CHAPTER 8 SUMMARY CONCLUSIONS AND SCOPE FOR THE FUTURE STUDY

8.1 GENERAL

The aim of this study was to evaluate the potential of utilizing FA, MS, and GGBS as supplementary cementitious materials along with SP in the construction industry. To investigate the effects of these pozzolanic materials, the research was divided into four sections, namely the impact on binding material properties and mortar mechanical properties, SP dosage optimization through the marsh cone test, influence on mechanical and durability properties of concrete, and CS prediction through machine learning.

Although the findings of each chapter have been separately integrated, this chapter presents an overview of the conclusions drawn from the entire investigation. Furthermore, based on the results obtained, suggestions and future research directions have been identified that could further enhance the properties of concrete admixed with FA, MS, GGBS and SP

Overall, the study found that the use of these supplementary cementitious materials improved the properties of the binding material and enhanced the mechanical characteristics of mortar and concrete. In addition, the durability properties of concrete were improved, making it more resistant to permeability, carbonation, corrosion and other forms of deterioration.

8.2 SUMMARY AND CONCLUSION

1.) Compared to the control sample, 10% MS sample shows a 1% increase in consistency, the 30% FA sample shows a 2% increase in consistency, and 50% GGBS sample shows the highest increase in consistency at 3%.

The use of mineral admixtures such as FA and GGBS can significantly increase the initial and final setting times of concrete. Micro silica, on the other hand, has a moderate increase in initial setting time and a small increase in final setting time.

2.) The initial setting time of S-II/MS is 38.1% higher than S-I/C, while that of S-III/FA and S-IV/GGBS is 71.4% and 95.2% higher, respectively. Similarly, the final setting time of S-II/MS is 7.1% higher than S-I/C, while that of S-III/FA and S-IV/GGBS is 21.4% and 14.3% higher, respectively.

3.) Based on the experimental results, it can be concluded that S-I/C has the highest compressive strength of mortar among all types of concrete tested at 3 days of testing. S-II/MS has a highest compressive strength at 7 days and 28 days of testing. S-III/FA and S-IV/GGBS have lower compressive strengths than S-I/C and S-II/MS at all ages, which can be attributed to their pozzolanic properties, leading to slower reaction rates and lower early strength development.

4.) Flow time of cement paste without any mineral admixtures were compared with cement paste containing MS, FA and GGBS. Flow time of cement paste was contemplated to increase significantly by adding mineral admixtures as cement replacement. From the experimental investigation, it was observed that saturation level of SP is inversely proportional to the w/b ratio. The type of mineral admixture used and their properties as well as the shape of cementitious grain has influence in altering the saturation level and efficiency of SP.

5.) Based on the test results, three conclusions can be drawn regarding the mechanical properties of concrete.

Firstly, it can be observed that as the water-cement ratio increases, the compressive strength, splitting tensile strength, and flexural strength of the concrete decrease across all sample types. For example, the compressive strength of the control concrete (C40) decreases by 40.48% from 35.97 MPa at 0.4 w/b ratio to 21.41 MPa at 0.55 w/b ratio after 7 days. The same trend can be observed for other samples such as SC40, SCF40, SCB40, and SCM40. The STS of CB40 is also 8.6% lower than that of C40 at 90 days.

Secondly, the addition of different mineral admixtures to the concrete mixture affects its compressive strength, splitting tensile strength, and flexural strength. For instance, the compressive strength of C40 is higher than CF40 and CB40 at 0.4 w/b ratio after 7 and 28 days, while micro silica admixed concrete has greater compressive strength than the control concrete. Furthermore, the addition of SP increases the compressive strength, with the maximum compressive strength observed in the SCM40 sample. Similarly, the FS of CM40 concrete mix is 10.5% higher than that of C40.

Thirdly, the combination of mineral admixture and SP affects the compressive strength, splitting tensile strength, and flexural strength of the concrete. For instance, the compressive strength of SCF45 is higher than that of SC45 and CF45 at all ages at 0.45 w/b ratio. The use of SP and mineral admixture also increases the FS and STS at all curing ages compared to the control concrete, suggesting that the combination of superplasticizer and mineral admixture improves the mechanical properties of the concrete.

Overall, micro silica admixed concrete shows the highest mechanical strength across all curing ages, while GGBS admixed concrete shows the least mechanical strength.

