CHAPTER 7
Summary and Conclusions

7.1 Summary

Anthropogenic wastes, FA and CT, are dumped around the globe and its necessary to surmount this problem. This environmental problem due to the disposal of such wastes are chiefly dependent on parent material characteristics. FA, a coal combustion waste, and CT, an uneconomic fraction of copper ore, have the potential to pollute the land, air, surface, and groundwater. The research work presented in this thesis gives a broader perspective in term of adverse effects on the environment by unmanaged disposal of both FA and CT. The physicochemical analyses of the waste materials are performed in the study to understand the long-term behavior and potential environmental pollution. Economically feasible and solution for sustainable utilization have been identified through careful experimentation, data collection, and systematic analysis. It will not only help in the reduction of the ill-effects on the surroundings but also preventing the wastage of valuable land. Available literature has given a detailed perspective of both waste materials (FA and CT) with respect to their applications and valorization of these abundant wastes due to chemical composition, small particle size, ample reserves, and pozzolanic ingredients. The mineralogy and elemental analysis results, along with SEM images, give a fair idea of the constituents and their possible behavior. Different leaching tests were performed that have given an insight with regard to immobilization potential of FA and CT and possible adverse impacts on the environment. A sustainable utilization is proposed in the current work by combinedly replacing cement partially with FA and CT in the concrete mix design. Initially, LCA analysis was performed for the designed mix proportions of concrete. A detailed overview of the LCA process is presented. The midpoint and endpoint used for the LCA analysis, are discussed for sustainable design of concrete mix. Though there exist different approaches of LCA, cradle to the grave approach has been applied in this study due to its suitability as suggested in the literature by several researchers. The economic feasibility of the concrete mix has also been assessed before the casting of cubes. Conclusions are drawn from the current research are presented in the subsequent sections.

7.2 Leaching Studies

1. The ASTM and TCLP batch leaching study for fresh fly ash (FA-1) and weathered fly ash (FA-2) samples show that the value of zinc, copper, calcium, and magnesium are well below the WHO standards for both leaching tests, while the concentration of arsenic and selenium are above the WHO guidelines for both tests in FA-1 samples. Iron and manganese concentrations are also found higher for TCLP test leachate. The results also indicate that the values of all the elements in TCLP leachate are higher than the permissible limits for inert solid waste acceptance criteria, except for the lead in FA-1 samples and arsenic, cadmium and barium in FA-2 leachates.

2. Arsenic, nickel, chromium, and selenium concentrations exceeded the inert waste permissible limits in the extracts of FA-1 samples when they were tested by the ASTM method. The concentration values of arsenic and selenium are greater than the non-hazardous waste acceptance criteria in the leachates of FA-1 samples under both ASTM and TCLP tests. It has also been inferred that concentrations of iron and selenium in groundwater exceed marginally WHO standard limits prescribed for drinking water. Thus, it can be concluded that groundwater is affected marginally by the fly ash, especially in the context of these two parameters. The weathered FA-2 sample has demonstrated lower leachability as compared with the fresh FA-1 samples in many elements.

3. It should be noted, however, that the time distance of 30 days between the production, and disposal of FA-2 sample and that of FA-1 is rather limited and the weathering processes are not expected to have caused major alterations within this short timeframe. The results of the study may not capture the long-term impacts of weathering effects, which is one of the limitations of the study. However, the observations provide useful information and would aid researchers in planning further studies.

4. The results of batch leaching tests (ASTM and TCLP) after mixing of both (FA and CT) shows the higher value of As and Mn in leachate when CT concentration is high, these values are comparatively greater in TCLP test samples. Whereas, the value of Ni, Fe, and Mn concentration is higher than the WHO limit in the leachate of the TCLP test, which increases as the CT concentration increases.

5. The correlation between pH values in TCLP batch leaching tests with Co, Cu, Fe, Mg, and Mn are positively correlated. The pH value of leachate is positively correlated and negatively correlated with Al, Ba, Ti, and V. FA, and CT ratio is negatively correlated with pH and Cu concentration but positively correlated with Ba, and V. Concentration of Al, Ba, Ti, and V is negatively correlated with the pH value, but Cu, Fe, Mg, and Mn are positively correlated with pH value. In the case of ASTM batch leaching test results, the pH value is not correlated with the ratio of FA and CT. However, Al, As, Ba, Cr, Se, and V are positively correlated with FA/CT ratio.

6. In column leaching the concentration of Al, Cd, Cr, Pb, and V in leachate is higher than the value of these in all three types of parent leachant and Fe concentration only for alkaline leachant. Which shows that there is possibility of sorption in the column and the waste material might be helping to immobilize the above elements.

7. The concentration of Mn in column leaching test is significantly higher than the WHO guidelines for all three leachant (distilled water, acidic leachant, alkaline leachant) however, it is decreasing gradually as time passes.

