CHAPTER 2
Literature Review

2.1. General

This chapter deals with the extensive literature review to understand various aspects of waste materials (FA and CT), along with the investigations carried out by eminent researchers/authors related to vulnerability impact assessment on the environment due to disposal of FA and CT. The utilization potential of FA and CT in a different field, assessed by many researchers are also presented. In later part of the chapter, studies covering the life cycle assessment of utilization potential of FA and CT in concrete are also discussed.

2.2 Environmental Impact and Co-Placement Studies of FA and CT

With growing energy demand, many industrialized and developing countries will continue to rely on coal for power generation in the decades to come. However, any such source of energy brings with its own technological advantages and disadvantages, as well as adverse environmental effects. Coal-based power generation produces large amounts of fly ash worldwide. The disposal of fly ash is considered as a potential source of contamination due to enrichment and surface association of trace elements in the ash particles, many of which are of prime environmental concerns. During transport, disposal and storage phases, the residues from coal combustion are subjected to leaching effects, and part of the undesirable components in the ashes may pollute the soil and in turn both ground and surface waters (Benito et al., 2001).

Though there exists dependency among the type of pollutants and their impact on the environment, no direct relationship has been established between the concentration of trace elements in fly ash and their leaching effects. The leaching volumes of trace elements are very firmly related to parent coal composition, its formation, ways to burn, redox condition and on pH (de Groot et al., 1989; Izquierdo and Querol 2012). At low pH about 2.0, the leachate has higher metal concentration than neutral. Fly ash, which is a finely divided amorphous alumino-silicate pozzolanic material contains different proportions of calcium. It produces various hydrates of calcium silicate and calcium aluminate when it is combined with Portland cement and water and reacts with calcium hydroxide. Sometimes, when there is no source of calcium hydroxide available, then fly ash containing higher calcium exhibits cementitious behaviour after reacting with water to form hydrates (Guo et al., 2013).

The calcium-rich fly ash can be used as the main ingredient in cement which can also be used in self-compacting concrete without compromising workability and compressive strength (Ponikiewski and Golaszewski, 2014). Abundant calcium content usually points to an advanced reactivity of fly ash. With the presence of sulfur and oxygen, highly reactive calcium promotes the formation of anhydrite (CaSO4). Moreover, the interaction of high-calcium fly ashes with water encourages the hydration of lime and gypsum to develop pozzolanic reactions (Boyat, 1998).

Thus, coal fly ash has potential applications in the management of acid-generating mine tailings since their chemical and mineralogical properties make them an excellent binding agent and a possible substitute for gypsum, anhydrite, lime, or limestone currently used in the mining industries (Boyat, 1998). Since coal fly ash has neutralization potential, when it is mixed with mine tailings sludge, acid-base reactions consume the acidic potential of tailings. With rising pH, metals in the solution lose their mobility. If the process is proven to be effective, it can be a cost-effective approach in the management of acid, generating mine tailings as coal fly ash can be obtained in large quantities at a relatively low cost. However, the leaching property of fly ash itself has to be checked and taken care of in the process.

Despite the fact that fly ash itself has leaching properties with toxic elements leaching out of it with time in contact with the aqueous medium, it has been used by a number of researchers in conjugation with mine tailings (with or without other materials or binders). The intention is the management of tailings and reduction in the Acid Mine Drainage (AMD) and other heavy metal leaching from the same, with encouraging results through laboratory as well as field studies (Yeleyis et al., 2009; Franks and Moran, 2014). Studies of mine spoil/tailings with fly ash are happening as early as 1977 when Fail and Wochok (1977) used fly ash as an amendment for strip mine spoils under field conditions. They went on to report that the addition of fly ash in all cases was useful as an acid soil neutralizer and substantially enhanced the growth and development of all experimental plants.

Column leaching experiments in the form of laboratory simulation of fly ash as an amendment to pyrite-rich tailings conducted by Sonderegger and Donovan (1984) showed that fly ash inter-layered with sulfide-rich tailings could reduce the vertical permeability of tailings by at least three orders of magnitude.

