "If pieces are used they shall weigh not less than one-third of the weight of the whole unit from which they were taken and in no case less than 5 pounds. The samples shall have had any loose particles removed or any rough or jagged edges ground smooth.

"When pieces are used as above, the dry weight of the unit shall be calculated by multiplying the weight of the undried unit by the ratio the dry weight of the piece bears to the same piece before drying." See A.S.T.M. specifications in the References that follow.

Samples for the absorption test shall be dried in a suitable oven maintained at a temperature between 100° and 115° C. and weighed at 24-hour intervals until the loss in weight does not exceed 1 per cent of the last previous weight. The dry weights shall then be obtained, and the samples immersed in water at room temperature, 15.6° to 26.7° C., for 24 hours.

At the end of the immersion period the samples are weighed while suspended by a metal wire and completely submerged in water. They are then removed from the water, placed on a $\frac{3}{8}$-inch or coarser wire mesh, and allowed to drain for 1 minute. Visible surface water is then wiped off with a damp cloth and the samples are immediately weighed.

The absorption, in pounds per cubic foot, is determined from the following formula, the weights having been obtained in pounds:

$$\text{Absorption} = \frac{(W_3 - W_1)\,62.4}{W_3 - W_2}$$

where W_1 = dry weight;
W_2 = suspended-immersion weight;
W_3 = wet weight.

The per cent of moisture in the units as delivered can be determined as follows:

$$\text{Per cent of moisture} = \frac{W - W_1}{W_1}(100)$$

where W = weight of units as delivered.

The total per cent of absorption is calculated from the following formula:

$$\text{Per cent of absorption} = \frac{W_3 - W_1}{W_1} \times 100$$

RESULTS: Report results for each unit tested and the average results for the five blocks.

VALUE OF TEST: The absorption test is considered primarily as giving an indication of the quality of the concrete blocks. Under certain conditions, particularly where the units will be exposed to extreme weathering conditions, the results of this test serve to determine the suitability of the product for use. For standard requirements, see the A.S.T.M. specifications referred to below.

QUESTIONS AND PROBLEMS:

1. Deduce the several formulas given under "Method".
2. Under what conditions of use would the per cent of absorption of concrete building units be of vital importance?
3. Consult Johnson, pages 513-515, for several of the more common designs of concrete masonry units.

REFERENCES:

Johnson: Pages 513-517
A.S.T.M. Serial Designation C 90-39

NOTES

EXP. NO. 48
DATE: ....

GENERAL SUBJECT: Testing of Clay Sewer Pipe.

SPECIFIC OBJECT: Determination of Crushing Strength.

SAMPLE:

APPARATUS: Universal Testing Machine, Top and Bottom Bearing Blocks, Pans, and Trowel.

METHOD: Three-edge bearings are used in this test. The pipe should be bedded on the two lower knife edges with a thin fillet of plaster of Paris. This should be allowed to set up for a few hours before the specimen is tested. The sample is tested in the universal testing machine, the load being gradually applied until failure occurs. The crushing strength is obtained by dividing the total load at failure by the net inside length of the pipe or the distance from the bottom of the socket to the end of the spigot.

This method is equally applicable to the testing of portland-cement-concrete sewer pipe.

RESULTS: Report results for individual specimens, and the average for all tests. Results should be given in pounds per lineal foot of pipe.

VALUE OF TEST: Sewer pipe must be strong enough to sustain the weights of earth covering of various depths. The results of this test will enable the engineer to determine if clay sewer pipe has the proper crushing strength. The test also serves, to some extent, as an indication of the quality of the pipe.

QUESTIONS AND PROBLEMS:

1. Consult A.S.T.M. specifications and note other forms of bearings used in determining the crushing strength of clay sewer pipe.
2. Under ideal testing conditions, where will failures of the pipe in this test occur simultaneously?
3. Explain the necessity for knowing the crushing strength of sewer pipe.

REFERENCES:

Johnson: Pages 297-300, 517-519
Mills: Pages 419, 422-423
A.S.T.M. Serial Designations C 13-35 and C 14-35.

NOTES

EXP. No. 49
DATE: . . . .

GENERAL SUBJECT: Testing of Clay Sewer Pipe.

SPECIFIC OBJECT: Hydrostatic Test.

SAMPLE:

APPARATUS: End Pipe Covers with Gaskets, Rubber Hose and Connections, Standard Pressure Gage.

METHOD: The end covers with gaskets are put in place and tightened. The gage is attached to the hose, which is connected with a water line. Water is introduced into the pipe and the following pressures are maintained for the periods indicated:

5 lbs. per sq. in. for 5 minutes.
10 lbs. per sq. in. for 10 minutes.
15 lbs. per sq. in. for 15 minutes.

The specimens shall show no leakage under these pressures.

This method is equally applicable to the testing of portland-cement-concrete sewer pipe.

RESULTS: Report leakage, if any, for each specimen tested.

VALUE OF TEST: Clay sewer pipe is used for transmitting liquids, and must be impervious to water in order to prevent loss of the liquid carried and infiltration of water from the soil, as such infiltration would reduce the capacity of the pipe for the purpose for which it is used.

QUESTIONS AND PROBLEMS:

1. Should clay sewer pipe be used under conditions where it will be subjected to hydrostatic pressure?
2. What, then, are the principal reasons for the requirements of the hydrostatic test?
3. What are the essential differences between clay sewer pipe and clay drain tile?

REFERENCES:

Johnson: Pages 297-300, 517-519
Mills: Pages 419, 422-423
A.S.T.M. Serial Designations C 13-35 and C 14-35

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EXP. No. 50
DATE: ....

GENERAL SUBJECT: Testing of Clay Sewer Pipe.

SPECIFIC OBJECT: Absorption Test.

SAMPLE:

APPARATUS: Boiling Apparatus, Hammer, Drying Oven, Balances.

METHOD: The method is essentially the same as that used for the determination of the absorption of building brick. Approximately square specimens are broken from the pipe to be tested. These are dried to constant weight, are immersed in boiling water for 5 hours, and are then allowed to cool in the water. When the samples are removed from the water, the surplus water is blotted off and the samples are then weighed. The increase in weight divided by the dry weight of the samples, and the result multiplied by 100, gives the per cent of absorption.

This method is equally applicable to the testing of portland-cement-concrete sewer pipe.

RESULTS: Report the per cent of absorption for each sample and the average for all specimens tested.

VALUE OF TEST: The absorption test is largely a measure of the quality of the pipe, since the results will indicate how well it has been manufactured. If very porous, a pipe may disintegrate when subjected to alternate freezing and thawings. For these reasons, a clay sewer pipe should not have an absorption in excess of 8 per cent.

QUESTIONS AND PROBLEMS:

1. Would the same results be obtained for absorption if the whole section of pipe were used rather than broken fragments?
2. What materials are used for glazing the surface of clay sewer pipe?
3. Under what conditions would it be unsafe to use clay sewer pipe with a high per cent of absorption?

REFERENCES:

Johnson: Pages 297-300
Mills: Pages 419, 422-423
A.S.T.M. Serial Designations C 13-35 and C 14-35

NOTES

EXP. NO. 51
DATE: ....

GENERAL SUBJECT: Testing of Concrete and Waterproofing Compounds.

SPECIFIC OBJECT: Determination of the Permeability of Concrete and the Value of Waterproofing Compounds.

SAMPLES:

APPARATUS: 1-, 2-, and 3-inch Sections of 7-Inch Wrought-Iron Pipe, Cast-Iron Caps and Connections, Force Pump, Gage, Pan, Graduate, and Apparatus for Mixing Concrete.

METHOD: Samples of concrete, either with or without the waterproofing ingredients, are prepared and the wrought-iron molds are filled. The molds should rest on smooth oiled steel plates or plate glass. The storage of the molded samples depends on the purpose for which the tests are being run. For example, if it is desired to show the difference in permeability of concrete between curing in dry air and curing wet, then half of the samples should be kept in dry air, and the other half in large pans of water or in a humidity room. In the latter case it will be necessary to store the samples in moist air for the first 24 hours. If the effectiveness of a waterproofing compound is being tested, then the samples containing the ingredients should be left in dry air, and the permeability compared with both the permeability of concrete cured in dry air and that of concrete cured in the humidity room.

The time allowed for the molded samples to cure before being tested will vary, depending on the nature of the tests. It will generally be found that a period of 14 days will be satisfactory.

For the test, the caps are assembled on top and bottom of the specimen. The upper hose connection is attached to the pump, and the hydrostatic pressure is raised to 50 pounds per square inch and is kept at this pressure during the period of the test—generally 7 hours. A graduate, set under the outlet pipe, will enable the leakage to be determined for 15-minute intervals.

It might be noted that the opening in the top cap has an area of exactly 1/10 square foot, in order to simplify the calculation of the leakage in cubic centimeters per square foot of area exposed.

RESULTS: Report results for all specimens, both treated and untreated. Show time elapsed from application of pressure to first leakage, the average leakage for the time after specimen began to leak, and the maximum leakage for 1 hour. Express results in cubic centimeters per square foot per hour. It may be necessary to show the results on a separate white sheet attached to the report.

VALUE OF TEST: There are a great number of different materials on the market that are used for waterproofing concrete. This test offers a simple method of determining the value of these materials in comparison with untreated concrete. It is, likewise, possible by this test to show the practicability of obtaining impermeable concrete through proper curing and without the use of admixtures.

QUESTIONS AND PROBLEMS:

1. Give a few of the more common admixtures used in concrete for making it impermeable to water.
2. A pressure of 50 pounds per square inch corresponds to what hydrostatic head in feet?
3. What methods of external treatment are used for waterproofing concrete?

REFERENCES:

Johnson: Pages 490-494
Mills: Pages 362-363, 501
Ross: Pages 66-82, 220-229

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EXP. NO. 52
DATE: . . . .

GENERAL SUBJECT: Testing of Waterproofing Fabric.

SPECIFIC OBJECT: Determination of the Amount of Bitumen.

SAMPLE:

APPARATUS: Centrifugal Extractor, Analytical Balances, Rule, Scissors, Beaker, Desiccator.

METHOD: A square of the fabric, 6 inches on a side, is carefully cut off. This is weighed on the analytical balances. It is then put in the bowl of the extractor and covered with carbon disulfide or carbon tetrachloride. After a few minutes, the machine is started; it is run slowly at first, and then the speed is increased. The solution coming off is caught in a beaker. When the solution ceases to flow, the machine is stopped. The washing with the solvent and the extraction are then repeated, until the liquid coming off is clear. The clean fabric is then removed from the machine, dried, cooled in the desiccator, and weighed. From the loss of weight, in grams, the number of pounds of asphalt per 100 square feet can be computed by the following formula:

$$B = \frac{400}{453.6} \times g$$

where B = pounds of bitumen per 100 square feet;
g = loss of weight, in grams.

Enough samples of a particular product should be tested so that the average of the results will be truly representative. Tests on individual samples will not check very closely, because of variations in quantity of bitumen and also unequal stretching of the fabric.

If it is necessary to determine the character of the bitumen, this can be done by evaporating the solvent and applying the usual tests for bituminous materials described in Experiments Nos. 55 to 66, inclusive.

The same method described in this test is applicable to an examination of roofing felts.

RESULTS: The results should be reported in grams per 36 square inches and in pounds per 100 square feet. Report individual results and the average of the class.

VALUE OF TEST: The waterproofing material in many prepared fabrics and felts is bitumen. Therefore the amount of bitumen in these materials is a direct measure of their value and probable service in actual use.

QUESTIONS AND PROBLEMS:

1. Deduce the formula given under "Method".
2. Count the number of threads per inch of width for each dimension of the fabric used.
3. Consult standard specifications and determine the requirements for the cloth used in preparing waterproofing fabric.
4. Give a few typical cases in which the use of waterproofing fabric would be indicated.

REFERENCES:

Barton and Doane: Pages 239-241
Besson: Pages 298-301
Johnson: Pages 490-494
Mills: Pages 362-363, 501
Ross: Pages 31-52 *et seq.*

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Exp. No. 53
Date: ....

General Subject: Testing of Galvanized Metal.

Specific Object: Determination of the Amount of Zinc Coating.

Sample:

Apparatus: 100-cc. Graduate, 10-cc. Graduate, 250-cc. Beaker, Scale, Drying Oven, Analytical Balances, Desiccator, Porcelain Dish, Micrometer Gage.

Method: Samples of the metal to be tested are cut into squares, each $2\frac{1}{4}'' \times 2\frac{1}{4}''$. This can best be done with a hack saw. The squares of metal are washed with gasoline and carbon disulfide in order to clean them thoroughly. They should then be dried, cooled in the desiccator, and weighed on the analytical balances.

A solution of antimony chloride is prepared by dissolving 3.2 grams of $SbCl_3$ in 100 cc. of HCl. Then, 100 cc. of HCl is put in the porcelain dish, and 5 cc. of the solution of antimony chloride is added. A square of the metal is dropped into the HCl and allowed to remain from 15 to 30 seconds, or until the evolution of hydrogen, indicated by the bubbles, has ceased. The metal is then removed immediately, thoroughly washed and scrubbed in running water, dried, cooled, and weighed. The loss of weight in grams will be the weight of the coating in ounces per square foot.

Separate solutions may be used for each piece of metal, or the same HCl may be used for several tests if 5 cc. of the antimony chloride solution is added for each piece of metal.

Several measures of the thickness of the uncoated metal should be made with the micrometer gage. By consulting Table 12, page 277, the gage of the metal can be determined.

Results: The results should be reported both in grams per sample and in ounces per square foot. For the latter, report individual results and the average of the class.

Value of Test: Most sheet metal composed of iron will rust unless protected. It may be painted, but for many cases this is impractical. Galvanizing the metal with a zinc coating is the most common method of protecting it. The life of the metal is governed largely by the amount of the zinc coating; hence, this test is important. A usual specification is that at least 2 ounces per square foot of surface must be used. This includes both sides of the sheet metal.

