CHAPTER 6
SUMMARY AND CONCLUSION

6.1 INTRODUCTION

In the present research work blending of large amount of waste materials, such as, Fly ash (FA), Silica Fume (SF), Ground Granulated Blast Furnace Slag (GGBS), Metakaolin (MK) and Lime powder (LP) was used to make binary and quaternary binders, mortars and concrete for construction applications. The physical, mechanical, durability and micro structural properties were studied through stability based approach.

The blending of cement with SCMs is advantageous on several fronts, i.e. cost savings in cement production, reducing the green house effect, recycling of waste products and improvement in the desired physical as well as mechanical properties of mortars and concretes prepared with blended or binders.

The quaternary combinations of SCMs provided substantial advantages over the concrete mix prepared with only OPC. Hence, finding a right proportion of various SCMs to develop composites that can provide good strength and durability of the concrete matrices is the ultimate objective of the research carried out in the present study. To moderate the sustainability and suitability of any construction material, strength and durability properties are very important parameter. Here, the strength characteristics of unitary, binary and quaternary binders are studied through various conventional tests, such as, compressive strength, split tensile strength, flexural strength and bond strength, to understand the engineering performance of the combination of concrete. The mechanism of the strength development was explained through the micro structural analyses using Scanning Electron Microscopy (SEM) and X-Ray Diffraction (XRD). SEM analysis was useful in understanding the changes in surface morphology and XRD analysis were carried out to identify the hydration production phases. To ensure the long term durability of concrete, its durability properties were tested by performing chloride ion permeability test, ultrasonic pulse velocity test and sulfate attack test. To check the
economy of the composites, cost analyses were studied. The overall findings of the study, therefore, are helpful in developing quaternary binders and concretes on an industrial scale to decrease our total dependency on OPC.

The experimental results of physical, mechanical, durability and micro structural studies were presented in previous chapters. The following major conclusions have been drawn from the present study.
6.2 MAJOR CONCLUSION

Some of the important and major conclusions of the present research work are as follows:

1. Replacement of OPC by 30% with FA, SF and GGBS has very limited influence on the consistency, but replacement impact on consistency increases as it reaches 50%, however an increase in consistency was recorded within standard limit and almost similar to the OPC. These findings suggest that supplementary cementitious materials have almost negligible impact on consistency.

2. Standard consistency in quaternary binder (OPC–FA–SF–MK) increases with increasing percentage levels of MK, owing to the high surface area of MK and high levels of water demand. These findings revealed that by controlling the percentage level of MK in binder, both water and standard consistency requirements can be addressed.

3. The effect of 30–50% partial replacement of OPC with various amounts of SCMs retards the initial and final setting times of the binary, ternary and quaternary binders, and develop better compressive strength at 28 and 90 days as compared to OPC.

4. As compared to ternary (OPC–FA–SF) binder, the setting properties in quaternary concrete increases (OPC-FA-SF-GGBS) with the addition of GGBS. This indicates that increasing amount of pozzolanic materials increases the hydration process, hence increase in setting time.. The advantage of delayed setting times allowing concrete to be worked for longer periods which usually occurs during delays in transport, delays in mixing and using the concrete etc. These types of combination also help to reduce the risk of cold joints in larger concrete pours.

5. Setting time of quaternary binder increases at lower replacement of MK. Initial and final setting time decreases with the higher amount of MK in quaternary binder. The silica fume and metakaolin are highly reactive, and small size of particles speeds up the reaction with calcium hydroxide.
6. The quantity of finer material added within the binder increases the amount of water demand. The quaternary systems have a 10–30% increased water demand when compared to OPC alone as the binder.

7. Based on the compressive strength results of binders and mortars, the production of Portland cement – with (50% OPC + 30% FA + 10% SF + 10% GGBS/MK) or (50% OPC + 20% FA + 15% SF + 15% GGBS/MK) can be considered as suitable options for the commercial production of quaternary blend binders.

8. Reduction impermeability of 1:3–1:6 mortars can be achieved by using the quaternary binder systems which is strongly supported by the RCPT results. The compressive strengths of these mortars achieved at 7 days of age ranging from 20 to 30 MPa, which is acceptable for various applications.