The research conducted by Bayat (1998) also indicated that coal fly ash has potential applications in mine tailing's management because of its chemical and mineralogical properties making the ash a good alkaline binding agent and a possible substitute for gypsum, anhydrite, lime or limestone. Jang and Kim (2000) performed studies on solidification and stabilization of Pb, Zn, Cd, and Cu in tailings wastes using cement and fly ash and concluded that the combined materials increased the strength of solidified tailings wastes and also immobilized the heavy metals present in contaminated tailings wastes to a considerable extent. Mohamed et al. (2002) studied the treatment of mine tailings using lime; Class C fly ash, and aluminum as well as their combinations.

In the laboratory study performed by Polat et al. (2002), lignitic fly ashes from two power stations in western Turkey were used to neutralize synthetic AMD from a pyritic ore specimen in northern Turkey. Xenidis et al. (2002) carried out long-term kinetic column tests to study the potential use of lignite fly ash in the control of acid generation from sulfidic tailings and suggested that the optimum amount of fly ash addition to Lavrion tailings, in terms of neutralization and hydraulic conductivity reduction, lies between 20% and 30%. Dermatas and Meng (2003) examined the use of fly ash for stabilization and solidification of heavy-metal-contaminated soils. They found that lead and hexavalent chromium are immobilized due to surface adsorption, whereas trivalent chromium is stabilized by hydroxide precipitation. Owing to the additional alkaline agent, pH buffer capacity was enhanced, and heavy metal leachability was restricted to the levels that are well below the regulatory limits. Ciccu et al. (2003) evaluated the use of fly ash, red mud, and bauxite ores for immobilizing metallic and metalloid elements contained in severely contaminated soil samples taken from a tailings pond.

Addition of fly ash or red mud, or a combination of the two, to contaminated soils drastically reduced the heavy metal concentrations from effluents, as observed from results of columns containing the mixtures of the additives and the contaminated soil. Shang and Wang (2005) investigated the utilization of fly ash as a contaminant barrier to reduce the escape of contaminants via AMD generating tailings and concluded that fly ash was very effective in the containment of the pollutants well below the leachate criteria set by the local regulatory body. Shang et al. (2006) performed a site-specific study to evaluate the feasibility of co-disposal of fly ash and mine tailings to reduce environmental impacts of acid-generating mine tailings from Sudbury tailings disposal site using fly ash from Nanticoke generating station. They reported that co-placement of coal fly ash with mine tailings has the benefit of immobilizing trace elements, especially heavy metals.

In another study conducted by Vadapalli et al. (2008), in addition to the neutralization of AMD from a South African coal mine with fly ash from a local power station, solid residues recovered from neutralization reactions were tested for unconfined compressive strength and elastic modulus in order to assess their suitability as backfill material. Strength testing was carried out for 410 days with and without the addition of ordinary Portland cement, and it was found that the solid residue with a pozzolanic binder added gained 300% greater strength than without, both of which increased in strength over time. Yeheyis et al. (2009) conducted a site-specific laboratory investigation to evaluate the efficiency of coal fly ash to control the formation of acid mine drainage (AMD) from mine waste. The study involved mixing of fly ash from Atikokan Thermal Generating Station and mine tailings from Musselwhite mine at different proportions. They investigated the chemistry of AMD and the optimal mix of FA and mine tailings, and it was concluded that fly ash could be used in the management of reactive mine tailings in the co-placement approach, thus ensuring prevention of AMD in the long-term. The fly ash is observed mostly alkaline and having a negative charge on the surface. Due to this property, it is recommended to use fly ash for the removal of metal ions from aqueous solution as well as gases through adsorption. It also contains some amount of unburnt carbon which also works as an excellent adsorbent.