6.) The results of permeability tests conducted on different concrete mixtures with varying w/b ratios and ages showed that an increase in w/b ratio led to an increase in the permeability of concrete. The effect was consistent across different groups of concrete, such as C, CF, CB, CM, SC, SCF, SCB, and SCM. The addition of mineral admixtures, such as fly ash, ground granulated blast furnace slag, and micro silica, to concrete also affected its permeability. At 28 days, the FA and GGBS admixed concrete showed higher permeability than the control concrete, while the CM group exhibited lower permeability than the control concrete.

Further the addition of superplasticizer (SP) to concrete can effectively reduce its permeability compared to without SP concrete mix. For instance, coefficient of permeability of Superplasticizer admixed control concrete (SC40, SC45, SC50, and SC55) reduced approximately 38% as compare to the without SP admixed concrete control concrete (C40, C45, C50, and C55).

The addition of mineral admixtures and superplasticizers significantly reduced the water permeability of concrete compared to the control concrete without SP (C40, C45, C50, and C55). At all w/b ratios and testing periods, the SCM group consistently exhibited the lowest permeability coefficient, followed by the SCF and SCB groups. The use of mineral admixtures and superplasticizers can improve the durability of concrete by reducing its water permeability.

7.) From the experimental results, it can conclude that the use of Accelerated Carbonation Curing (ACC) can significantly increase the compressive strength of concrete. The percentage increase in compressive strength due to ACC varies depending on the mix and water to binder ratio (w/b) of the concrete. In general, the CB group shows the highest increase in compressive strength, followed by CF and SCB groups. The C and CM groups show moderate improvement in strength, while the SC and SCM groups show a relatively low increase in strength.

The w/b ratio has a significant impact on the carbonation depth of concrete. As the w/b ratio increases, the concrete becomes more permeable to CO2, leading to a deeper carbonation depth. This trend is observed across various concrete mix, including C40 to C55, CF40 to CF55, CB40 to CB55, CM40 to CM55, SC40 to SC55, SCF40 to SCF55, and SCM40 to SCM55. Therefore, it is important to consider the w/b ratio in the design of durable concrete structures to ensure their long-term performance and resistance to carbonation.

The addition of mineral admixtures can significantly affect the carbonation resistance of concrete. The addition of FA and GGBS generally reduced the carbonation resistance, while the addition of MS improved the carbonation resistance.

The addition of superplasticizers (SPs) to concrete improves its carbonation resistance by reducing the water-to-cement ratio, minimizing entrained air voids, and enhancing the microstructure of the concrete. This improvement is evident across all types of mineral admixtures used in the study. The reduced carbonation depth in the SP-containing concrete specimens, compared to the without SP concrete specimen, indicates a significant increase in carbonation resistance, ranging from 12.41% to 35.56% reduction in carbonation depth depending on the water-to-binder ratio. Therefore, the use of SPs in concrete can lead to enhanced durability properties, including carbonation resistance, which is crucial for long-term infrastructure sustainability.

The addition of mineral admixtures and SP can significantly improve the carbonation resistance of concrete. The use of SCM showed the highest improvement in carbonation resistance compared to SCF and SCB. The combination of SCM and SP can have a synergistic effect on carbonation resistance, creating a denser and more impermeable microstructure, reducing the number of voids in the concrete, and further reducing the carbonation rate. In addition to chemical and physical changes, microstructural changes may also contribute to improved carbonation resistance. The improved durability of concrete in carbonating environments can lead to longer service life and reduced maintenance costs for concrete structures.

8.) The addition of mineral admixtures and superplasticizers resulted in a significant reduction in the mass loss of concrete subjected to acid attack. The use of 30% FA and SP (SCF), 50% GGBS and SP (SCB), and 10% MS and SP (SCM) led to reduced mass loss by 20.65-25.28%, 26-28.17%, and 23.63-27.16%, respectively, compared to the control mixture (C) at various w/b ratios. Therefore, it can be concluded that the combined use of mineral admixtures and superplasticizers can improve the acid resistance of concrete.

The use of SP with mineral admixture resulted in lower strength loss due to acid attack compared to the control mixture without any additives at all w/b ratios tested. Among the mineral admixtures tested, SCF showed the highest strength loss reduction at all w/b ratios, followed by SCB and SCM. The results suggest that the combination of SP and mineral admixture can be an effective strategy to mitigate the strength loss of concrete under acid attack

The use of SP in combination with mineral admixtures resulted in lower corrosion rates in concrete due to acid attack compared to control concrete without any additives. At all w/b ratios tested, the inhibition efficiency of SCF, SCB, and SCM was higher than that of the control mixture. The highest inhibition efficiency was observed in SCB, followed by SCM and SCF. Overall, the results indicate that the combined use of mineral admixtures and SP can improve the durability of concrete against acid attack and reduce the corrosion rate of steel reinforcement.