9. The compressive strength of quaternary concrete increases with the addition of pozzolanic materials and the improvement of strength indicates that the pozzolans are more effective with low water/binder ratio. The quaternary concrete with G3 [50% OPC + 30% FA + 10% SF + 10% GGBS] and M3 [50% OPC + 30% FA + 10% SF + 10% MK] have shown the best results in terms of a good compressive strength.

10. In all cases, the flexural strength and tensile strength of quaternary concrete have shown acceptable results. The optimum G3 [50% OPC + 30% FA + 10% SF + 10% GGBS] and M3 [50% OPC + 30% FA + 10% SF + 10% MK] have shown 10% and 25% higher flexural strength as compare to control mix and around 11.2% and 11.9% higher tensile strength than control mix at the age of 365 days.

11. UPV test on all the combinations have shown good to excellent velocity, which indicate that the utilization of supplementary cementitious materials, such as, FA, SF, GGBS and MK makes concrete structure denser and helpful in increasing its resistance against moisture content penetration. Maximum UPV values were recorded for G3 [50% OPC + 30% FA + 10% SF + 10% GGBS] and M3 [50% OPC + 30% FA + 10% SF + 10% MK].

12. With increase in percentage of supplementary cementitious materials as well as age, chloride permeability in concrete, decreases due to the higher surface area of the cementitious material used in the binder. This leads to higher density of
the concrete as indicated in the microstructure. Concrete prepared with quaternary G3 [50% OPC + 30% FA + 10% SF + 10% GGBS] and M3 [50% OPC + 30% FA + 10% SF + 10% MK] have shown 96.64% and 97.35% lower charge in comparison to 100% OPC at the age of 365 days.

13. All quaternary concretes showed excellent durability to sulfate attack than plain concrete. After 365 days, maximum sulfate expansion values of 0.48% (365 days) in plain concrete and 0.12% (in binary concrete) to 0.03% in quaternary concrete were obtained. This indicates that quaternary concrete is more durable as compare to normal concrete.

14. Smaller particle size and higher specific surface area of supplementary cementitious materials are favorable to produce highly dense and impermeable concrete; however, they cause low workability and more water demand which may be offset by adding effective super plasticizer.

15. Quaternary concrete could be the best substitute of OPC concretes. It’s utilization in construction may help in reducing the burden on natural raw materials used in OPC and promote the utilization of waste materials in construction.

16. Based on the cost analysis these binders are very economic. If these types of combinations are used in RMC plant then construction cost can be reduced manifold.
6.3 SIGNIFICANCE OF THE PRESENT WORK

- Most of the SCMs used in the present study are industrial by-products, i.e., Fly Ash, GGBS, SF, MK and LP. This research work clearly demonstrates the effective utilization of these industrial by-products in the civil engineering construction and help in saving the environment due to their unsafe disposal. It will also help in reducing the use of conventional materials that are facing acute shortage due to restrictions by the law enforcing agencies on their quarry.

- The developed quaternary concrete could be the best substitute of OPC concretes. It’s utilization in construction may help in reducing the burden on natural raw materials used in OPC and will reduce our dependence on OPC and promote the utilization of waste materials in construction.
6.4 FUTURE SCOPE

The utilization of Supplementary cementitious materials in the construction industry has increased tremendously. There is a lot of potential for usage of FA, GGBS, MK, SF and LP in concrete. However, the characterization of blending quaternary cement is not much established due to lack of systematic study and limited availability of data. The following suggestions are made for exploring effective utilization of quaternary blended cement in construction industry:

- The quaternary blended cement performs well in strength and durability factors, which is evidenced in the microstructure also.
- The addition of various types of fibers in the quaternary mix is expected to increase the tensile and flexural strength of the specimens. The study has a wide scope for future investigation.
- Further investigations have to be carried out regarding cracking, creep, temperature development and deformation.
- The use of the SCMs in road works and bridge approaches could be investigated further, as it has a high potential due to huge consumption.
- Furthermore, an investigation on the pore structure of the quaternary mix, other properties that affect durability such as gas permeability, freeze-thaw resistance, etc. and a study correlating the ponding tests with RCPT results for the quaternary mix may be another avenue to explore.