Ahmaruzzaman (2010) reviewed that the fly ash grout injection used in the underground mining site. It reduces the AMD by working as an insulator between pyritic materials and water. Fly ash as mine void filling not only prevents the groundwater but also give supports to mining site where standing coal pillars are going to crumble. Kusuma et al. (2013) used the fly ash with the overburden rock and results that it prevents AMD. It has good pH variation handling capability and control oxygen diffusion into the column. Edraki et al. (2014) reviewed tailings management approaches like a paste and thickened tailings, its reuse; recycling and processing again; and proactive management. It has been observed that the tailings properties are related to the environmental happenings. Lee et al. (2014) worked on AMD due to reactive mine tailings (mine tailings that contain sulphide minerals like pyrite and pyrrhotite). Fly ash, and mine tailings used collectively on Musselwhite mine and result in a reduction in leaching because of cementation formation due to hydration of fly ash. Bolan et al. (2014) worked on soil amendment to prevent AMD. There are immobilizing amendments where sorbent materials decrease the mobility of metals ions and precipitating agents, which are also used to retard the transfer rate of metals ions passing into the food chain. Park et al. (2014) reviewed on the beneficial use of coal combustion by-products. They discussed the utilization of coal combustion by-products in neutralizing AMD, soil restoration, soil improvement for re-vegetation, mine void back fillings.

2.3 Utilization Potential of FA and CT

Fly ash, the residue of pulverized coal is come from the combustion process along with other gases. It is majorly composed of silica, alumina, ferrous oxide, and calcium oxide in different proportion based on the properties of the parent coal. It is used in a variety of engineering applications because of the inherent properties. The chemical composition, fine particle size, abundant reserves, and pozzolanic ingredients are the primary deciding factors for suggesting it for different applications. Based on various parameters, the utilization potential of FA is shown in Fig. 2.1. Table 2.1 shows the dominant field in which attempt has been made by researchers to find out the utilization potential of FA in different applications.

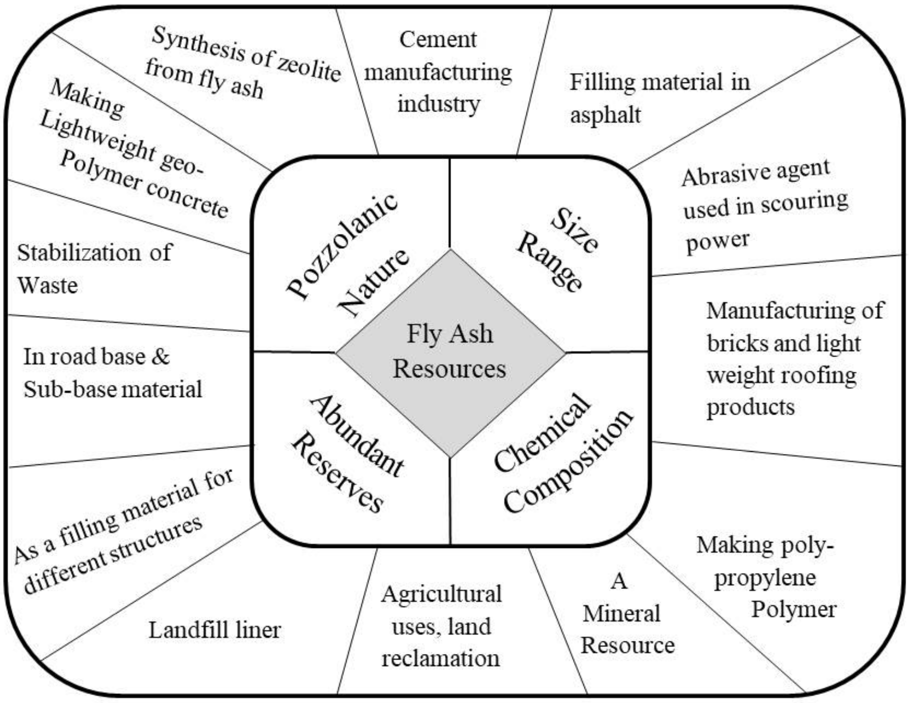

Fig. 2.1 Different applications of fly ash based on the inherent parameters

Table 2.1 Research work done related to utilization of fly ash in different areas