QUESTIONS AND PROBLEMS:

1. Prove that the amount of coating in grams for a piece of metal $2\frac{1}{4}'' \times 2\frac{1}{4}''$ is equal to the coating in ounces per square foot.
2. Give several other methods of protecting metal from rusting.
3. What are the conditions under which steel will rust most readily?
4. Give several theories as to why certain metals *corrode.*

REFERENCES:

Barton and Doane: Pages 185-187
Johnson: Pages 787-805
Mills: Pages 173-175, 255-258
A.S.T.M. Serial Designation A 90-39

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Exp. No. 54

Date: ....

General Subject: Testing of Wire Rope.

Specific Object: Determination of Tensile Strength and Per Cent of Elongation.

Sample:

Apparatus: Universal Testing Machine, Special Grips for Socketing Wire Rope, Scales.

Method: The difficulty of testing individual wire strands, wire rope, and cable lies in securing adequate and satisfactory means for holding the ends. For wire rope, special sockets must be used. Plans and descriptions of these are given in Johnson's *Materials of Construction,* page 670.

A section of rope must be cut so that, after being fixed in the sockets and in the testing machine, there will be a distance of 24 inches between the jaws of the machine. The rope should be served at several places before being cut, in order to prevent its becoming unwound. The ends are then drawn through the conical sockets and the wires are broomed. The ends of the strands are cleaned with gasoline, washed in caustic potash, and then tinned in molten babbitt.

Each end is drawn down into the socket until the broomed portion fills the conical space. Molten babbitt metal is now poured into the socket so as to fill it completely. The sockets are then anchored or gripped in the testing machine, the distance between jaws is measured exactly, and the load for rupture is determined.

When initial failure of the sample takes place, the exact distance between the jaws is determined. The difference between this distance and that obtained previously to applying the load is used in calculating the per cent of elongation.

The tensile strength of the rope is obtained by dividing the ultimate load by the actual cross-sectional area of the wires composing the cable.

Results: Report ultimate load, strength of rope in pounds per square inch, and per cent of elongation.

VALUE OF TEST: Wire rope is used for a large variety of purposes in construction and industry. Its ultimate tensile strength must be known in order to determine the safe load that it will carry. Generally, a factor of safety of 5 is used, but this should be at least 8 for passenger-elevator rope. Wire rope has a tensile strength of from 75 per cent to nearly 100 per cent of the total strength of the individual wires tested separately.

QUESTIONS AND PROBLEMS:

1. Compute the gross area of the rope and compare it with the net area.
2. Compare the tensile unit strength of the rope with the tensile strength of the individual wires.
3. Why is it necessary to clean the ends of the wire with gasoline and caustic soda prior to tinning them in molten babbitt?
4. Consult the references and determine what factors of safety are common with wire rope under several conditions of use.

REFERENCES:

Johnson: Pages 669-672
A.S.T.M. Serial Designation A 122-33

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NOTES

TESTING OF BITUMINOUS MATERIALS

Source.—There are two main classes of bituminous materials: asphalts and tars. The asphalts occur as such in nature or are derived from the distillation of petroleum. Tars are obtained in the destructive distillation of bituminous coal. The character of these materials varies considerably, depending on their source.

Characteristics.—Tests conducted on bituminous materials are for the purpose of determining their physical characteristics. The most important tests are those designed to determine the consistency of the material and its behavior when heated. There are other general tests made for specific purposes. For example, specific gravity tests serve to identify the material and to check successive shipments. Tests for total bitumen enable the engineer both to identify the material and to determine its economic value.

Samples.—Bituminous materials, as commonly handled in the laboratory, are liquid, semi-solid, or solid. The difficulties of obtaining suitable samples for a specific test depend on the consistency of the material at normal temperature. For example, samples from liquid materials can be obtained easily. Samples from semi-solid and solid materials are obtained with more difficulty. Usually, to obtain the proper samples, these latter materials must be first softened in suitable equipment. Excessive heating in obtaining samples may change materially the physical characteristics of the bitumen.

It will be found that semi-solid and solid bitumens can be readily cut with a hot knife. The knife may be heated over a gas flame. It should be free of bitumen when it is heated; otherwise, the liquid material will drop onto the burner. This can be avoided by keeping a piece of waste conveniently near and wiping the knife frequently. After a piece of bitumen is cut out of the sample container with the hot knife, the piece can be reduced to the liquid form by heating it in a large kitchen spoon. A very low flame should be used, and care should be exercised so there will be no loss of volatile material that may be present in the bitumen.

Pouring Test Specimens.—In several of the tests on bituminous materials, it is necessary to form the test specimens in suitable molds. The bitumen, reduced to the liquid form as previously described, is poured into the molds. This must be done with extreme care. It will be found convenient to make use of the top of the tin box used in the penetration test (see Experiment No. 61). The top is bent so that it will have a V-shaped cross-section. The bitumen is transferred from the spoon to the top, and from this it can be readily poured into the molds.

Temperature Control.—Bituminous materials are extremely sensitive to changes of temperature. Certain tests are run at definite temperatures, and extreme care must be exercised in each case to see that there is no variation from the temperature specified. Unless this precaution is observed, it will be difficult to check tests on identical materials. It will frequently be necessary to calibrate the thermometers. This can be done by using various materials with different boiling points. The periods of storage of test specimens under constant temperature conditions are specified in the different tests given. These periods have been selected on the basis of experience. If the specimens are left in storage at the specified temperature and for the required length of time, the bituminous material will attain the normal temperature throughout its mass.

Cleaning Apparatus.—The student who is to test bituminous materials should learn early that it is necessary to keep all apparatus thoroughly clean. At first, there will be a tendency to leave glassware, thermometers, knives, and other apparatus full of bitumen. All equipment and apparatus used should be cleaned just as soon as the student has finished with it. For example, knives, spoons, and thermometers can be wiped fairly clean while the bitumen is still warm. Further cleaning can be accomplished by the use of gasoline and carbon disulfide. The student should be cautioned in the use of volatile and dangerous solvents. Carbon tetrachloride should be readily available for use in case of fire.

Standard Specifications.—The student should consult Tables 8 and 9 in the Appendix and note the variations in the physical characteristics of the various bituminous materials, depending on their uses. By doing this, the student will be enabled to classify a bituminous material according to its use after he has determined its physical characteristics from tests. The data given are somewhat general, and it will be found that specifications for bituminous materials in effect with the various State Highway Departments may vary somewhat from the physical characteristics as shown in the Tables.

Cut-back Materials.—Since 1930 there has been a tremendous increase in the use of cut-back asphalt and tars, as well as emulsions, in highway construction. They are furnished in a large number of grades, each designed for a particular type of construction. The testing of these materials follows the usual methods that are described in this Manual, with the difference that it is often necessary to separate the solvent and base material. This is done in accordance with the method outlined in A.S.T.M. Serial Designation D 402-36. The separated materials are then tested in accordance with the usual procedure for other bituminous materials. In Table 7, pages 272 and 273, there are given typical specifications for cut-back asphaltic materials.

There are two important variations, however, in tests run on the original cut-back material. The viscosity is determined with the Saybolt Furol Viscosimeter, the method being the same as that outlined in Experiment No. 59 except that a special orifice tube is used. In the case of flash point, this is determined with the Tagliabue open cup. These methods are described in detail in A.S.T.M. Serial Designation D 56-36 and A.A.S.H.O. Method T-72-35.

Exp. No. 55
Date: ....

General Subject: Testing of Bituminous Materials.

Specific Object: Specific Gravity by Hydrometer Method.

Sample:

Apparatus: Set of Hydrometers, Bunsen Burner, Beaker, Thermometer, Hydrometer Jar, Quart Cup, Pan.

Method: The test is run at a temperature of 25° C. The liquid material to be tested is poured into the quart cup and brought to a temperature of 25° C. In the meantime the pan is filled with water at the same temperature and the hydrometer jar is placed in it. When the bituminous material is at the required temperature, it is poured into the jar and tested with the proper hydrometer. Several readings should be taken, it being important that the temperature of the liquid be maintained at exactly 25° C. during the readings.

If the liquid is viscous, it is necessary to press the hydrometer down slightly and note if it rises to the same point. If it does not, the specific gravity cannot be determined by this method. The pycnometer method, described in Experiment No. 56, should then be used instead.

The hydrometers are calibrated at a temperature of 15.5° C. It is therefore necessary that the specific gravities obtained by this method at 25° C. be multiplied by a constant. The constant to be used is 1.002.

Results: Report individual results and the average for a particular material.

Value of Test: Specific-gravity tests are generally made as check tests and for the purpose of identifying materials. The range of specific gravities for a variety of bituminous materials is given in the tables on pages 273 and 274, and also in Bauer's *Highway Materials,* page 25. This particular method can be used only for liquid materials.

Questions and Problems:

1. Explain how a hydrometer can be calibrated.
2. How was the value of the correction factor, 1.002, determined?

3. What are the principal advantages of using the hydrometer method in determining the specific gravities of liquid materials?
4. Determine the relation between specific gravity expressed as a *ratio* and in degrees Baumé.

REFERENCES:

Barton and Doane: Pages 210-212, 280-282, 320-321
Bauer: Pages 24-25, 202-204
Besson: Pages 303-306, 309-316
A.S.T.M. Serial Designation D 287-36

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Exp. No. 56
Date: ....

General Subject: Testing of Bituminous Materials.

Specific Object: Specific Gravity by Pycnometer Method.

Sample:

Apparatus: Hubbard Pycnometer, 250-cc. Beaker, Thermometer, Kitchen Spoon, Spatula, Desiccator, Analytical Balances, Drying Oven.

Method: The pycnometer must first be calibrated. This is done by cleaning and drying it thoroughly. It is then weighed, with the stopper, on the analytical balances. This weight is called *a*. The pycnometer is then filled with freshly-boiled distilled water at 25° C. and reweighed. This weight is called *b*. The procedure thereafter depends on whether the material to be tested flows readily or is viscous.

For a material that flows readily, the pycnometer is filled with the liquid at a temperature of 25° C. The pycnometer and contents are weighed. This weight is called *c*. The specific gravity can then be calculated by the formula:

$$\text{Specific gravity} = \frac{c - a}{b - a}$$

For a viscous material, the pycnometer is filled about one-half full with the liquid at 25° C. It will be necessary, in order to do this, to heat the material, pour it into the pycnometer, and then cool the bottle and contents for at least 1 hour in water at 25° C. The pycnometer is weighed. This weight is called *c*. The pycnometer is then completely filled above the viscous liquid with distilled water at 25° C. It is weighed again, and the weight is called *d*. The specific gravity is calculated from the following formula:

$$\text{Specific gravity} = \frac{(c - a)}{(b - a) - (d - c)}$$

The Hubbard pycnometer is fairly easy to clean if care is used. The distilled water should be emptied and the pycnometer put in the drying oven until its contents liquefy. The bituminous material can then be poured out. With a piece of waste and a little carbon disulfide, the bituminous material remaining can be wiped out, so that the pycnometer will be clean.

RESULTS: Report individual results and the average for a particular material. The detailed calculations may be shown on a separate sheet.

VALUE OF TEST: See Experiment No. 55. This method is used on liquid and semi-liquid bituminous materials.

QUESTIONS AND PROBLEMS:

1. Note the shape of the stopper of the pycnometer. What is the purpose of this?
2. Deduce the formulas given under "Method".
3. Consult a catalog of laboratory supplies and note the several types of specific gravity flasks available.
4. Why is distilled water used in this experiment?

REFERENCES:

Barton and Doane: Pages 207-210, 320-321
Bauer: Pages 24-25, 205-208
Besson: Pages 303-306, 309-316
A.S.T.M. Serial Designation D 70-27

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EXP. NO. 57
DATE: ....

GENERAL SUBJECT: Testing of Bituminous Materials.

SPECIFIC OBJECT: Specific Gravity by Displacement Method.

SAMPLE:

APPARATUS: Analytical Balances, Straddling Platform, Thermometer, Silk Thread, 150-cc. Beaker, Brass Mold, Kitchen Spoon, Spatula.

METHOD: The test specimen is formed in the brass mold, which must first be amalgamated. This is done as follows: The mold and the brass plate are thoroughly cleaned by washing and scrubbing first with carbon disulfide and then with dilute HCl. The brass is next rubbed with a dilute solution of mercuric chloride and then with mercury. When properly amalgamated the surface will have a smooth, silvery appearance. The amalgamation is for the purpose of preventing the bituminous material from sticking to the mold.

A small quantity of the material is melted in the kitchen spoon. Care must be taken to melt the material slowly and so that there will be no loss of volatile constituents. When the material is liquid enough, the brass mold is poured heaping full; and, after the material has been allowed to cool, the excess is cut off with a hot spatula. The mold and its contents are then left until they have attained a temperature of about 25° C.

When the required temperature is reached, the mold is removed, the sample of bituminous material is suspended from the hook of the analytical balances by a piece of silk thread, and its weight is obtained. This weight is called a. The sample is then weighed while immersed in a beaker of distilled water at 25° C., the beaker resting on the straddling platform. The weight is recorded as b. The specific gravity is calculated from the following formula:

$$\text{Specific gravity} = \frac{a}{a - b}$$

RESULTS: Report individual results and the average for all tests on a particular material.

VALUE OF TEST: See Experiment No. 55. This test is usually made on solid bituminous materials only.

QUESTIONS AND PROBLEMS:

1. Why is it necessary to mold a specimen of the material rather than use a broken fragment?
2. What effect would the weight of the silk thread have in this method of determining specific gravity?
3. Under what conditions would this method not be applicable, without modifications, in determining the specific gravity of a solid bituminous material?

REFERENCES:

Barton and Doane: Pages 206-207, 320-321
Bauer: Pages 24-25, 209-210
Besson: Pages 305-306, 309-316
A.S.T.M. Serial Designation D 71-27

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EXP. NO. 58
DATE: ....

GENERAL SUBJECT: Testing of Bituminous Materials.

SPECIFIC OBJECT: Determination of Specific Viscosity.

