CHAPTER-8

CONCLUSION AND FUTURE RECOMMENDATIONS

8.1 Conclusion of the Study

The major findings of this research are to examine the effect of GGBFS inclusion and concentration of NaOH on various industrial wastes (Pond ash, MSW Reject, and Red mud). This detailed study is divided into four types of geopolymer in which a particular geopolymer discusses separately their synthesis, their strength and other properties. Based on the findings of the present investigation, the following conclusions are drawn.

(a) The effect of GGBFS on the specific gravity of different types of geopolymer concluded that the specific gravity of Pond ash ($P_{100}G_0$) has been increased from the value 2.041 to 2.57 up to 100 % replacement of Pond Ash with GGBFS (P_0G_{100}).

(b) The specific gravity of MSW reject is 2.34. On adding GGBFS the specific gravity of the mixtures has been slightly decreased up to mix $M_{80}G_{20}$ (2.27). On further increasing the amount of GGBFS (up to 40%) in the mix the specific gravity has been increased to the value 2.57 $M_{60}G_{40}$. 90% replacement of MSW reject with GGBFS ($M_{10}G_{90}$) provides the 2.80 value of specific gravity.

(c) In the Red Mud-GGBFS geopolymer, the results of the specific gravity of the designed mixtures reported that the specific gravity of the Red Mud is 3.125. On replacing the Red mud with GGBFS, the specific gravity of the mixtures has been decreased. 90% replacement of Red Mud with GGBFS, the specific gravity of the mix $R_{10}G_{90}$ reached 2.74.

(d) The grain size distribution curve of the Pond ash- GGBFS mixes also changed upon adding GGBFS to the mixes. A minor change was observed in the percentage of sand

and silt particles. There are no significant changes in the percentage of clay articles on adding GGBFS in the Pond ash-GGBFS mixes.

(e) The grain size distribution of MSW consists of 80.8% sand, 17.5% silt and 0.293% clay. It is reported that the percentage of sand decreases and the percentage of silt increases on adding GGBFS in the MSW reject waste. A minor increment has been also observed in the percentage of clay on adding the GGBFS in the MSW reject.

(f) The effect of GGBFS on the grain size distribution of the Red Mud is that the percentage of sand in the mix has been decreased and the percentage of silt has been increased. The percentage of clay did not show any particular trend. Up to 50% addition of slag the percentage of slag decreased. Beyond this addition of GGBFS clay percentage became constant and then slightly increased.

(g) From the compaction analysis of Pond ash-GGBFS it can be concluded that MDD (maximum dry density) has been continuously increased and OMC has been decreased continuously on adding GGBFS in the mixtures.

(h) From the compaction analysis of MSW-GGBFS mixes, it can be concluded that MDD of the MSW-GGBFS mixes has been increased up to 50% addition and the OMC value shows the improper trend. At the 50% addition, the MDD of the mix $M_{50}G_{50}$ was 1.626 g/cc and the OMC observed at this proportion is 17.8%. Beyond this percentage of GGBFS, the value of MDD has been decreased to the value of 1.516 g/cc at the 90% addition of GGBFS. The value of OMC has started increasing beyond the 50% GGBFS addition.

(i) The compaction characteristics of Red mud have been changed after adding the GGBFS percentage. The value of maximum dry density (MDD) of Red mud has been found to be 1.52 g/cc and the optimum moisture content of the Red mud has been calculated as 31%. On replacing the Red mud with GGBFS the value of MDD of the Red mud-GGBFS has been increased to the value 1.596 g/cc at the 50% addition of GGBFS in the mix. Beyond this addition of GGBFS the value of MDD of the mix has started decreasing to the value of 1.538 g/cc. On the other hand, the value of OMC continuously decreases with the addition of GGBFS.

(j) In the Pond ash-Red mud Geopolymer analysis, it can be concluded that the maximum dry density (MDD) of the Pond ash has been increased when pond ash is replaced with Red mud. The value of MDD of Pond ash ($P_{100}R_0$) has been reached from 1.157 g/cc to 1.53 g/cc up to 90% replacement of Pond ash with Red mud ($P_{10}R_{90}$). While the value of OMC on adding the Red Mud to the mixture overall decreases.

(k) As the Bulk density (g/cc) of Pond ash-GGBFS geopolymer increases, the value of permeability (cm/sec) decreases upon adding GGBFS in the mixtures.

(l) The permeability of MSW Reject was 2.395×10^{-4} cm/sec. On adding the GGBFS in the MSW reject the value of permeability has been recorded low. On 10% replacement of MSW reject with GGBFS, the value of permeability reached 6.2069×10^{-5} cm/sec. The lowest value of permeability has been recorded to 4.719×10^{-6}cm/sec when 90% MSW reject was replaced by GGBFS.