S. No	Utilization	Author	Details
1	As an adsorbent	Sen and De (1987)	After the pretreatment through a hydrothermal process, they found it is much effective in the adoption of mercury.
		Rio and Delebarre (2003)	They investigated that the adoption capacity of sulfo-calcic fly ash is higher than silico-aluminous fly ash irrespective of pH.
		Banerjee et al. (2005)	They investigated the adsorption capacity of aluminium and iron impregnated fly ash and found higher than that available in raw fly ash as it increases with a rise in pH for Hg (II) and Removal of Cr (VI) and Hg (II)
		Kuncoro and Fahmi. (2013)	They heated and sieved fly ash (diameter at the order of 149-250 μm) and concluded that fly ash mixed with CH_3COOH removes Hg effectively.
		Liu et al. (2013)	They developed a zeolite precursor by enhancing the fly ash and making a hybrid mesoporous aluminosilicate sieve, which works as a very effective adsorbent.

		Li et al. (2017)	They investigated how the adsorption capacity of fly ash for phosphorus increases when lime and clay are added.
2	Zeolites synthesized from fly ash	Querol et al. (1995)	They introduced a novel approach to change the fly ash into low-grade zeolites using hydrothermal treatment.
		Ahmaruzzaman (2010)	Author has reviewed and concluded that the zeolite manufactured from fly ash has a good ability to remove phosphorus and can be utilized in wastewater treatment.
		Zhou et al. (2014)	They manufactured a single-phase zeolite NaP1, a higher adoption capacity material for volatile organic compounds through a controlled the synthesis process.
3	Construction industry (in Concrete/ Cement)	Ravina et al. (1986)	They replaced cement with fly ash from 35% to 50% and concluded a reduction of 5-7% water needs in concrete for target sump.
		Ahmaruzzaman (2010)	Author has reviewed the effectiveness of fly ash in concrete and its reaction with lime.
		Ondova et al. (2012)	They investigated how a proper water-cement ratio can mitigate the problem of low early strength of fly ash-based concrete.
		Badar et al. (2014)	They developed geopolymer concrete by using fly ash samples of varying Ca content and conclude that concrete with fly ash containing less Ca content has better durability.
		Garrabrants et al. (2014)	They investigated how leaching varies with the replacement of cement content under the different proportion of fly ash.
4	Lightweight building material, Brick Manufacturing	Reidelbach (1970)	They manufactured fly ash bricks and pointed out that the weight of fly ash bricks is about three times lighter than the regular clay bricks.
		Cultrone et al. (2004)	They investigated that the porosity of brick is a function of mineralogical composition and kiln temperature. The higher temperature made the bricks vitreous a huge variation in porosity and size.
		Ahmaruzzaman (2010)	Author explains how the lightweight, rigid roofing tiles are a better replacement of regular clay products.
		Shakir et al. (2013)	Manufactured the bricks by fly ash, quarry dust, and billet scale and concluded that they are highly sustainable and can be used vastly.
5	Road base/ sub-base	Shen et al. (2009)	Experimented and find out that the steel slag, fly ash and phosphogypsum-solidified material can be used effectively as a road sub-base.
6	Mine backfill	Yao et al. (2012)	They made material for backfilling by which is silica alumina-based and manufactured by combining coal refuse and fly ash with a proportion of 5 (750 °C) and 15 (at 20 °C) percent respectively. The