SAMPLE:

APPARATUS: Engler Viscosimeter, 100-cc. Graduate, 50-cc. Graduate, Quart Cup, Thermometer, Stop-Watch.

METHOD: The viscosimeter must first be calibrated. The instrument is set up, care being taken that the outlet hole is clean. Its cleanliness may be tested by holding a lighted match underneath while looking through it from above. If it is not clean, a small piece of tissue paper may be drawn through it. The stopper is inserted and the inner vessel is filled to the top of the projections with water at 25° C. The times for the passage through the hole of 50 and 100 cc. of water are determined from several trials. Between trials, the level of water must, of course, be brought to the top of the projections.

In the meantime, the liquid to be tested is put in the quart cup and its temperature is brought to that at which the test will be run. (See tables on pages 273 and 274. A temperature of 40° C. is usually specified for tars.) While this is being done, the liquid in the outer vessel is brought to the same temperature by means of the ring burner underneath. The material to be tested is then poured into the inner vessel until the level reaches the top of the projections. The ring burner and the gas flame should be so adjusted that the temperature at which the test is to be run will be maintained. Thereafter, the stopper is removed and the times for the passage of 50 and 100 cc. of the material are ascertained. The specific viscosity is calculated from the following formula:

$$\text{Specific viscosity} = \frac{\text{Time in seconds for passage of liquid}}{\text{Time in seconds for passage of water}}$$

Water is generally used in the outer vessel. However, if the test is to be run at 100° C. or a higher temperature, cottonseed oil must be used.

RESULTS: Report results for each test run as well as the average for all tests on the same material. Give also the data obtained in calibrating the viscosimeter.

VALUE OF TEST: This test is primarily to determine the consistency of the material at a specified temperature or at various temperatures. This knowledge is essential in selecting a bituminous material for a particular purpose. Obviously, this method can be employed only for fluid materials. With the present wide use of liquid bituminous materials for surface treatment of roads, this test has become of considerable significance.

QUESTIONS AND PROBLEMS:

1. Why is the time for the passage of 100 cc. of water more than twice the time for the passage of 50 cc. of water.
2. Consult a catalog of laboratory equipment and note several types of viscosimeters available.
3. Why is cottonseed oil used in the outer bath if the temperature at which the test is to be run is 100° C. or more?

REFERENCES:

A.A.S.H.O., 1938, Method T-54-35, page 224
Barton and Doane: Pages 220-222, 279-281, 319-322
Bauer: Pages 27-28, 236-238
Besson: Pages 277-279, 309-312

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EXP. No. 59
DATE: ....

GENERAL SUBJECT: Testing of Bituminous Materials.

SPECIFIC OBJECT: Determination of Viscosity of Lubricating Oil.

SAMPLE:

APPARATUS: Saybolt Universal Viscosimeter, 60-ml. Flask, Thermometers, Pipette, Stop-Watch, Quart Cup.

METHOD: The general methods to be followed are the same as those employed with the Engler viscosimeter in Experiment No. 58, except that this test is not run with reference to water. The Saybolt viscosimeter should be standardized, particularly the outlet tube. The oil to be tested is poured into the tin cup and the temperature is brought slightly above that specified for the test. The viscosimeter is set up and the liquid in the bath is brought to the proper temperature. The oil is poured into the tube and enough excess is used to bring the level to the filling mark. The level in the overflow tube is then brought down below the top of the main tube by means of the pipette.

When both the bath and the oil are at the specified temperature, the 60-ml. flask is placed under the outlet, the cork at the bottom is withdrawn, and the stop-watch is started. The viscosity is the time in seconds for the flow of 60 ml. of the oil at the temperature specified. For lubricating oil, one of the following temperatures is used:

100° F., 130° F., 210° F.

RESULTS: Report individual results and the average for all tests run on a particular oil.

VALUE OF TEST: The viscosity of a lubricating oil is one of its most important physical properties. Because of the wide range of temperature under which it will be used, the ideal oil would have the same viscosity at low and at high temperatures. This ideal is difficult to obtain. Oils with various viscosities are specified for different purposes, and this test affords a standard method of determining if an oil will be suitable for a particular purpose. See the table on page 275.

Questions and Problems:

1. Why are different temperatures specified in running this experiment?
2. Is there a relation between the specific gravity of lubricating oil and its viscosity?
3. Compare the specific gravities of petroleum, gasoline, light lubricating oil, heavy lubricating oil, and paving asphalt.

Remarks:

The same general procedure outlined in this method is also followed in determining the viscosities of fuel and road oils and cut-back asphaltic materials. See page 200. The Saybolt Universal Viscosimeter may be used, but it must be equipped with a different size orifice tube. The specifications for these tubes are given in the A.S.T.M. reference listed below.

References:

Bauer: Pages 239-244
A.S.T.M. Serial Designation D 88-38

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Exp. No. 60
Date: ....

General Subject: Testing of Bituminous Materials.

Specific Object: Determination of Consistency (The Float Test).

Sample:

Apparatus: Aluminum Float and Three Brass Collars, Thermometer, Pans, Brass Plate, Spoon, Spatula, Stop-Watch.

Method: The small brass plate is amalgamated in accordance with the method outlined in Experiment No. 57. The sample is next melted in the kitchen spoon, and, when the material is sufficiently fluid, each collar is filled, a slight excess of material being used. After the material has been allowed to cool, the excess is cut off with a hot spatula. The molds, still on the brass plate, are immersed in ice water maintained at 5° C., and are allowed to remain for at least 15 minutes.

The pan is filled with water, and this is brought to the temperature at which the test is to be run. (It is generally 50° C. for tar products. See page 274.) The gas flame is so regulated that the temperature will be maintained during the test. When the test is to be run, a brass collar is screwed into the aluminum saucer, the saucer is placed in the water bath, and the stop-watch is started. The time is recorded from the instant the saucer is put into the water until water breaks through the sample and enters the saucer. This is a measure of the consistency of the material.

For asphalt products, the samples in the brass collars are allowed to cool to room temperature before being placed in the ice-water bath. For tar products, the samples are immersed in the ice water as soon as the collars are filled.

Results: Generally only one test will be run for the entire section. Report the time obtained for the sample in each collar, and the average for all of them.

Questions and Problems:

1. Why is the time for storage of the specimen in ice water specified as not less than 15 minutes?

2. What two factors are responsible for the material being forced upward through the column?
3. Why are the collars and plate on which the specimens are molded made of brass?
4. Compare the consistencies of several materials as obtained in this test with their specific gravities.

REFERENCES:

Barton and Doane: Pages 202-203, 223-226, 279-281, 319-322

Bauer: Pages 27-28, 30, 232-235

Besson: Pages 274-277, 309-312

A.S.T.M. Serial Designation D 139-27

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EXP. No. 61
DATE: . . . .

GENERAL SUBJECT: Testing of Bituminous Materials.

SPECIFIC OBJECT: Determination of Penetration.

SAMPLE:

APPARATUS: Tin Box, Stop-Watch, Knife, Thermometer, Penetrometer, Glass Dish.

METHOD: The tin box is first filled to within 1 cm. of the top or to a depth not less than 15 mm. This is accomplished by melting the material in a cup or dipper and then pouring it into the tin box. The material must then be stirred to eliminate air bubbles and to secure uniformity. After being allowed to cool to room temperature, the box and contents are placed in the glass dish, and the whole is immersed in water, maintained at the temperature at which the test will be run, for at least 1 hour.

The penetrometer is set up with the proper weight in position. The glass dish with the tin box and contents are transferred to the base of the penetrometer. The dish must be kept full of water at the required temperature during the test. The needle is brought into contact with the surface of the material, and the dial is read. The rod is then loosened and the needle allowed to penetrate for 5 seconds, as indicated by the stop-watch. The final reading is taken. The difference between the two readings will give the penetration.

Absolute control of the temperature of the material is necessary if accurate results are to be obtained. The instant when the needle comes into contact with the surface of the material can be determined by watching its reflection in the asphalt. It is best not to attempt to ascertain the time by starting and stopping the watch, but to leave the watch running, and to release and stop the needle as the hand passes the 5-second marks. After each test, the needle must be cleaned with a piece of waste wet with carbon disulfide.

This test is run at various temperatures and weights. The most usual combination is a weight of 100 grams at a temperature of 25° C.

RESULTS: Report individual results and the average for all tests on the same material tested under the same conditions.

VALUE OF TEST: See Experiment No. 58 for value of test. This particular method is used for semi-solid and solid bituminous materials. Specifications generally require that it also be made on asphalt samples which have been subjected to the volatilization test. See Experiment No. 65.

QUESTIONS AND PROBLEMS:

1. Explain the necessity for storing the box and contents in water for at least 1 hour previous to determining the penetration.
2. Under what conditions would different weights be used in determining penetration of a particular material?
3. What is the purpose of immersing the specimen in water at a specified temperature while the test is being made?
4. Consult specifications for road-building materials and note the variation in the penetration of the bituminous material with the type of surface to be constructed as well as with its location.

REFERENCES:

Barton and Doane: Pages 213-216, 278-282, 319-321
Bauer: Pages 28, 220-222
Besson: Pages 272-274, 316-318
A.S.T.M. Serial Designation D 5-25

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EXP. No. 62
DATE: ....

GENERAL SUBJECT: Testing of Bituminous Materials.

SPECIFIC OBJECT: Determination of Melting Point by the Ring-and-Ball Method.

SAMPLE:

APPARATUS: Ring-and-Ball Apparatus, Brass Plate, 600-cc. Beaker, Stand and Clamp, Thermometer, Kitchen Spoon, Knife.

METHOD: The material to be tested is heated in the spoon until it will pour readily. The ring of the ring-and-ball apparatus is placed on an amalgamated brass plate and filled to excess with the fluid sample. After the material cools, the excess is cut off with a hot knife. The sample, together with the ball, is put in water maintained at 5° C., and allowed to remain for at least 15 minutes.

The ring-and-ball apparatus is assembled in the beaker, into which freshly boiled distilled water at 5° C. has been poured to a depth of 8.25 cm. The ring is transferred to the support in the beaker, the bottom of the ring being exactly 2.54 cm. above the bottom of the beaker. The thermometer is placed so that the bottom of the bulb is level with the bottom of the ring and ¼ inch from it. The ball is placed on the top, and in the exact center, of the sample. The temperature of the water is now raised at the rate of 5° C. per minute. The temperature when the ball touches the bottom of the beaker is recorded as the melting point.

The beginner will find difficulty at first in raising the temperature at the constant rate of 5° C. per minute. It is suggested that the setting of the gas flame be regulated by several trials before the test is actually run.

RESULTS: Generally, several tests are run on the same material. The results of individual tests should be reported, as well as the average for all tests on the same material.

VALUE OF TEST: This test is of importance in determining the stability of various bituminous materials. It is a usability test, for from the results obtained the engineer can determine if a particular material will be suitable for certain conditions.

The ring-and-ball method is designed primarily for asphalt products. The cube-in-water method was devised for tar products. See Experiment No. 63. It has now become the practice to use the ring-and-ball method for determining the melting point of both asphaltic and tar products.

Questions and Problems:

1. Why is it essential that the temperature of the water be raised at a uniform and specified rate?
2. Explain the necessity for using freshly boiled distilled water in this experiment.
3. Consult specifications and compare the melting point of the asphalt used in constructing a bituminous-macadam pavement with that of a blown asphalt used as a joint filler.

References:

Barton and Doane: Pages 218-220, 278-282, 319-322
Bauer: Pages 28-29, 223-227
Besson: Pages 280-283, 311-316
A.S.T.M. Serial Designation D 36-26

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Exp. No. 63
Date: . . . .

General Subject: Testing of Bituminous Materials.

Specific Object: Determination of Melting Point by the Cube-in-Water Method.

Sample:

Apparatus: Brass Mold and Plate, 600-cc. Beaker, Copper Wire 12 Gage, Thermometer, Spoon, Knife.

Method: A sample of the material is formed in a ½-inch cubic mold. The mold and a brass plate must first be amalgamated as described in Experiment No. 57. The material is heated gently in the spoon and the mold is filled slightly above level. After cooling, the excess is cut off with a heated knife.

The beaker is placed on a support so that it can be heated with a shielded gas flame. Freshly boiled distilled water is poured in to a depth of 9.5 cm. It is well to place a piece of white paper on the bottom to prevent the material from sticking. The water is maintained at a temperature of 15.5° C. A hook is formed by bending the length of the wire to a right angle, the length of the short end being 1 inch.

The molded material is removed from the mold and fastened to the short end of the wire through its exact center. It is then suspended by means of the wire in the beaker so that its lowest point will be exactly 1 inch from the bottom of the beaker. It is left in this position for 15 minutes, the water being maintained at the constant temperature of 15.5° C. The thermometer is so suspended that the bottom of the bulb is level with the bottom of the cube and ¼ inch from it.

At the end of the required period, the temperature of the water is raised at the constant rate of 5° C. per minute. The temperature when the sample touches the bottom of the beaker is recorded as the melting point.

Results: Generally, several tests are run on the same material. The results of individual tests should be reported, as well as the average for all tests on the same material.

VALUE OF TEST: This test is important in determining the stability of bituminous materials at different temperatures. It is a usability test, for by means of the results of this test the engineer is enabled to select the proper bituminous material for a particular purpose. The cube-in-water method of determining the melting point is designed specifically for tar products.

QUESTIONS AND PROBLEMS:

1. Give the reason why this particular method would not be applicable in determining the melting point of certain asphalts.
2. Consult specifications for the tar used in built-up roofs and note the requirement for the melting point.
3. Why is it necessary to specify a minimum value of the melting point for a tar used in constructing a bituminous-macadam surface?

REFERENCES:

Barton and Doane: Pages 216-218, 278-282, 319-322
Bauer: Pages 29-30, 228-231
Besson: Pages 283-286, 311-316
A.S.T.M. Serial Designation D 61-38

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Exp. No. 64
Date: ....

General Subject: Testing of Bituminous Materials.

Specific Object: Determination of Flash and Fire Points.

Sample:

Apparatus: Cleveland Open Cup Oil Tester, Testing Flame Taper, Thermometer, Knife.