9.) . eXtreme Gradient Boosting (XGBoost) algorithm optimized with Genetic Algorithm (GA) was utilized for developing an efficient model. The R value obtained for GA-

XGBOPC and GA-XGBPPC models in training (TR) and testing (TS) dataset are almost $\geq$ 0.90. Mean Absolute Error (MAE) and Root Mean Square Error (RMSE) value obtained for GA-XGBOPC model were 2.155 and 2.923, respectively. Similarly, for GA-XGBPPC model were 1.815 and 2.888, respectively. The developed models were found to predict more than 90% observation within ±20% variations. The level-1 and level-2 validation results certify the GA-XGBOPC and GA-XGBPPC models' generalizability. Ultimately, a user-friendly labor less and financially feasible computer software or tool was generated in python for assistance to the field and design engineers in estimating the CS of concrete.

8.3 RECOMMENDATIONS

Based on the findings of the current investigation, the following recommendations are being made to maximize the positive impacts of FA, GGBS, MS, and SP without compromising the structural integrity:

1.) Careful selection of mix proportions: The optimal mix proportion of FA, GGBS, MS, and SP should be carefully selected to ensure that the desired strength and durability are achieved without adversely affecting the structural integrity.

2.) The combined use of mineral admixture and SP is highly advisable as it not only reduces the consumption of binding material but also minimizes the carbon footprint, resulting in better sustainability. Moreover, this combination results in enhanced strength and durability of the structure, making it a highly cost-effective and eco-friendly option.

3.) The use of GGBS and SP in combination is recommended, particularly in situations where the concrete structure may be exposed to acidic environments. This combination has been found to improve the durability and resistance of the concrete while also reducing the risk of chemical degradation.

4.) The combined use of MS and SP is advisable to enhance the resistance of concrete against carbonation or in carbonation exposure.

5.) For residential purposes with mild exposure conditions, the use of FA and SP is advisable. This approach is not only beneficial to the sustainable environment but also helps to reduce the cost of construction.

6.) The developed user interface tool was found considerably suitable for the future convenience of the site engineers in predicting the 28-days CS of concrete

8.4 SCOPE FOR THE FUTURE STUDIES

Following are the suggestions for the future research that are important to further reinforce the idea of FA, GGBS, and MS as a supplementary cementitious material:

1.) In addition to the experiments performed in this study, tests for analyzing the freezing and thawing properties of concrete, as well as its abrasion and temperature resistance, when admixed with FA, GGBS, MS, and SP, may be conducted

2.) To assess the effectiveness of the synergistic effect of mineral admixtures and SP, a double durability parameter may be performed. For instance, the first test could involve subjecting the concrete to carbonation, followed by testing for water permeability. Another test could involve acid resistance followed by permeability testing, or high temperature exposure followed by carbonation, permeability, or acid attack testing.

3.) Performing a cost analysis can help contractors better understand the potential impact on project costs when using mineral admixtures along with SP in concrete. By analyzing the cost of materials, labor, and equipment needed for the project, a comprehensive cost estimate can be created. Additionally, the cost analysis can also take into account any potential savings that may result from using mineral admixtures and SP, such as improved concrete durability and reduced maintenance costs over time. Ultimately, a thorough cost analysis can provide valuable insights that can help contractors make informed decisions about which concrete mix design to use for their projects.

4.) To better understand the potential synergistic effects of SP and mineral admixtures in concrete, an embodied energy and carbon analysis may be performed.

5.) Enhancing the workability and pumpability of self-consolidating concrete through the combined use of mineral admixtures and SP. This topic could involve investigating the effects of different combinations and dosages of mineral admixtures and SP on the rheological properties of self-consolidating concrete, including its viscosity, yield stress, and plastic viscosity. The goal would be to identify the optimal combination and dosage of these materials to achieve a highly workable and pumpable self-consolidating concrete mix.

6.) Evaluating the influence of SP and mineral admixtures on the drying shrinkage and creep behavior of concrete for improved durability. This topic could involve conducting experimental studies to investigate the impact of mineral admixtures and SP on the shrinkage and creep behavior of concrete over time. The aim would be to identify the optimal combination and dosage of these materials to reduce the potential for cracking and improve the long-term durability of the concrete.