			above combination meets EPA requirements, exhibits a good bearing capacity and higher flowing ability.
7	As landfill liner	Mollamahmutoğlu et al. (2001)	Lower permeable liner materials were manufactured, using fly ash by adding bentonite as a binding agent with 5% to 30% and find out that with 20% bentonite the liner material can be used effectively as a liner.
		Cokca et al. (2004)	Manufactured a liner using fly ash, rubber, and bentonite work well for making the liner.
		Çoruh et al. (2010)	Determines leaching of zine reduced significantly by combined using fly ash phosphogypsum and red mud as a liner material.
		Sivapullaiah et al. (2011)	Investigate the leachability, permeability, and strength with curing and find that when used as the base material in the liner, due to lower hydraulic conductivity, leaching will be very less.
8	Making of polypropylene polymer	Bandyopadhyay et al. (2010)	They found that the fly ash with an altered colour within 5% of calcium carbonate make almost identical color polypropylene polymer and very effective to use as a replacement.
9	Making New porous composite material	Yildirim et al. (1996)	They investigated the strength and durability of fly ash and polypropylene polymer composite material blocks and recommended to use as insulation and building materials.
10	Agriculture (Soil Amendment)	Ukwattage et al. (2013)	They recommended the use of fly ash as soil amelioration material in sandy and clay soils to improve the water retaining potential and hydraulic conductivity.
		Ram et al. (2014)	They highlighted that silt-size particle, less bulk density, more moisture retaining power, availability of plant nutrients under optimum pH make fly ash a useful soil amendment material.
11	Mineral Resource	Pedlow (1978)	Author has studied the extraction of minerals from fly ash and concluded that the use of sulfuric acid extraction, artificial magnetic extraction, lime sintering, and magnetic separation method could increase the effectiveness of materials.
		Cheremisinoff (1988)	Author has recommended using fly ash as a source of a variety of minerals (Al, Ca, Fe, Mg, Na, P, S, and Si).
		Guo et al. (2017)	They used Na_2CO_3 activated acid leaching process and successfully extracted the valuable alumina from fly ash.
12	Waste Stabilization	Dermatas et al. (2003)	The quicklime, combined with fly ash, acts as an effective waste stabilization agent by reducing the leachate and increasing the stress-strain properties of the soil. The release of pozzolanic material is the

			only adverse effect as ettringite is formed during this process, which causes swelling and deterioration.
13	As an abrasive agent	Sen et al. (2003)	In the patent, they successfully used the fly ash as an abrasive agent and described, as the particle size of fly ash is similar to the scouring powder, much cheaper and readily available.
14	Low Strength Controlled Material	Gabr et al. (2000)	They manufactured a controlled low-strength material by using fly ash, cement, water, and fine aggregate with having strength equating with stabilized soil.

Copper is widely used in different application due to its greater electrical with higher thermal conductivity with less corrosiveness. Due to its high utilization potential, the demand has increased exponentially and caused the production reached nearly up to 20 million tons during the year 2017 (Ober, 2018). In the copper mine, the acid mine drainage makes a huge waste pond of copper tailing with the ratio of about 128 tons of waste tailings to produce one tone of pure copper (Beniwal et al., 2015; Gordon, 2002). The tailing contains chiefly Aluminium, Cadmium, Lead, Magnesium, Hydroxides, and other trace elements, which deteriorate the environment and human health (Kundu et al., 2016; Yang et al. 2013). The adverse impact on air, surface and groundwater, land and aquatic animals due to copper tailings have been pointed out in many studies (Castilla et al. 1996; Rösner, 1998; Sharma et al., 2001). There is a great need to overcome this problem by providing a scientifically, feasible, sustainable utilization of this waste. Attempts have been made by many researchers (Beniwal et al., 2015; Gupta et al. 2016) in different ways to use copper tailing as a replacement of sand in concrete manufacturing, stabilization of soil and brick manufacturing. Various applications of CT are detailed in Table 2.2.