Method: The open cup oil tester shall be filled to the filling line with the material to be tested. The filling line is $\frac{3}{8}$ inch below the top of the cup. The apparatus is set up on a support with a suitable heating flame underneath and near a stand from which a thermometer can be suspended. The bottom of the bulb of the thermometer shall be $\frac{1}{4}$ inch from the bottom of the cup and halfway from the center of the cup to the back.

The temperature is raised at a rate not exceeding 30° F. per minute, till a point is reached approximately 100° F. below the probable flash point. Thereafter, the rise in temperature is at the rate of 9 to 11° F. per minute. The testing flame shall have a diameter of $\frac{5}{32}$ inch, and must be swung over the entire surface of the liquid. The temperature is taken when the first flash, completely across the surface, takes place. This is recorded as the *flash point.*

The heating is continued at the specified rate until, when the testing flame is applied, the material takes fire and burns for at least 5 seconds. The temperature is recorded as the *fire point.* The flame can be extinguished by quickly putting on the cover.

Results: Report the temperature at which the material flashed, and the temperature at which it took fire and burned.

Value of Test: This is a most important usability test. It serves to determine if there are volatile constituents in the material, as well as to establish the safe temperature to which the material may be heated. It is made on many asphalt products, as well as lubricating oils. The volatile constituents of tars are determined by the distillation test. See Experiment No. 66.

QUESTIONS AND PROBLEMS:

1. Explain the necessity for raising the temperature of the material at a uniform and specified rate.
2. Consult specifications for lubricating oils and determine the flash points for several grades.
3. Note from Tables 7 and 8, pages 272 and 273, the difference in the flash points of a road oil and an asphalt cement used for construction.

REFERENCES:

Barton and Doane: Pages 243-244, 278-280, 319-324
Bauer: Pages 31, 259-263
Besson: Pages 291-294, 312-316
A.S.T.M. Serial Designation D 92-33

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EXP. No. 65
DATE: ....

GENERAL SUBJECT: Testing of Bituminous Materials.

SPECIFIC OBJECT: Determination of Loss on Heating (Volatilization Test).

SAMPLE:

APPARATUS: Constant Temperature Electric Oven, Tin Box, Spoon, Knife, Thermometer, Analytical Balances, Desiccator.

METHOD: If the sample contains water, it must be dehydrated before it is used for this test. See A.S.T.M. Serial Designation D 370-33. The tin box is first weighed, and then 50 grams of the water-free material is put in it, the rough balances being used for the weighing. The weight of box and sample is then found on the analytical balances, and the weight of the sample is thus obtained. This weight should not vary by more than 0.2 gram from the 50 grams specified.

The electric oven is brought to a temperature of 163° C., and the sample placed on the revolving shelf. The sample remains in the oven for 5 hours from the time the temperature again reaches 163° C., during which period the variation in temperature shall not be more than 1° C. The shelf is revolved constantly at the rate of 5 to 6 revolutions per minute.

At the end of the required period the box and sample are removed, cooled in the desiccator, and reweighed. The loss due to volatilization is determined as follows:

$$\text{Per cent of loss} = \frac{\text{Loss in weight}}{\text{Weight of sample}} \times 100$$

It is frequently necessary to determine the penetration of the sample after the volatilization test has been run. This should be done in accordance with the method described in Experiment No. 61.

RESULTS: Report individual results and the average for all tests run on the same material.

VALUE OF TEST: This is a direct usability test. It is an accelerated test which serves to determine the probable life of the bituminous material in actual use. It may also determine the nature of the material, as, for example, whether it has been cut-back. This test is run on asphalt products. The distillation test accomplishes the same purpose for tar products. See Experiment No. 66.

QUESTIONS AND PROBLEMS:

1. Explain the necessity for specifying the weight of the material to be used in this test.
2. Explain the necessity for requiring that the sample be placed on a revolving shelf in the electric oven.
3. For what materials would it be essential that the penetration be determined after the sample has been submitted to this volatilization test?

REFERENCES:

Barton and Doane: Pages 248-250, 278-280, 319-324
Bauer: Pages 31-32, 251-255
Besson: Pages 286-288, 312-316
A.S.T.M. Serial Designation D 6-39T

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Exp. No. 66
Date: ....

General Subject: Testing of Bituminous Materials.

Specific Object: The Distillation Test.

Sample:

Apparatus: Copper Still with Dehydration Connections, Engler Distillation Flask, Thermometer, Condenser, Stand and Clamps, Shield, Balances, Five 25-cc. Graduates.

Method: If the material to be tested contains water, it must first be dehydrated. (For a detailed description of the method of doing this, see A.S.T.M. Serial Designation D 370-33.) The retort is weighed. From the known specific gravity of the material, the weight of 100 cc. of the sample is determined, and this weight is added to that of the retort. Enough of the water-free material is then poured into the retort (placed on one side of the rough balances) to balance exactly the weight of the retort and 100 cc. of the material.

The retort is then set up on a ring stand with the thermometer, condenser tube, and connections. The bulb of the thermometer should be opposite the outlet for the connecting tube. The end of the condenser tube shall be not less than 50, and not more than 60, cm. from the bulb of the thermometer. A graduate, the weight of which has been previously determined, is placed under the end of the condenser tube.

The shield is put in position so that the gas flame will not be affected by air currents. The gas flame shall be so regulated that the distillation shall proceed at the rate of from 50 to 70 drops per minute. When the temperature for the first fraction is reached, the graduate is removed and another one is put in its place. The process is continued for the other fractioning points until a temperature of 300° C. is reached. The volumes and weights of the several fractions are then determined and the per cent of each is calculated.

The beginner will find it difficult to regulate the gas flame so that the required rate of distillation will be maintained. Experience, as well as a knowledge of the material, is necessary before this test can be run satisfactorily.

Fractions are taken for the following ranges of temperature:

Up to 110° C.
110-170° C.
170-235° C.
235-270° C.
270-300° C.
Residue

For the method of distilling cut-back asphaltic products, see A.S.T.M. Serial Designation D 402-36.

RESULTS: The weights, calculations, and results of the test should be shown on a separate sheet attached to the report. Prepare a table similar to the one below:

FRACTION	VOLUME CC.	WEIGHT GRAMS	PER CENT		CHARACTER
			VOLUME	WEIGHT	
To 110° C.	....	....	....	....	....
110-170° C.	....	....	....	....	....
170-235° C.	....	....	....	....	....
235-270° C.	....	....	....	....	....
270-300° C.	....	....	....	....	....
Residue	....	....	....	....	....
Total	....	....	....	....	....

VALUE OF TEST: This test is most generally run on tar products. It accomplishes for tars the same relative results determined for asphalt products by the volatilization and flash- and fire-point tests. From the results of the distillation test, the engineer gains information not only about the constituents of the material, but also about the probable uses for which it is adapted.

QUESTIONS AND PROBLEMS:

1. What is the purpose of using exactly 100 cc. of tar for this experiment?
2. Examine the distillates and classify them according to their specific gravities.

3. What physical qualities of asphaltic products correspond to the qualities determined for tars by the distillation test?

References:

Barton and Doane: Pages 250-255, 280-282, 321-325
Bauer: Pages 33, 245-250
Besson: Pages 288-291, 311, 314, 316
A.S.T.M. Serial Designation D 20-30

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Exp. No. 67
Date: . . . .

General Subject: Testing of Bituminous Materials.

Specific Object: Determination of Total Bitumen.

Sample:

Apparatus: Gooch Crucible, Filtering Flask and Connections, Vacuum Pump, 150-cc. Erlenmeyer Flask, Analytical Balances, Drying Oven, Tongs, Desiccator.

Method: A sample of about 2 grams is used. The material is melted in a spoon and poured into the flask, the weight of which has been previously obtained. The flask, with sample, is then weighed, and the exact weight of the sample is obtained. About 100 cc. of carbon disulfide is poured into the flask, and it is then set aside.

An asbestos filter is next prepared. Fibre asbestos is cut into small pieces and put in a flask with distilled water. The crucible is set up over a suction flask, and the asbestos solution poured into it. This is allowed to settle, and then is drawn down with the suction. Additional amounts of the solution are used until the mat will barely admit light when held before the eyes. The crucible with filter is then dried in the oven, and heated to incandescence over a Meeker-type burner. The crucible is cooled in the desiccator and weighed.

The crucible is set up over the suction flask, and the contents of the flask (containing the sample of bitumen) are decanted through it. This must be done slowly, and care must be taken that none of the undissolved residue from the flask is poured onto the filter. Suction may be used to facilitate the passage of the solution through the filter. It will be found best, however, to use the suction sparingly. When the contents of the flask have been decanted, fresh carbon disulfide is poured into the flask to wash down the sides, and this likewise is decanted onto the filter. Finally, fresh carbon disulfide is washed through the filter until it comes through clear. Suction is then applied and continued until there is no perceptible odor of the solvent. The crucible is then dried, cooled, and weighed. From the initial and final weights, the weight of insoluble material can be determined. The flask used should be dried and weighed, and the increase in weight should be added to that of the insoluble material caught on the filter. Likewise, as a further refinement, the filtrate containing the bitumen should be evaporated, dried, and burned, and the weight of the ash should be added to the weight of the insoluble material. The per cent of bitumen will be

$$100 - \frac{\text{Total weight of insoluble materials}}{\text{Weight of sample}} \times 100$$

If the percentage of ash is desired, this can be obtained by burning the crucible and contents in a Meeker-type burner after the last weighing just described. After ignition, the crucible should be cooled and reweighed. This last weight, minus the weight of the crucible, will give the weight of the ash. The per cent of ash will be calculated as follows:

$$\text{Per cent of ash} = \frac{\text{Weight of ash}}{\text{Weight of sample}} \times 100$$

The method described here is applicable only to materials containing a high percentage of bitumen. For certain native asphalts and some tars, a longer method is used. This is described in detail in the references that follow.

The method described here is used also in finding the "Percentage of Bitumen Insoluble in Carbon Tetrachloride (Carbenes)" and the "Percentage of Bitumen Insoluble in Paraffin Naphtha (Asphaltenes)". See A.S.T.M. Serial Designation D 165-27.

RESULTS: Report the percentages of bitumen and ash. Give individual results and the average for all tests run on the same material. The detailed data and calculations should be shown on a separate sheet attached to the report.

VALUE OF TEST: This test is made on all bituminous materials. It is of economic importance, serving to determine the value of the particular bituminous material. Oil asphalts are generally high in bitumen, the native asphalts having a much lower bitumen content. *Bitumen* is the only substance of real value in asphalts and tars. Everything else present is in the nature of an adulterant.

QUESTIONS AND PROBLEMS:

1. Explain the necessity for heating the crucible to incandescence before weighing and using it.
2. Why is it necessary to use the suction sparingly in passing the solution through the filter?
3. How can it be determined if all of the insoluble material in the sample has been caught on the filter?
4. What is the difference between "fixed carbon" and "free carbon"?
5. Consult specifications and determine the approximate per cents of bitumen in natural asphalt, petroleum asphalt, high-carbon tar and low-carbon tar.

REFERENCES:

Barton and Doane: Pages 229-235, 278-282, 319-323
Bauer: Pages 25-27, 211-213
Besson: Pages 294-301, 309-314
A.S.T.M. Serial Designation D 4-27

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EXP. No. 68
DATE: . . . .

GENERAL SUBJECT: Testing of Bituminous Materials.

SPECIFIC OBJECT: Determination of Ductility.

SAMPLE:

APPARATUS: Ductility Machine with Brass Molds and Plates, Pan, Spoon, Knife, Thermometer.

METHOD: The molds and brass plate are first amalgamated. See Experiment No. 57. The material to be tested is heated until fluid and is then strained through a 50-mesh sieve. The molds, having been assembled on the brass plate, are filled with the fluid material, care being taken that the spoon is moved from one end of a mold to the other during the filling process, and that an excess of material is used. The filled molds are then stored in water at 25° C. for 30 minutes, after which the excess material is cut off with a hot knife. The samples are next returned to the water bath, where they must remain for 1½ hours until tested.

The ductility machine is filled with water, and the temperature of this is regulated so that it will not differ by more than 0.5° C. from 25° C. while the test is being run. The rate of travel of the pointer of the machine should be tested, the specified rate being 5 cm. per minute. At the end of the storage period the side pieces are removed from the molds, and the ends of the clips are put over the pegs in the machine. The pointer is adjusted to ZERO, and the machine started. The material will stretch to a very fine thread and will finally break when its cross-section has been so reduced that the thread is barely perceptible. The reading of the scale when the thread of material breaks should be recorded as its *ductility*.

The sample must be covered with water to a depth of at least 1 inch throughout the test.

RESULTS: These tests are usually run on several samples of each material. The results of individual tests, as well as the average, should be reported.

VALUE OF TEST: Paving technologists are not entirely agreed as to the value of this test. It may be classed as a usability test, if ductility is a measure of the value of a particular asphalt for a specific purpose. It more generally serves as an identification test to distinguish a blown asphalt from a straight-run asphalt. It is useful as a control test in the refining of asphalts.

QUESTIONS AND PROBLEMS:

1. Explain the process of manufacturing a "blown" asphalt.
2. What are the essential differences in the physical characteristics of a blown asphalt and a residual asphalt?
3. Explain the necessity for conducting this test with the sample completely immersed in water maintained at a specified temperature.

REFERENCES:

Barton and Doane: Pages 226-228, 278-280, 319-322
Bauer: Pages 30-31, 256-258
Besson: Pages 302-303, 316 and 364
A.S.T.M. Serial Designation D 113-39

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Exp. No. 69
Date: . . . .

General Subject: Testing of Bituminous Pavements.

Specific Object: Analysis of Pavements.

Sample:

Apparatus: Centrifugal Extractor, Hot Plate, Pan, Trowel, Balances, Beaker, Evaporating Dish, Set of Standard Sieves, Mechanical Shaker.