8. In the column leaching test, the concentration of Ni in the leachate of distilled water and alkaline leachant is higher than WHO standards only for the initial 96 hours. However, in acidic leachant the concentration value greater (0.16 mg/L in the 130 hrs leachate) than WHO standards.

9. In acidic leachant, the Fe concentration in all the leachate collected after 64 hrs is above the standards. The concentration found 85.04 mg/L in the last collected sample at 130 hrs.

10. The results of groundwater samples collected nearby Khetri copper tailing pond, show higher concentrations of elements Al, Ca, Cu and Fe which crosses the prescribed standards and samples collected nearby Suratgarh thermal power plant, the concentration of Fe found above the standards.

7.3 Utilization in Concrete and LCA Analysis

This study examines the feasibility of combined utilization of FA and CT as an alternative to partially replace cement in concrete by assessing compressive strength, cost, and environmental

impact. FA and CT were initially characterized, and their suitability for partial replacement of cement in concrete is identified through X-Ray Fluorescence test and Scanning Electron Microscopy. Later, various mix design proportions are synthesized for the partial replacement and specimens are prepared. The performance of samples are evaluated in terms of strength, economic feasibility, and environmental sustainability. The final remarks drawn from this study is presented below:

1. The density of the concrete is observed to be increasing with the addition of CT in combination with FA. It may be due to the higher specific gravity and smaller particle size of CT.

2. The FA and CT have a higher percentage of pozzolanic compounds, which reacts with the excess lime generated during the initial hydration of cement. This reaction contributes to the additional strength of the concrete.

3. The results of the compressive strength test highlight the significance of the combined utilization of FA and CT in concrete. The prepared specimens showed a very competitive compressive strength compared to the control mix. For FA 10% and CT 5% as a replacement of cement in concrete, the compressive strength is significantly higher (8.27% for w/c ratio 0.45 and 1.7% for w/c ratio 0.5) than the control mix.

4. Replacement of FA up to 20% and CT up to 5% provides higher compressive strength than the target strength. Beyond this limit, there is a reduction in compressive strength, which is due to the absence of cementing material available to react with pozzolanic compounds.

5. Replacing cement with FA and CT will also help in reducing the cost of concrete production from 6.5% to 18.08% for Mix M1 at w/c ratio 0.5 to M6 at w/c ratio 0.45 respectively. It is found out that for better compressive strength and comparative economic viability, replacement of cement with 10% FA and 5% CT at a water-cement ratio of 0.45 is the most favorable. Similarly, the replacement of cement with 20% FA and 5% CT is found to be the most economical mix without compromising compressive strength.

6. The results of LCA analysis shows a notable reduction in greenhouse gas emission, which positively impacted and reduced the endpoint environmental impacts (ecosystem

quality, human health, and resources).

7. The reduction in CO_2 emission by lowering the cement consumption leads to a progressive decrement in global warming potential (GWP). The midpoint analysis shows that all-important factors (viz., climate change, human toxicity, etc.) associated with environmental impact assessment have been reducing with the higher replacement of cement with FA and CT.

8. The FA is extensively used as a replacement of cement, and various standards have recommended maximum replacement limit of 30% of cement in concrete. This replacement marginally increases the compressive strength of concrete whereas if CT alone is used to replace cement in concrete partially, the compressive strength of mix reduces as the proportion of CT increases, which is due to low reactiveness of tailings particles. However, the findings of the present study show that the combined utilization of FA and CT improves not only the compressive strength of the concrete, but also it significantly reduces the production cost.

7.4 Future Scope of the Work

There are many aspects of pollution potential, and possible utilization of FA and CT, which have been attempted in this study. However, for the future work, there is always further scope available for research in the utilization, characterization, and analysis of FA and CT. In this context, some of the work can be taken up for future research as mentioned below:

1. More prolong leaching effect in column study can be performed with a variable height of FA and CT waste materials.

2. A fresh LCA for the new modified concrete will be more helpful if the inventories are developed for a specific purpose.

3. Performing microstructure analysis of hardened concrete will provide more insights about the structural changes to understand the durability of the modified concrete.

4. Evaluation of other strength parameters like flexure strength, tensile strength, etc. will facilitate more diverse applications of the utilization of FA and CT in concrete.

5. The modified concrete is economical and use of FA and CT as the waste materials is a sustainable solution, but for a better future of the infrastructure development, alternate environment-friendly and economically viable cementing material should also be identified/developed which can fully replace the cement.

7.5 Major Contributions of the Thesis

1. The utilization of FA and CT in concrete will reduce the requirement of cement for the built environment, which would further reduce the severe pollution generated in the environment.

2. A vast amount of FA and CT covering the area of valuable land all over the world can not only be utilized in a more effective and sustainable manner but also associated ill-effects happening to the surrounding can be minimized.

3. Optimum utilization FA and CT in concrete will also economically beneficial to the construction industry.