Table 2.2 Research work done related to the utilization of copper tailings in different fields

S. No	Utilization	Author	Details
1	In concrete	Onuaguluchi and Eren (2012a)	Cement partially replaced with copper tailings at 5% and 10%. It negatively affects the setting time, porosity, and slump value. There is a significant improvement in abrasive strength, mechanical strength, and reduction in penetration of chloride.
		Beniwal et al. (2015)	They investigate the compressive strength of concrete (fine aggregate replaced partially with copper tailings) at different water binder ratio. It was inversely proportional to water binder ratio and technically possible.
		Gupta et al. (2016)	The fine aggregate is replaced with copper tailings by them, suggested up to 70% replacement in all structural component, and higher for nonstructural parts for higher shrinkage strain, water permeability, carbonation of copper tailings.
		Kundu et al. (2016)	They have replaced cement with copper tailings partially and suggested that, at 10% replacement of cement with copper tailings, the unconfined compression test gives acceptable results and works as a stabilizing agent to reduce leaching.
		Onuaguluchi and Eren (2016)	They find out that copper tailings replaced partially with cement will show early corrosion while if used as an additive (5%) in the pre-wetted form it delayed the corrosion and cost-effective.
		Zheng et al. (2016)	They have attempted to understand the effect of water reducing admixture and limestone powder on copper tailings. They pointed out that the workability increases with an increase in the dose of limestone powder thus improves unconfined compressive strength.
2	Metal recovery	Falagán et al. (2017)	They explored the possibility of extraction of copper and silver from copper tailings in the presence of different bacteria from a leached solution. The bioprocessing process has been found fairly economical and environment-friendly.
		Liu and Huang (2017)	They have attempted to recover magnetite ore from copper tailings. They observed that there is a high possibility of Arsenic (As) solubility in the process and recommended to retain the magnetite at the upper layer to overcome the risk.
		Smolinskii et al. (2017)	They try to extract the copper from copper tailings by using a mixture of ptoluidine and toluene. They have applied the radiometric method along with fair guidelines for efficient extraction.

3	Bricks manufacturing	Fang et al. (2011)	They proposed autoclaved sand-lime brick using copper tailings with low silica content and recommended to utilize up to 50% copper tailings combine with river sand and sand powder to achieve significant strength.
		Ahmari and Zhang (2012)	They have successfully manufactured eco-friendly bricks using a geo-polymerization method, which complies with ASTM standards.
		Ahmari and Zhang (2013)	They studied the durability of bricks manufactured from copper tailings, cement kiln dust, geopolymer, and results in the improvement of unconfined compressive strength when cement kiln dust is added.

2.4 Life Cycle Assessment and its Use in Concrete Production

Infrastructure development through the construction industry is considered as one of the predominant sources of global warming through a considerable amount of greenhouse gas emissions (Junnila and Horvath, 2003; Damtoft et al. 2008). It has been estimated that the manufacturing of infrastructure of the built environment is responsible for 40% of the total greenhouse gas emissions (Vieira, 2008; DOE, Buildings Energy Data Book 2011). The concrete plays a vital role in this process. For sustainable development, it is very much essential that the future demand of concrete must be made by taking into consideration of adverse impact on the environment. About 5% of the global emission are due to concrete manufacturing that is about 2.1 billion tons coming from anthropogenic activity, chiefly the processing of clinkers in cement manufacturing (CIEP, 2009). These emissions are majorly coming from the combustion process in the cement industry, which is about 4-5 Gigajoules for each ton of production. Other than that, the calcination of limestone is also contributing to this emission. It has also been observed and roughly estimated that in the manufacturing of one metric ton of cement clinker 0.87 tons of carbon dioxide is released into the atmosphere. The fire can be varied with the manufacturing process used, its efficiency, electrical grid, and the combustion fuel used. The conservation of the environment is a significant issue for sustainable development. It is essential to consider the cement industry among the top polluting ones while forming mitigation policies for greenhouse gas emissions. Other than CO_2, there are other environment-related factors arises during the whole life cycle of the concrete. A more accurate step-by-step scientific approach is required for quantifying the overall environmental impact assessment of concrete from its production to utilization and disposal. Life cycle assessment (LCA) process is used to evaluate the said ill-effects on the environment.