Method: The method consists in dissolving the bitumen in the pavement with carbon disulfide or carbon tetrachloride, and separating the solution from the aggregate by means of a centrifugal extractor. About 500 grams of sheet asphalt pavement or 1,000 grams of asphaltic concrete will constitute the sample. The sample is obtained from a section of pavement, and is then heated in a pan until it can be broken up with a trowel. It is allowed to cool and its weight is determined. The sample is placed in the bowl of the centrifugal extractor, the felt ring placed in position, and the cover put on and tightened.

About 150 cc. of the solvent is poured into the bowl through the small holes in the cover. The material is allowed to digest for a few minutes, a bottle put under the spout, and the motor started. The speed should be slow at first, and should be gradually increased until the liquid comes from the spout in a thin stream. When the first charge has drained, the motor is stopped, and a fresh portion of solvent is put in. The operation is repeated from four to six times, or until the liquid coming from the extractor is almost clear.

After the extraction is completed, the bowl is removed from the machine onto a large sheet of paper. The cover is taken off; the contents, together with any mineral matter on the cover or rings, are brought together on the paper; and, when they are dry, are weighed.

The total solution of bitumen is stirred thoroughly and an aliquot part taken. This is put in a tared quartz dish. The solvent is evaporated over a steam bath or an electric hot plate, and then the residue is ignited and burned to ash.

The total weight of the ash in the solution should be added to that of the mineral matter. The per cent of bitumen in the sample is determined as follows:

$$\text{Per cent of bitumen} = 100 - \frac{\text{Weight of mineral matter}}{\text{Weight of sample}} \times 100$$

The aggregate is next separated into various sizes by means of sieves. This part of the test is identical with the method outlined in Experiment No. 16. The usual sieves employed are indicated in the table given below.

It is sometimes required that the bitumen be recovered and its physical characteristics determined. Methods of doing this are described in the references that follow.

TABLE FOR EXPERIMENT NO. 69

RESULTS OF SIEVE ANALYSIS ON SAMPLE

Sieve Number	Weight Retained	Per Cent Retained	Per Cent Passing*
1″			
¾″			
½″			
No. 8			
No. 10			
No. 20			
No. 30			
No. 40			
No. 50			
No. 80			
No. 100			
No. 200			
Passing No. 200			
Bitumen			
Totals			

* The per cents in the last column are figured from the weight of the material that passes the sieve and is retained on the *next smaller* size.

RESULTS: Report the percentage of bitumen found. The results of the mechanical analysis of the aggregate should be shown in a table similar to the one given on page 246.

VALUE OF TEST: This is a very valuable test for the engineer engaged in paving. First, it is a method which enables one to analyze a pavement already in service, with a view to determining its constituents; and, second, it affords a means of analyzing mixtures for pavements under construction, in order to determine if they are being prepared in accordance with the specifications.

QUESTIONS AND PROBLEMS:

1. What part of the mineral matter will generally be found in the solution extracted from the sample?
2. Fifty grams of the solution extracted from a sample, when evaporated and burned, yielded 1.85 grams of non-combustible material. There were 957.5 cc. of the filtrate. What amount of mineral matter passed through the filters in the extraction process?
3. Consult Besson's *City Pavements*, page 319, and note the per cent of bitumen specified for each of the four general types of bituminous-concrete pavements.
4. From the grading of the mineral aggregate obtained in this experiment, determine the type of pavement from which the sample was cut.

REFERENCES:

Barton and Doane: Pages: 239-242, 258, 261-271
Bauer: Pages 108-123
Besson: Pages 298-301, 319-324

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EXP. No. 70
DATE: . . . .

GENERAL SUBJECT: Testing of Bituminous Mixtures.

SPECIFIC OBJECT: Design of Sheet-Asphalt Mixture (The Pat Test).

SAMPLES:

APPARATUS: Pan, Balance, Armored Thermometer, Set of Standard Sieves, Wooden Paddle, Manila Paper.

METHOD: A typical grading for the mineral aggregate of the mixture is selected. The different sands to be used are then separated into their component sizes in accordance with the method outlined in Experiment No. 12. If a sand is available which has the proper grading, this may be used; otherwise, two or more sands must be combined until the mixture has the specified grading. A tri-axial diagram (see Fig. 12 in the Appendix) will facilitate doing this.

The sand, mineral filler, and asphalt are then heated to the proper temperature and are thoroughly mixed in the pan. The mixture will probably have to be reheated to the right temperature before the pat test is run. It is important that the specified temperature be used when the pat test is made, if its result is to be trustworthy.

In making the pat test, a paddle full of the mixture is placed on the manila paper, which in turn is on a wooden surface. The paper is folded over on the pat and pressed down with a piece of wood. After this, the paper is struck five sharp blows with the paddle. The character of the stain on the paper indicates whether enough bitumen has been used in the mix.

RESULTS: The calculations involved in the design of the mixture may be shown best on a separate sheet. Under the heading "Results" on the regular report, the character of the stain should be described.

VALUE OF TEST: The behavior of the pavement in service depends directly on the character and amount of bitumen used in the mix. If too much is used, the pavement will shove in hot weather; if too little, it will crack in cold weather. This test offers a method of determining when the correct percentage has been used. This method is useful not only in the laboratory, but also for plant control in actual construction.

QUESTIONS AND PROBLEMS:

1. Consult specifications for the construction of sheet-asphalt pavements and determine the temperature at which the pat test should be run.
2. What determines the amount of filler to be used in a sheet-asphalt mixture?
3. In general, will the per cent of bitumen increase with the per cent of filler, or *vice-versa?*
4. What will be the difference in the behavior of a sheet-asphalt pavement where a deficiency of bitumen is used and where an excess of bitumen is used?

REFERENCES:

Barton and Doane: Pages 258, 261-271
Bauer: Pages 108-123
Besson: Pages 319-338

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NOTES

APPENDIX

Specifications, Charts, and Useful Tables

CONTENTS

STANDARD SPECIFICATION FOR MORTAR SAND

A. Material Covered

1. This specification covers fine aggregate for use in cement mortar.

B. General Requirements

2. Sand for mortar shall consist of hard, strong, durable, uncoated mineral or rock particles, free from injurious amounts of organic or other deleterious substances.

C. Size Requirements

3. Sand for mortar shall be uniformly graded from fine to coarse within the following limits:

Passing No. 8 sieve	100 per cent
Passing No. 50 sieve	15- 40 per cent
Passing No. 100 sieve	0- 10 per cent

(Weight removed by decantation not more than 5 per cent)

D. Physical Properties

4. Organic Impurities. Mortar sand, when subjected to the colorimetric test for organic impurities and producing a color darker than the standard shall be rejected unless it is shown by adequate tests that the impurities causing the color are not harmful in mortar.

From: Standard Specifications for Highway Materials and Methods of Sampling and Testing. The American Association of State Highway Officials (abbreviated A.A.S.H.O.). Specification M-45.

STANDARD SPECIFICATION FOR FINE AGGREGATE FOR PORTLAND-CEMENT-CONCRETE PAVEMENTS OR BASE COURSES, HIGHWAY BRIDGES, AND INCIDENTAL STRUCTURES

A. Material Covered

1. This specification covers fine aggregate for portland-cement-concrete pavements or bases, highway bridges, and incidental structures.

B. General Requirements

2. Fine aggregate shall consist of sand or other approved inert materials with similar characteristics, or a combination thereof, having hard, strong, durable particles.

C. Physical Properties

3. (*a*) Deleterious Substances. The maximum per cents of deleterious substances shall not exceed the following values:

	Per Cent, by Weight
Removed by decantation	3
Coal	1
Clay lumps	1
Other local deleterious substances (such as shale, alkali, mica, coated grains, and soft and flaky particles)	.
Total coal, clay lumps, shale, soft fragments, and other local deleterious substances	5

(It is recognized that under certain conditions maximum per cents of deleterious substances less than those shown in the table should be specified.)

(*b*) All fine aggregate shall be free from injurious amounts of organic impurities. Aggregates subjected to the colorimetric test for organic impurities and producing a color darker than the standard shall be rejected unless they pass the mortar strength test as specified in Section 4.

4. (*a*) Mortar Strength. Tensile strength.* Mortar briquettes consisting of 1 part by weight of portland cement and 3 parts by weight (when approved by engineer, these proportions may be by volume assuming 1 cubic foot of cement to weigh 94 pounds) of fine aggregate, mixed and tested in accordance with

* This requirement for tensile strength is not included in the Standard Specifications of the A.A.S.H.O.

the methods described in the "Standard Specifications and Tests for Portland Cement" of A.S.T.M., for tension tests shall show a tensile strength at the age of 7 and 28 days not less than that of 1:3 standard Ottawa-sand mortar of same consistency made with same cement.

(*b*) Mortar Strength. Fine aggregates, when subjected to the mortar strength test, shall have a compressive strength, at the age of 7 and 28 days, equal to or greater than that developed by mortar of the same proportions and consistency made of the same cement and graded Ottawa sand.

5. Concrete Strength. Fine aggregate passing the maximum size sieve requirement, and conforming to the requirements for uniformity given in Section 6 (*b*), but otherwise failing to meet the requirements herein provided for grading or mortar strength, may be used if, when tested in combination with the cement and coarse aggregate to be used in the work, in the proportion specified for the class of concrete under construction, the crushing or transverse strength of the concrete at the end of 7 and 28 days is at least equal to the strength required for the class of concrete in which the material is to be used.

D. Size Requirements

6. (*a*) Fine aggregate shall be well graded from coarse to fine and when tested by means of laboratory sieves shall conform to the following requirements:

	Per Cent
Passing ⅜-in. sieve	100
Passing No. 4 sieve	85–100
Passing No. 16 sieve	35– 80
Passing No. 50 sieve	2– 30
Passing No. 100 sieve	0– 5

(The figures shown in the above table are suggested as limiting per cents. They should be altered within these extreme limits to suit local conditions. In the interest of workability, it is recommended that, wherever practicable, the minimum amount passing the No. 4 sieve be at least 90 per cent and the minimum amount passing the No. 50 sieve be at least 5 per cent.)

(*b*) The above gradation represents the extreme limits which shall determine suitability for use from all sources of supply. The gradation from any one source shall be reasonably uniform and not subject to the extreme percentages of gradation specified above. For the purpose of determining the degree of uniformity, a fineness modulus determination shall be made upon representative samples, submitted by the contractor, from such sources as he proposes to use. Fine aggregate from any one source having a variation in fineness modulus greater than 0.20 either way from the fineness modulus of the representative sample submitted by the contractor may be rejected. Fine aggregate from different sources of supply shall not be mixed or stored in the same pile, nor used alternately in the same class of construction or mix, without permission from the engineer.

(The fineness modulus of an aggregate is determined by adding the per cents by weight retained on the following sieves having square openings, and dividing by 100:

3 in., $1\frac{1}{2}$ in., $\frac{3}{4}$ in., $\frac{3}{8}$ in.,
No. 4, No. 8, No. 16, No. 30, No. 50, No. 100)

From: Standard Specifications for Highway Materials and Methods of Sampling and Testing. The American Association of State Highway Officials. Specification M-6.

STANDARD SPECIFICATION FOR SAND FOR BITUMINOUS MIXTURES

A. Material Covered

1. This specification covers the general characteristics and grading of sand for use in bituminous pavements, bituminous mortars, bituminous fillers, or mastics.

B. General Requirements

2. The sand shall consist of grains of quartz or other hard, durable rock, moderately sharp and free from a coating of any injurious material. The sand shall be free from lumps of clay, loam, organic matter, or other foreign matter.

C. Size Requirements

3. When tested by means of laboratory sieves, the sand shall conform to the following requirements:

	Per Cent
Total passing No. 4 sieve	100
Total passing No. 10 sieve	95–100
Passing No. 10 sieve, retained on No. 40 sieve	18–50
Passing No. 40 sieve, retained on No. 80 sieve	30–60
Passing No. 80 sieve, retained on No. 200 sieve	15*–40
Total passing No. 200 sieve	0–5

* For bituminous concrete, the minimum required shall be 12 per cent.

From: Standard Specifications for Highway Materials and Methods of Sampling and Testing. The American Association of State Highway Officials. Specification M-29.

STANDARD SPECIFICATION FOR COARSE AGGREGATE FOR PORTLAND CEMENT CONCRETE

A. Material Covered

1. This specification covers the quality and size of coarse aggregate for use in concrete pavements or bases, highway bridges, and incidental structures.

B. General Requirements

2. Coarse aggregates shall consist of crushed stone, gravel, blast-furnace slag, or other approved inert materials of similar characteristics, or combinations thereof, having hard, strong, durable pieces, free from adherent coatings and conforming to the requirements of these specifications.

C. Physical Properties

3. The amount of deleterious substances shall not exceed the following limits:

	Recommended permissible limit, Per cent by weight	Maximum permissible limit, Per cent by weight
1. Soft fragments	2.	5
2. Coal and lignite	0.25	1
3. Clay lumps	0.25	0.25
4. Material passing the No. 200 sieve	0.5	1.0
5. Other local deleterious substances	as specified	as specified

(The recommended requirements should be specified on all work where it is economically practicable to obtain materials conforming thereto.)

(Only one set of figures for per cent by weight should be included.)

4. Percentage of loss on gravel, crushed stone, or slag by the Los Angeles testing machine, not more than — — .

5. The weight per cubic foot of slag shall not be less than seventy pounds (70 lbs.).

6. (*a*) When the coarse aggregate is subjected to five alternations of the sodium sulfate soundness test (magnesium

sulfate soundness test), the weighted percentage of loss shall be not more than —— per cent.

(The method of test shall be at the option of the engineer, who should insert a numerical requirement based on his experience with the test.)

(*b*) Coarse aggregate failing to meet the requirement given in Section 6 (*a*) may, at the option of the engineer, be subjected to an alternate freezing and thawing test and may be accepted provided the weighted percentage of loss at the end of——alternations does not exceed——per cent by weight.

(The engineer should insert appropriate requirements based on his experience with the test.)

(*c*) The requirements for soundness given in (*a*) and (*b*) above may be waived in case of aggregate for use in structures or portions of structures not exposed to weathering.