(m) The value of permeability of Red mud has been calculated as 2.822×10^{-4} cm/sec. After the replacement of 10% Red mud with GGBFS, the value of the coefficient of permeability suddenly dropped to the value of 7.698×10^{-6} cm/sec. on further replacement of Red mud with GGBFS the value of permeability slightly increases, but overall, the value of the coefficient of permeability has been decreased.

(n) As the density of Pond ash-GGBFS mixes increased upon adding GGBFS, the unconfined compressive strength also increased. Significant values of UCS were not observed in the mixtures activated with water. When the mixes are activated with different concentrations of the sodium hydroxide, a noticeable value of UCS has been observed. Strength has been increased with the increment in the concentration of the sodium hydroxide. But with increasing dose of sodium hydroxide strength slightly started decreasing.

(o) There is a significant improvement in the UCS of MSW-GGBFS when activated with different concentrations of sodium hydroxide. However, there is no noticeable improvement when MSW-GGBFS mixes are activated with water. Mix $M_{100}G_0$ did not show any significant strength activating with water. Even on activating with higher concentration, this mix registered the 0.072 MPa UCS value at 10 M NaOH concentration. When 10% MSW Reject is replaced with GGBFS in the mixes, a recognizable value of UCS is not achieved in the mixes activating with 4M NaOH. Up to 30% replacement of MSW with GGBFS there is no great improvement in the mixes of MSW-GGBFS. 40% addition of GGBFS in the mix $M_{60}G_{40}$ provides the 1 MPa value of UCS at the 7 days of curing period. With the increasing concentration of NaOH, strength increases. But when the concentration reaches beyond the 6M, the value of UCS slightly decreases.

(p) In the UCS analysis of Red mud-GGBFS, it can be concluded that the UCS value of the Red mud without alkali GGBFS ($R_{100}G_0$) has been found as 0.39 MPa. But there is no major improvement in further replacement of Red mud with GGBFS without alkali. The improvement in the UCS of the Red mud –GGBFS has been shown with the alkali activation of the mixtures at different concentrations. It is observed that 2 and 4M concentrations of NaOH added to Red mud-GGBFS mixes showed the maximum UCS.

(q) In the UCS analysis of Pond ash-Red mud Geopolymer, the UCS for the particular Pond ash-Red mud mixes has been increased with increasing concentration of NaOH. Overall the UCS value of Pond ash-Red mud mixes has decreased on addition of the Red mud in the mixes.

8.2 Contribution of this Study

Millions of wastes are generated worldwide which needs to be managed for a better environment. This concept of developing the geopolymer also reduces the global warming effect in the environment. This study presented a big contribution to the best of waste utilisation as geopolymer materials to lead the sustainable materials in the infrastructure industry. For understanding the use of Pond ash-GGBFS, MSW-GGBFS, Red mud-GGBFS and Pond ash-Red mud geopolymers as construction material, sample of 10cm size cube of mix 1:1.5:3 (GGBFS: pond ash: 10 mm aggregate) for mix Pond ash-GGBFS mix $P_{60}G_{40}$ activated with 10M NaOH has been casted and tested for compressive strength as per **IS: 516 (BIS, 1959)** at the different curing period of 3,7,14 and 28 days. The results of compressive strength have been recorded as 1 MPa, 9.6 MPa, 10.6 MPa and 15 MPa respectively. These results are of supportive to utilize both pond ash and GGBFS activated with alkali as eco-friendly materials in geopolymer concrete. From the results based on pond ash-GGBFS geopolymer, it can also be inferred that the minimum value of UCS 750 kPa obtained in all the proportions of pond ash-GGBFS-NaOH mixtures has been meeting the criteria of stabilized sub-base material as per **IRC 37 (2012)** for construction of roads after a curing for period of 28 days. Similarly, the field applications for the use of MSW-GGBFS, Red mud-GGBFS & Pond ash-Red mud geopolymers in geotechnical, road and as construction industry etc. can be explored.

8.3 Future Scope and Limitations

This study is limited to a short curing period of 56 days. This research can be done for a long curing period. This methodology for developing the geopolymer also applied on the other alumina-silicate rich materials. Geopolymer concrete stands as an innovative and environmentally-friendly construction material, providing a sustainable alternative to traditional Portland cement concrete. Its utilization holds the potential to contribute significantly to the mitigation of global warming, a pressing global concern. Furthermore, by opting for geopolymer concrete, the demand for Portland cement which is responsible for producing huge amount of CO_2 can be effectively reduced. This technology also useful in reducing the high amount of industrial waste (Pond Ash, Red Mud, Municipal solid waste and GGBFS etc.) and also helpful in cleaning of polluted landfills.