LCA process is very proven process to handle such a high volume of concrete production and the native environment issues. The LCA results facilitate a very heterogeneous audience which is working to cope up with environmental related changes. There are various stakeholders (scientific standards forming persons, urban planning teams, green building standards developing persons, and construction industries, etc.), which are associated with decision making process at different stages. Along with that, the material manufacturers are also there, who are very eager to facilitate material with a reduced carbon footprint. It is the need of these material manufacturers to produce greener material (concrete) to remain competitive. By using the LCA approach, one can quickly estimate the impact on the environment from each of the ingredient from its procurement, utilization to disposal by using the cradle to grave approach. The LCA process is very diverse, and its accuracy is very much dependent on how much details of the input and output data (volume, mass, energy) has been used while compiling the life cycle inventory (LCI). If the input data is misleading, less accurate or insufficient, the LCI is unable to facilitate reliable LCA results. It can be easily said that the credibility of LCA is entirely dependent on credibility of life cycle inventories. A progressive development along with awareness for global environmental protection leads to the dawn of many different approaches, concepts, and tools to assess the environmental impact assessment of any product from its production, transportation, utilization to disposal. LCA is a widely accepted tool to serve this purpose and provide comprehensive data in this regard.

LCA technique has been applied for concrete by Nisbet et al. (2000). Some researchers have used his technique to perform an impact assessment of modified concrete. Corinaldesi (2010) finds out that the effect of replacing 30% aggregate with the recycle aggregates. It has also observed that the use of recycled aggregate in concrete will reduce the production cost as well as the environmental impacts (Braga et al., 2007). From extraction to production followed by transportation, construction, utilization, and demolition, six different stages have been studied using LCA by Knoeri et al. (2013) who confirmed that the cement production contributes significantly on environmental impact in the production of concrete. Marinković et al. (2010) have studied and suggested that the environmental impact due to aggregate predominantly depends on the transportation distance from the aggregate manufacturing site to the construction sites.

2.5 Gap in Existing Research

After going through the above research papers and reports, it is found that there exist extensive works by the researchers with regard to utilization of FA in different fields.

A detailed work has been carried out to assess the adoption potential of FA for the removal of various constituents from the solution. However, studies are very limited on how to utilize copper tailings along with fly ash. The immobilization potential of FA has also been identified to combine it with tailings and reduce the acid mine drainage and leaching of heavy metals. However, few researchers did site-specific studies on co-placement of fly ash and copper tailings. Minimal works have reported on copper mine tailings but there is no work done for the combined utilization of fly ash and mine tailings hence more effort is needed in this direction.

2.6 Summary

Outstanding work done by eminent researches along with the brief finding is presented in this chapter. Initially impact on surroundings due to FA and CT with the combined leaching studies are discussed. It was observed that the disposal, transportation, and storage of FA lead to affect the surrounding soil, surface, and groundwater adversely. The calcium-rich FA can be used to manage acid generation mine tailings, due to its inherent mineralogy and binding nature. Many researchers have investigated how the chemical composition, fine particle size, ample reserves, and pozzolanic ingredients make it suitable for the various application and valorization of this abundant waste. A considerable amount of about 128 tons of waste tailings to produce one tone of pure copper, is generated in the copper mining. It certainly leads to severe impact on surrounding environment. Some effort is done in the utilization potential of copper tailing in different areas. However, as the demand of copper is increasing exponentially due to its versatile uses, more core investigation is needed in this regard.

In the last part of the chapter utilization potential and earlier research work performed associated with life cycle assessment (LCA) is presented. LCA process is used to evaluate the said ill-effect on the environment. Its results enable authorities to cope up with environmental related changes. It is an accurate step by step scientific process to quantify the overall environmental impact assessment of process/product from its production to utilization and disposal. This method is very diverse, and the reliability and accuracy are majorly depending on the accuracy of the input and output data, which are mainly based on LCI.