D. Size Requirements

Grading. Coarse aggregate shall be well graded, between the limits specified, and the size or sizes designated shall conform to the following requirements:

Designated Sizes	Per cent by weight passing laboratory sieves having square openings, in inches							
	2½	2	1½	1	¾	½	⅜	No. 4
No. 4 to ½ in.	....	....	....	....	100	90-100	....	0-15*
No. 4 to ¾ in.	....	....	....	100	90-100	....	20-55	0-10
No. 4 to 1 in.	....	....	100	90-100	....	25-60	....	0-10
No. 4 to 1½ in.	....	100	95-100	....	35-70	....	10-30	0-5
No. 4 to 2 in.	100	95-100	....	35-70	....	10-30	....	0-5
¾ in. to 1½ in.	....	100	90-100	20-55	0-15	....	....	....
1 in. to 2 in.	100	90-100	35-70	0-15	....	....	....	....

* Not more than 5 per cent shall pass a No. 8 sieve.

(Attention is called to the fact that the shape of aperture specified for determining compliance with specifications for size of coarse aggregate has no relation to the size or shape of aperture or type of screen used in the production of the material.)

From: Standard Specifications for Highway Materials and Methods of Sampling and Testing. The American Association of State Highway Officials. Specification M80-38.

STANDARD SPECIFICATION FOR GRAY-IRON CASTINGS

PHYSICAL PROPERTIES AND TESTS

Tensile Strength Classification

1. Gray-iron castings conforming to these specifications shall be known and listed by classes........, according to minimum tensile strengths of test bars as follows:

Class	Tensile Strength, Minimum Lb. per Sq. In.
No. 20	20,000
No. 25	25,000
No. 30	30,000
No. 35	35,000
No. 40	40,000
No. 50	50,000
No. 60	60,000

Transverse Test

2. Transverse tests shall be optional and the following minimum breaking loads are specified:

Transverse Test Bar	0.875 In. in Diameter	1.2 In. in Diameter	2.0 In. in Diameter
Span Length	12-In. Supports	18-In. Supports	24-In. Supports
Class	Breaking Load at Center, Min., Lb.	Breaking Load at Center, Min., Lb.	Breaking Load at Center, Min., Lb.
No. 20	900	1,800	6,000
No. 25	1,025	2,000	6,800
No. 30	1,150	2,200	7,600
No. 35	1,275	2,400	8,300
No. 40	1,400	2,600	9,100
No. 50	1,675	3,000	10,300
No. 60	1,925	3,400	....

From: A.S.T.M. Standards, Serial Designation A 48-36.

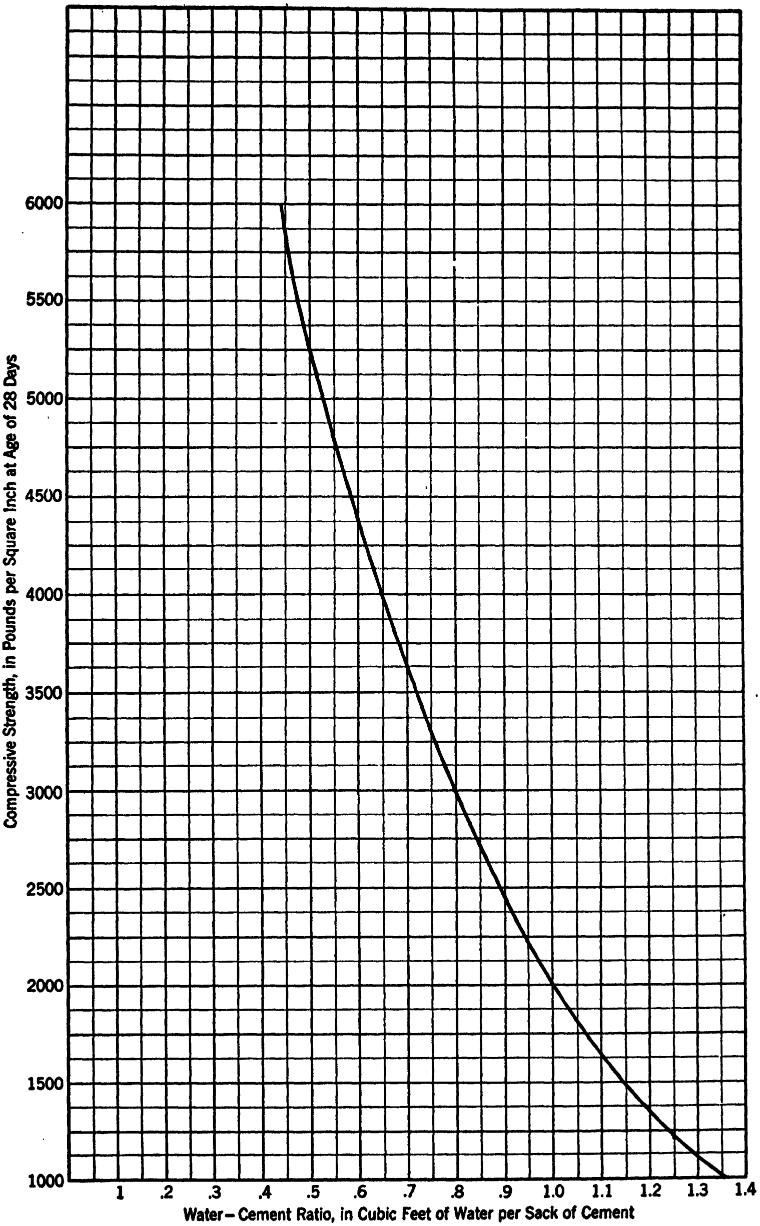

FIG. 9. STANDARD WATER-CEMENT-RATIO CURVE. BASED ON TESTS CONDUCTED BY THE PORTLAND CEMENT ASSOCIATION.

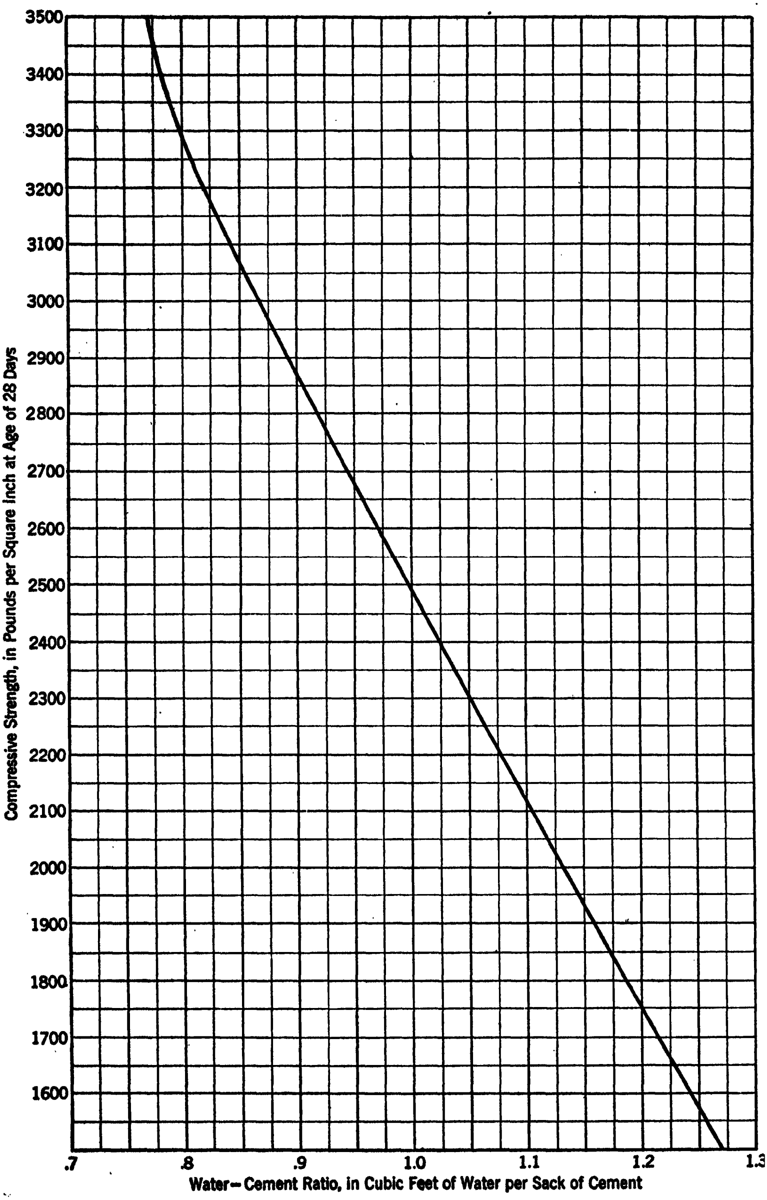

FIG. 10. RELATION BETWEEN COMPRESSIVE STRENGTH OF CONCRETE AND WATER-CEMENT RATIO. FROM TESTS ON NORTH CAROLINA SANDS AND GRAVEL OF GOOD QUALITY.

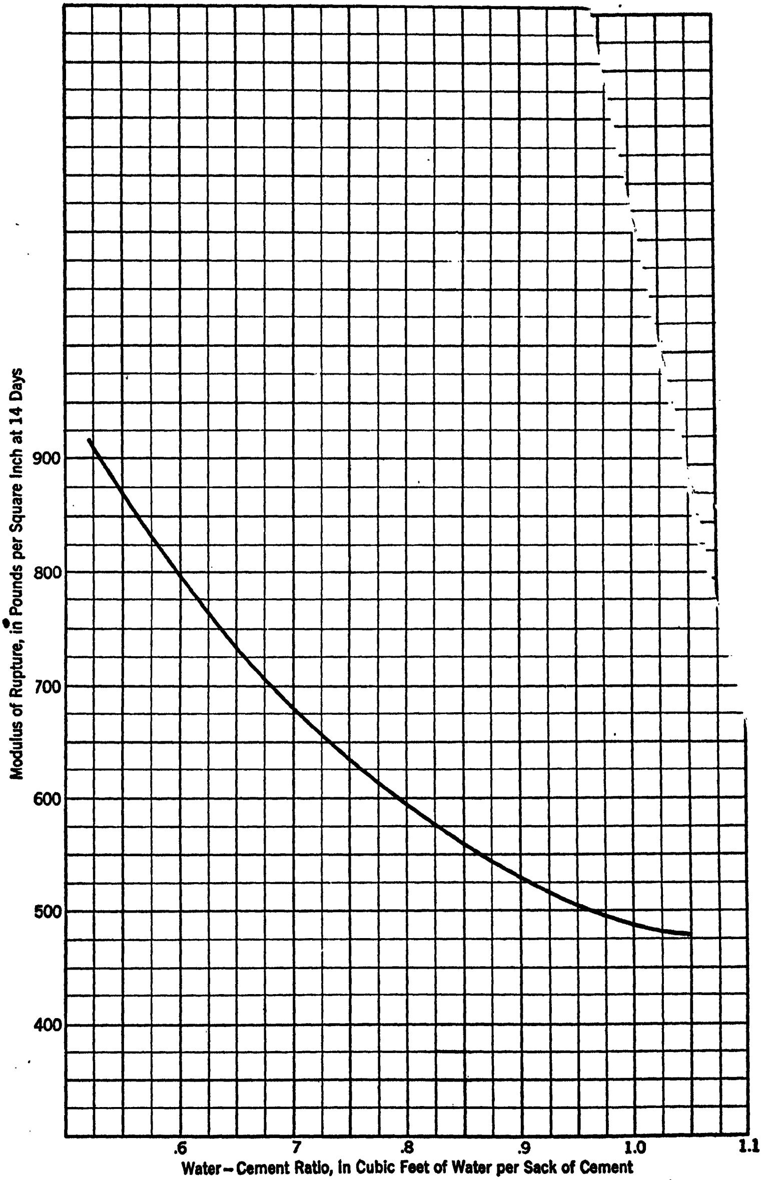

FIG. 11. RELATION BETWEEN MODULUS OF RUPTURE OF CONCRETE AND WATER-CEMENT RATIO. FROM TESTS ON NORTH CAROLINA SANDS AND GRAVEL OF GOOD QUALITY.

TYPICAL BITUMINOUS MIXTURES

For Ba... Construction with Bituminous Concrete

Material	Per Cent
P...g 2½-in., retained on 1-in. screen..........	15 to 45
P...ng 1¼-in., retained on ¼-in. screen..........	15 to 45
...l of above two grades......................	53 to 70
...ing ¼-in. screen............................	25 to 40
...men soluble in carbon disulfide..............	4 to 7

Fo... Pavement Surfaces

Composition of Mixture	(1) Binder Per Cent	(2) Concrete Per Cent	(3) Topeka Per Cent	(4) Topping Per Cent
Pa...g 1-in., retained on ½-in.	70	50		
P...g ½-in., retained on 10-mesh......	20	18	25	
P...ng 10-mesh, retained on 20-mesh				3.0
...ng 20-mesh, retained on 30-mesh		9	20	5.0
...ing 30-mesh, retained on 40-mesh .				8.0
...sing 40-mesh, retained on 50-mesh	5		23	11.0
...sing 50-mesh, retained on 80-mesh		12		23.5
...ssing 80-mesh, retained on 100-mesh			15	13.0
...ssing 100-mesh, retained on 200-mesh .				13.0
...assing 200-mesh		4	8	13.0
...er cent of bitumen	5	7	9	10.5
Total	100	100	100	100.0

Notes: Column (1): Typical grading for the binder course used under sheet asphalt wearing surface.

Column (2): Bituminous concrete for wearing surface, somewhat similar to bitulithic, with the maximum size of aggregate equal approximately to one-half the thickness of the surfacing.

Column (3): Bituminous concrete for wearing surface, somewhat similar to "Topeka", with the maximum size of aggregate limited to one-half inch.

Column (4): Sheet asphalt wearing surface.

From: Besson's *City Pavements*. McGraw-Hill Book Co., 1923, p. 319.

TABLE NO. 1

CLASSIFICATION OF BUILDING BRICK ACCORDING TO PHYSICAL REQUIREMENTS

Grade	Compressive Strength (Bricks Flatwise), Lb. per Sq. In., Average Gross Area		Modulus of Rupture (Bricks Flatwise), Lb. per Sq. In., Average Gross Area		Water Absorption by 5-Hr. Boiling, Per Cent	C/B[a]
	Average of 5 Bricks	Individual Minimum	Average of 5 Bricks	Individual Minimum	Individual Maximum	Individual Maximum
A	4,500 or more	3,500	600 or more	400	....	....
B	2,500-4,500	2,000	450 or more	300	....	....
C	1,250-2,500	1,000	300 or more	200	....	....
AW-1	4,500 or more	3,500	....	....	20	0.80
BW-1	2,500-4,500	2,500	....	....	20	0.80
AW-2	4,500 or more	3,500	....	....	20	0.85
BW-2	2,500-4,500	2,500	....	....	20	0.85

[a] The ratio C/B is the ratio of absorption by 24-hr. submergence in cold water to that after 5-hr. in boiling water.

From: A.S.T.M. Standards, Serial Designation C 62-36T. See also A.S.T.M. Standards C 62-37T and C 62-39T.

TABLE NO. 2

CLASSIFICATION OF LOAD-BEARING WALL TILE

(According to results of physical tests, tile shall be classified as LB X and LB on the basis of these absorption and strength requirements)

Use	Designation of Class	Absorption,[a] Per Cent			Compressive Strength Based on Gross Area,[b] Lb. per Sq. In.			
					End-Construction Tile		Side-Construction Tile	
		Average of 5 Tests	Individual Maximum	Individual Minimum	Average of 5 Tests	Individual Minimum	Average of 5 Tests	Individual Minimum
Not restricted[c]	*LB X*	5 to 16	19	4	1,400 or more	1,000	700 or more	500
Where not exposed to frost action[d]	*LB*	5 to 25	28	4	1,000 or more	700	700 or more	500

[a] The range in per cent of absorption for tile delivered to any one job shall be not more than 12.

[b] Gross area of a unit shall be the total area of a section including cells perpendicular to the direction of loading. Re-entrant spaces are included in the gross area, unless these spaces are to be occupied in masonry by portions of adjacent units.

[c] Tile classed as *LB X* shall be considered to be suitable for general use in masonry construction and to be especially adapted for use in masonry exposed to severe weathering, provided they are burned to the normal maturity for the clay. They shall also be considered suitable for the direct application of stucco. Tile of class *LB X* shall be accepted under all conditions in lieu of tile classed as *LB*.

[d] Tile classed as *LB* shall be considered as being suitable for general use in masonry where not exposed to frost action or for use in exposed masonry where protected with a facing of 3 in. or more of stone, brick, terra cotta, or other masonry.

From: A.S.T.M. Standards, Serial Designation C 34-39.

TABLE NO. 3

PHYSICAL TEST REQUIREMENTS OF CLAY SEWER PIPE

Internal Diameter, In.	Average Crushing Strength, Minimum, Lb. per Linear Foot		Average Absorption, Maximum, Per Cent
	Three-Edge-Bearing Method	Sand-Bearing Method	
4	1,000	1,430	8
6	1,000	1,430	8
8	1,000	1,430	8
10	1,100	1,570	8
12	1,200	1,710	8
15	1,370	1,960	8
18	1,540	2,200	8
21	1,810	2,590	8
24	2,150	3,070	8
27	2,360	3,370	8
30	2,580	3,690	8
33	2,750	3,930	8
36	3,080	4,400	8

From: A.S.T.M. Standards, Serial Designation C 13-35.

TABLE NO. 4

PHYSICAL TEST REQUIREMENTS OF CONCRETE SEWER PIPE

Internal Diameter, In.	Average Crushing Strength, Lb. per Linear Foot		Maximum Absorption, Per Cent
	Three-Edge-Bearing Method	Sand-Bearing Method	
4	1,000	1,430	8
6	1,000	1,430	8
8	1,000	1,430	8
10	1,100	1,570	8
12	1,200	1,710	8
15	1,370	1,960	8
18	1,540	2,200	8
21	1,810	2,590	8
24	2,150	3,070	8

From: A.S.T.M. Standards, Serial Designation C 14-35.

Note: Specifications for larger sizes of pipe are given in A.S.T.M. Standards, Serial Designation C 75-35.

STANDARD SPECIFICATIONS FOR BILLET-STEEL CONCRETE REINFORCEMENT BARS

1. (*a*) The bars shall conform to the following requirements as to tensile properties:

TABLE NO. 5
TENSILE REQUIREMENTS

Properties Considered	Plain Bars			Deformed Bars			Cold-Twisted Bars
	Structural-Steel Grade	Intermediate Grade	Hard Grade	Structural-Steel Grade	Intermediate Grade	Hard Grade	
Tensile Strength, Lb. per Sq. In.	55,000 to 70,000	70,000 to 90,000	80,000 min.	55,000 to 70,000	70,000 to 90,000	80,000 min.	Recorded only
Yield point, Min., Lb. per Sq. In.	33,000	40,000	50,000	33,000	40,000	50,000	55,000
Elongation in 8 In., Min., Per Cent	1,400,000[1] / Tensile Strength	1,300,000[1] / Tens. str. but not less than 16 per cent[1]	1,200,000[1] / Tensile Strength	1,250,000[1] / Tensile Strength	1,125,000[1] / Tens. str. but not less than 14 per cent[1]	1,000,000[1] / Tensile Strength	5

[1] See Section 2.

(*b*) The yield point shall be determined by the drop of the beam or halt in the gage of the testing machine.

2. (*a*) For plain and deformed bars over $\frac{3}{4}$ inch in thickness or diameter, a deduction from the per cents of elongation specified in Section 1 (*a*) of 0.25 per cent shall be made for each increase of $\frac{1}{32}$ inch of the specified thickness or diameter above $\frac{3}{4}$ inch.

(*b*) For plain and deformed bars under $\frac{7}{16}$ inch in thickness or diameter, a deduction from the per cents of elongation specified in Section 1 (*a*) of 0.5 per cent shall be made for each decrease of $\frac{1}{32}$ inch of the specified thickness or diameter below $\frac{7}{16}$ inch.

3. (*a*) The test specimen shall stand being bent cold around a pin without cracking. The following requirements for degree of bending and sizes of pins shall be observed:

TABLE NO. 6

BEND-TEST REQUIREMENTS

Thickness or Diameter of Bar	Plain Bars			Deformed Bars			Cold-Twisted Bars
	Structural-Steel Grade	Intermediate Grade	Hard Grade	Structural-Steel Grade	Intermediate Grade	Hard Grade	
Under $\frac{3}{4}$ inch	180 deg. $d = t$	180 deg. $d = 2t$	180 deg. $d = 3t$	180 deg. $d = t$	180 deg. $d = 3t$	180 deg. $d = 4t$	180 deg. $d = 2t$
$\frac{3}{4}$ inch or over	180 deg. $d = t$	90 deg. $d = 2t$	90 deg. $d = 3t$	180 deg. $d = 2t$	90 deg. $d = 3t$	90 deg. $d = 4t$	180 deg. $d = 3t$

Explanatory Note: d = the diameter of pin about which the specimen is bent;
t = the thickness or diameter of the specimen.

(*b*) Bend tests shall be made on specimens of sufficient length to insure free bending and with apparatus which provides:

(1) Continuous and uniform application of force throughout the duration of the bending operation;
(2) Unrestricted movement of the specimen at points of contact with the apparatus;
(3) Close wrapping of the specimen about the pin or mandrel during the bending operation.

From: A.S.T.M. Standards, Serial Designation A 15-39.

TABLE NO. 7

SPECIFICATIONS FOR CUT-BACK ASPHALTIC MATERIALS FOR HIGHWAY CONSTRUCTION

(a) SLOW CURING LIQUID PRODUCTS

Specification Designation	SC-0	SC-1	SC-2	SC-3	SC-4	SC-5
General Requirements	The material shall meet the following requirements when tested in accordance with the methods hereinafter enumerated.					
Furol Viscosity at 77° F.	75–150	....	....	....	....	....
" " " 122° F.	....	75–150	....	....	....	....
" " " 140° F.	....	....	100–200	250–500	....	....
" " " 180 °F.	....	....	....	....	125–250	300–600
Water, per cent	0.5—	0.5—	Material shall be free from water.			
Flash, Cleveland Open Cup, °F.	150+	150+	175+	200+	225+	250+
Distillation						
Total Distillate to 680° F.	15–40	10–30	5–25	2–15	10—	5—
Float Test on Residue at 122° F., sec.	15–100	20–100	25–100	50–125	60–150	75–200
Asphalt Residue of 100 Penetration, %	40+	50+	60+	70+	75+	80+
Ductility Asphalt Residue at 77° F.	100+	100+	100+	100+	100+	100+
Per cent Soluble in Carbon Tetrachloride*	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+

* If the material fails to meet the requirement for solubility it will be acceptable if its solubility in carbon disulphide is 99%+, and proportion of bitumen soluble in carbon tetrachloride is 99.65%+.

(b) MEDIUM CURING LIQUID PRODUCTS

Specification Designation	MC-0	MC-1	MC-2	MC-3	MC-4	MC-5
General Requirements	The material shall be free from water and shall meet the following requirements when tested in accordance with the methods hereinafter enumerated.					
Flash Point (Open Tag.)° F.	100+	100+	150+	150+	150+	150+
Furol Viscosity at 77° F.	75–150	....	....	....	....	....
" " " 122° F.	....	75–150	....	....	....	....
" " " 140° F.	....	....	100–200	250–500	....	....
" " " 180° F.	....	....	....	....	125–250	300–600
Distillation						
Distillate (per cent of total distillate to 680° F.)						
To 437° F.	25—	20—	10—	5—	0	0
" 500° F.	40–70	25–65	15–55	5–40	30—	20—
" 600° F.	75–93	70–90	60–87	55–85	40–80	20–75
Residue from distillation to 680° F.						
Volume % by difference	50+	60+	67+	73+	78+	82+
Tests on Residue from Distillation						
Penetration 77° F., 100 g., 5 sec.	120–300	120–300	120–300	120–300	120–300	120–300
Ductility 77° F.*	100+	100+	100+	100+	100+	100+
Per cent Soluble in Carbon Tetrachloride	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+

* If penetration of residue is more than 200 and its ductility at 77° F. is less than 100, the materials will be acceptable if its ductility at 60° F. is 100+.

(C) RAPID CURING LIQUID PRODUCTS

Specification Designation	RC-0	RC-1	RC-2	RC-3	RC-4	RC-5
General Requirement	The material shall be free from water and shall meet the following requirements when tested in accordance with the methods hereinafter enumerated.					
Flash Point (Open Tag.)° F.	....	....	80+	80+	80+	80+
Furol Viscosity at 77° F.	75–150	....	....	....	....	....
" " " 122° F.	....	75–150	....	....	....	....
" " " 140° F.	....	....	100–200	250–500	....	....
" " " 180° F.	....	....	....	....	125–250	300–600
Distillation						
Distillate (per cent of total distillate to 680° F.)						
To 374° F.	15+	10+	....	....	....	....
" 437° F.	55+	50+	40+	25+	8+	....
" 500° F.	75+	70+	65+	55+	40+	25+
" 600° F.	90+	88+	87+	83+	80+	70+
Residue from distillation to 680° F. Volume per cent by difference	50+	60+	67+	73+	78+	82+
Tests on Residue from Distillation Penetration 77° F., 100 g., 5 sec.	80–120	80–120	80–120	80–120	80–120	80–120
Ductility 77° F.	100+	100+	100+	100+	100+	100+
Per cent Soluble in Carbon Tetrachloride	99.5+	99.5+	99.5+	99.5+	99.5+	99.5+

(This Table from Asphalt Pocket Reference for Highway Engineers, 1941, Published by The Asphalt Institute, New York. Used with permission of the publishers.)

TABLE NO. 8

SPECIFICATIONS FOR ASPHALT CEMENTS

Grades	AP-1	AP-2	AF-1	AH-1	AB-1	AB-2	AT-1
Specific Gravity at 60° F.	1.00+	1.00+	1.00+	1.0–1.05	1.05–1.07	1.05–1.07	1.21–1.27
Flash Point (Cleveland Open Cup) ° F	347+	347+	347+	347+	347+	347+	347+
Pen. at 77° F. (100 g. 5 Sec.)	50–60	85–100	60–70	150–200	50–60	85–100	50–60
Ductility at 77° F. (CMS).	30+	100+	30+	100+	30+	100+	30+
Loss on Heating (50 g. 5 hrs. at 325° F.) %	1.0–	1.0–	1.0–	1.0–	3.0–	3.0–	3.0–
Pen. of Residue at 77° F. (100 g. 5 Sec.) (% of original)	60+	60+	60+	60+	50+	50+	50+
Proportion of Bitumen Soluble in CCl_4, %	99.0+	99.0+	99.0+	99.0+	99.0+	99.0+	99.0+
Total Bitumen Soluble in CS_2, %	99.5+	99.5+	99.5+	99.5+	94.0+	94.0+	60.0+

Note: AB-1 and AT-1 may be used where AP-1 is specified. AB-2 may be used where AP-2 is specified.

P Indicates Petroleum Asphalt
T Indicates Trinidad Asphalt
B Indicates Bermudez Asphalt

(From Standard Specifications for Roads and Structures, 1939. North Carolina State Highway and Public Works Commission.)

TABLE NO. 9

SPECIFICATIONS FOR TAR FOR ROAD CONSTRUCTION

Grades	RT-1	RT-2	RT-3-A	RT-4	RT-5	RT-6	RT-7	RT-8	RT-9	RT-10	RT-11	RT-12	RTCB-5	RTCB-6
Consistency:														
Engler Sp. Visc. at 40° C. (104° F.) ..	5–8	8–13	13–18	22–35										
Engler Sp. Visc. at 50° C. (122° F.) ..					17–26	26–40							17–26	26–40
Float Test at 32° C. (98.6° F.)							50–80	80–120	120-200					
Float Test at 50° C. (122° F.)										75–100	100–150	150–220		
Sp. Gr. at 25° C./25° C. (77 °F.)	1.08+	1.08+	1.09+	1.09+	1.10+	1.10+	1.12+	1.14+	1.14+	1.15+	1.16+	1.16+	1.09+	1.09+
Total Bitumen, % by weight	88+	88+	88+	88+	83+	83+	78+	78+	78+	75+	75+	75+	80+	80+
Water, % by volume	2.0–	2.0–	2.0–	2.0–	1.5–	1.5–	1.0–	0	0	0	0	0	1.0–	1.0–
Distillation, % by weight:														
To 170° C. (338° F.)	7.0–	7.0–	7.0–	5.0–	5.0–	5.0–	3.0–	1.0–	1.0–	1.0–	1.0–	1.0–	2.0–8.0	2.0–8.0
To 200° C. (392° F.)													5.0+	5.0+
To 235° C. (455° F.)													8.0–18	8.0–18.0
To 270° C. (518° F.)	35.0–	35.0–	30.0–	30.0–	25.0–	25.0–	20.0–	15.0–	15.0–	10.0–	10.0–	10.0–		
To 300° C. (572° F.)	45.0–	45.0–	40.0–	40.0–	35.0–	35.0–	30.0–	25.0–	25.0–	20.0–	20.0–	20.0–	35.0–	35.0–
Softening Point of Distillation Residue, °C.	35–60	35–60	35–60	35–60	35–65	35–65	35–65	35–65	35-65	40–70	40–70	40–70	40–70	40–70

(From Standard Specifications for Roads and Structures, 1939, North Carolina State Highway and Public Works Commission.)

TABLE NO. 10

UNITED STATES GOVERNMENT SPECIFICATIONS FOR LUBRICANTS

(Class I)

Specification	S. A. E. Number					
	20	30	40	50	60	70
Flash Point, not Lower Than	400° F.	410° F.	425° F.	445° F.	475° F.	510° F.
Viscosity Range, in Seconds	120[1]-185[1]	185[1]-255[1]	255[1]-75[2]	75[2]-105[2]	105[2]-125[2]	125[2]-150[2]
Pour Point, not Above	0° F.	0° F.	5° F.	10° F.	15° F.	15° F.
Carbon Residue, Maximum, Per Cent	0.10	0.15	0.25	0.40	0.70	1.00

[1] At 130° F.; [2] at 210° F.

TABLE NO. 11

REQUIREMENTS FOR SIEVE OPENINGS AND WIRE DIAMETERS

Designation	Corresponding U.S. Standard Sieve Series Numbers	Sieve Opening		Wire Diameter	
		mm.	in.	mm.	in.
1	2	3	4	5	6
4,760 micron	4	4.76	0.187	1.27	0.050
4,000 "	5	4.00	0.157	1.12	0.044
3,360 "	6	3.36	0.132	1.02	0.040
2,830 "	7	2.83	0.111	0.92	0.036
2,380 "	8	2.38	0.0937	0.84	0.0331
2,000 "	10	2.00	0.0787	0.76	0.0299
1,680 "	12	1.68	0.0661	0.69	0.0272
1,410 "	14	1.41	0.0555	0.61	0.0240
1,190 "	16	1.19	0.0469	0.54	0.0213
1,000 "	18	1.00	0.0394	0.48	0.0189
840 "	20	0.84	0.0331	0.42	0.0165
710 "	25	0.71	0.0280	0.37	0.0146
590 "	30	0.59	0.0232	0.33	0.0130
500 "	35	0.50	0.0197	0.29	0.0114
420 "	40	0.42	0.0165	0.25	0.0098
350 "	45	0.35	0.0138	0.22	0.0087
297 "	50	0.297	0.0117	0.188	0.0074
250 "	60	0.250	0.0098	0.162	0.0064
210 "	70	0.210	0.0083	0.140	0.0055
177 "	80	0.177	0.0070	0.119	0.0047
149 "	100	0.149	0.0059	0.102	0.0040
125 "	120	0.125	0.0049	0.086	0.0034
105 "	140	0.105	0.0041	0.074	0.0029
88 "	170	0.088	0.0035	0.063	0.0025
74 "	200	0.074	0.0029	0.053	0.0021
62 "	230	0.062	0.0024	0.046	0.0018
53 "	270	0.053	0.0021	0.041	0.0016
44 "	325	0.044	0.0017	0.036	0.0014

From: A.S.T.M. Standards, Serial Designation E 11-26. See this reference for permissible tolerances.

NOTE: The wire diameters given in the above Table are subject to certain tolerances, which would result in a minimum diameter and maximum diameter for the wires out of which each sieve is made. In A.S.T.M. Serial Designation E 11-39 both the minimum and maximum diameters of wires are given. See page 855, A.S.T.M. Standards, 1939, Part II.

TABLE NO. 12

U. S. STANDARD GAGE FOR SHEET AND PLATE IRON AND STEEL, 1893

Number of Gage	Approximate Thickness in Fractions of an Inch	Approximate Thickness in Decimal Parts of an Inch	Approximate Thickness in Millimeters
0000000	1-2	0.5000	12.7000
000000	15-32	0.4688	11.9063
00000	7-16	0.4375	11.1125
0000	13-32	0.4063	10.3188
000	3-8	0.3750	9.5250
00	11-32	0.3438	8.7313
0	5-16	0.3125	7.9375
1	9-32	0.2813	7.1438
2	17-64	0.2656	6.7469
3	1-4	0.2500	6.3500
4	15-64	0.2344	5.9531
5	7-32	0.2188	5.5563
6	13-64	0.2031	5.1594
7	3-16	0.1875	4.7625
8	11-64	0.1719	4.3656
9	5-32	0.1563	3.9688
10	9-64	0.1406	3.5719
11	1-8	0.1250	3.1750
12	7-64	0.1094	2.7781
13	3-32	0.0938	2.3813
14	5-64	0.0781	1.9844
15	9-128	0.0703	1.7859
16	1-16	0.0625	1.5875
17	9-160	0.0563	1.4288
18	1-20	0.0500	1.2700
19	7-160	0.0438	1.1113
20	3-80	0.0375	0.9525
21	11-320	0.0344	0.8731
22	1-32	0.0313	0.7938
23	9-320	0.0281	0.7144
24	1-40	0.0250	0.6350
25	7-320	0.0219	0.5556
26	3-160	0.0188	0.4763
27	11-640	0.0172	0.4366
28	1-64	0.0156	0.3969
29	9-640	0.0141	0.3572
30	1-80	0.0125	0.3175
31	7-640	0.0109	0.2778
32	13-1,280	0.0102	0.2580
33	3-320	0.0094	0.2381
34	11-1,280	0.0086	0.2183
35	5-640	0.0078	0.1984
36	9-1,280	0.0070	0.1786
37	17-2,560	0.0066	0.1687
38	1-160	0.0063	0.1588

The above table is based on iron and steel weighing 480 pounds per cubic foot. For steel weighing 489.6 pounds per cubic foot, multiply the thicknesses in the table by the factor 0.9804.

TABLE NO. 13

COMPARISON OF FAHRENHEIT AND CENTIGRADE DEGREES

C	F	C	F	C	F	C	F	C	F
0	32.0	38	100.4	76	168.8	114	237.2	152	305.6
1	33.8	39	102.2	77	170.6	115	239.0	153	307.4
2	35.6	40	104.0	78	172.4	116	240.8	154	309.2
3	37.4	41	105.8	79	174.2	117	242.6	155	311.0
4	39.2	42	107.6	80	176.0	118	244.4	156	312.8
5	41.0	43	109.4	81	177.8	119	246.2	157	314.6
6	42.8	44	111.2	82	179.6	120	248.0	158	316.4
7	44.6	45	113.0	83	181.4	121	249.8	159	318.2
8	46.4	46	114.8	84	183.2	122	251.6	160	320.0
9	48.2	47	116.6	85	185.0	123	253.4	161	321.8
10	50.0	48	118.4	86	186.8	124	255.2	162	323.6
11	51.8	49	120.2	87	188.6	125	257.0	163	325.4
12	53.6	50	122.0	88	190.4	126	258.8	164	327.2
13	55.4	51	123.8	89	192.2	127	260.6	165	329.0
14	57.2	52	125.6	90	194.0	128	262.4	166	330.8
15	59.0	53	127.4	91	195.8	129	264.2	167	332.6
16	60.8	54	129.2	92	197.6	130	266.0	168	334.4
17	62.6	55	131.0	93	199.4	131	267.8	169	336.2
18	64.4	56	132.8	94	201.2	132	269.6	170	338.0
19	66.2	57	134.6	95	203.0	133	271.4	171	339.8
20	68.0	58	136.4	96	204.8	134	273.2	172	341.6
21	69.8	59	138.2	97	206.6	135	275.0	173	343.4
22	71.6	60	140.0	98	208.4	136	276.8	174	345.2
23	73.4	61	141.8	99	210.2	137	278.6	175	347.0
24	75.2	62	143.6	100	212.0	138	280.4	176	348.8

25	77.0	63	145.4	101	213.8	139	282.2	177	350.6
26	78.8	64	147.2	102	215.6	140	284.0	178	352.4
27	80.6	65	149.0	103	217.4	141	285.8	179	354.2
28	82.4	66	150.8	104	219.2	142	287.6	180	356.0
29	84.2	67	152.6	105	221.0	143	289.4	181	357.8
30	86.0	68	154.4	106	222.8	144	291.2	182	359.6
31	87.8	69	156.2	107	224.6	145	293.0	183	361.4
32	89.6	70	158.0	108	226.4	146	294.8	184	363.2
33	91.4	71	159.8	109	228.2	147	296.6	185	365.0
34	93.2	72	161.6	110	230.0	148	298.4	186	366.8
35	95.0	73	163.4	111	231.8	149	300.2	187	368.6
36	96.8	74	165.2	112	233.6	150	302.0	188	370.4
37	98.6	75	167.0	113	235.4	151	303.8	189	372.2

For other temperatures use the following formulas:

$$F^\circ = \frac{9}{5} C^\circ + 32 \qquad (1)$$

$$C^\circ = \frac{5}{9} (F^\circ - 32) \qquad (2)$$

TABLE NO. 14

USEFUL METRIC CONVERSION FACTORS

Ounces	× 28.35	= grams
Pounds	× 453.6	= grams
Pounds	× 0.4536	= kilograms
Tons	× 907.2	= kilograms
Grams	× 0.03527	= ounces
Kilograms	× 35.27	= ounces
Kilograms	× 2.205	= pounds
Inches	× 25.40	= millimeters
Inches	× 2.540	= centimeters
Feet	× 0.3048	= meters
Yards	× 0.9144	= meters
Yards	× 0.0009144	= kilometers
Millimeters	× 0.03937	= inches
Centimeters	× 0.3937	= inches
Meters	× 3.281	= feet
Meters	× 1.094	= yards
Kilometers	× 1094	= yards
Liters	× 2.113	= pints
Cubic Inches	× 16.39	= cubic centimeters
Cubic Feet	× 28,320	= cubic centimeters
Cubic Centimeters	× 0.0610	= cubic inches
Cubic Centimeters	× 0.00003351	= cubic feet

(This table from Barton & Doane: "Sampling and Testing of Highway Materials." Used with permission of the publishers, McGraw-Hill Book Company, New York.)

(REPORT COVER SHEET)

NORTH CAROLINA STATE COLLEGE
of
AGRICULTURE AND ENGINEERING

Materials Testing Laboratory

Section No. Friday

Name of Student: L. Y. Merritt

Name of Instructor: S. Q. Adams

Course: Civil Engineering

Term: Third

Session: 1930-1931

SAMPLE REPORT

EXP. No. 65
DATE: 5/1/31

GENERAL SUBJECT: Testing of Bituminous Materials.

SPECIFIC OBJECT: Determination of Loss on Heating (Volatilization Test).

SAMPLE: Paving Asphalt (The Excelsior Oil Company).

APPARATUS: Constant Temperature Electric Oven, Tin Box, Spoon, Knife, Thermometer, Analytical Balances, Desiccator.

METHOD: A sample of the paving asphalt was weighed out in the tin box. This was accomplished by first obtaining the weight of the box on the analytical balances. Fifty grams was added to this weight, the tin box was put on the rough scales, and enough of the sample was added to balance. The exact weight of box and sample was then obtained on the analytical balances. From the two exact weighings, the weight of the sample was found.

The constant temperature oven had been previously turned on and the temperature checked. The sample and box were now put in the oven and allowed to remain for 5 hours, during which time the temperature was maintained at 163° C. At the end of this period the sample and box were removed, cooled in a desiccator, and again weighed on the analytical balances. The loss in weight was thus obtained, from which the per cent of loss was calculated. See next page for detailed calculations.

RESULTS: Loss on heating = 0.119 per cent.
Class average = 0.120 per cent.

VALUE OF TEST: This is a direct usability test. It serves to determine both the character of the bitumen and its probable useful life as a paving material. It may be classed as an accelerated test, since a relatively short period of time with a high temperature is used to determine the loss of volatile constituents. The results of this test, therefore, serve as an indication of the behavior of the material over a long period.

The loss on heating for paving asphalt should not generally exceed 1 per cent. For cut-back bituminous materials it may be as high as 15 per cent.

This test is not run on tar products, since the distillation test for those materials serves the same purpose.

DATA AND CALCULATIONS:

Weight of box and bitumen	58.9565 grams	
Weight of tin box	8.7563 grams	
Weight of sample........................		50.2002 grams
After Heating		
Weight of box and bitumen	58.8966 grams	
Weight of tin box..........	8.7563 grams	
Weight of sample		50.1403 grams
Loss of weight on heating...............		0.0599 gram

$$\text{Volatilization} = \frac{0.0599}{50.2002} \times 100 = 0.119 \text{ per cent.}$$