CHAPTER-9

CONCLUSIONS AND RECOMMENDATIONS

9.1 GENERAL

This chapter presents the conclusions from the results of the tests conducted for ascertaining the effect of neutral salts, strong alkaline salts, slightly acidic salts and strong acids present in mixing and curing water on the workability and strength properties of the three types of HPCs and also on the initial setting time and final setting time of cement blended with metakaolin and phosphogypsum. The safe limits for the various chemicals are also recommended based on the analysis of experimental results.

9.2 CONCLUSIONS

The following conclusions can be drawn based on the results obtained in the present investigation.

- The control mixes are HPC with only OPC, HPC with phosphogypsum and HPC with metakaolin. It is observed that both the setting times got retarded with the addition of phosphogypsum and metakaolin. It is observed that the compressive and split tensile strengths are more for HPC with metakaolin when compared with other two HPCs. And also it is observed that the strengths of HPC with only OPC are less when compared with other two HPCs. The XRD and SEM results show that the formation of Calcium silicate hydrate (C-S-H gel) and Portlandite in all the three HPCs. But the intensities of C-S-H gel and Portlandite differ in all the three HPCs. The intensity of C-S-H gel is more and the intensity of Portlandite is less for HPC with metakaolin when compared with other two
HPCs. This may be the cause for the higher strengths of HPC with metakaolin to be high.

- NaCl present in the deionised water accelerates initial and final setting times significantly when the concentrations are 10 g/L, 20 g/L and 30 g/L respectively. Workability has increased with the increase in concentration of NaCl. And also workability is more for HPC with metakaolin when compared to other two HPCs. Further, there is significant increase in compressive and split tensile strengths at 10 g/L, 20 g/L and 30 g/L concentrations respectively. From the results of XRD and SEM tests the formation of Albite compound is identified, which may be responsible for the above changes.

- KCl present in the deionised water retards both the setting times significantly from 2 g/L concentration of KCl. Workability has increased with the increase in concentrations of KCl. The significant increase in compressive and split tensile strengths of all the three HPCs is observed from 5 g/L at 7 days, 28 days and 90 days respectively. From the results of XRD and SEM tests the formation of Merlinoite compound is identified, which may be responsible for the above changes.

- Na$_2$SO$_4$ present in the deionised water retards both the initial setting time significantly from 6 g/L concentration. The final setting times are retarded significantly from 4 g/L concentration respectively. Workability has decreased with increase in concentration of Na$_2$SO$_4$. But workability is more for HPC with metakaolino when compared to other two HPCs. Significant decrease in the compressive and split tensile strengths is observed at 10 g/L and 20 g/L concentrations respectively at 7, 28 and 90 days respectively for all the three
HPCs. From the results of XRD and SEM tests the formation of Anorthite compound is identified, which may be responsible for the above changes.

• CaCO\textsubscript{3} present in the deionised water retards both the setting times significantly from 0.2 g/L concentration. The presence of CaCO\textsubscript{3} in mixing water decreased the workability as the concentration increased. But workability is more for HPC with metakaolin when compared to other two HPCs. No significant change is observed in compressive and split tensile strengths of all the three HPCs. From the results of XRD and SEM tests the formation of Rapid Creekite is identified, which may be responsible for the above changes.

• Na\textsubscript{2}CO\textsubscript{3} present in the deionised water accelerated both the setting times significantly from 4 g/L concentration. Workability decreased with the increase in concentration of sodium carbonate. The results indicate that there is significant decrease in the both the strength of all HPC at 7, 28 and 90 days respectively at 10 g/L and 20 g/L concentrations respectively and the rate of decrease in compressive strength also gradually increases with the increase in the concentration of sodium carbonate. But overall strengths for HPC with metakaolin are higher when compared with the other two HPCs. From the results of XRD and SEM tests the formation of Wegscheiderite compound is identified, which may be responsible for the above changes.

• NaHCO\textsubscript{3} present in the deionised water retarded both the setting times significantly at 4 g/L, 10 g/L and 20 g/L concentrations respectively. Workability decreased with the increase in the concentration of sodium bi-carbonate. There is significant decrease in both the strengths of all the three HPCs with the increase of the concentration of sodium bi-carbonate. And also here it is observed that the compressive strength and split tensile strength are higher for HPC with
metakaolin when compared with HPC with OPC and HPC with phosphogypsum. There is significant decrease in compressive and split tensile strengths from 10 g/L and 20 g/L concentrations at 7, 28 and 90 days respectively. From the results of XRD and SEM tests the formation of Kanemite compound is identified, which may be responsible for the above changes.

- CaCl$_2$ present in the deionised water retarded both the setting times significantly at 1 g/L and 2 g/L concentrations. Workability increased as the concentration of calcium chloride increased. The results indicate significant increase in the both the strengths of all the three HPCs at 1 g/L and 2 g/L concentrations respectively. But HPC with metakaolin has higher strengths when compared to other two HPCs. From the results of XRD and SEM tests the formation of Gismondine compound is identified which may be responsible for the above changes.

- MgSO$_4$ present in the deionised water accelerated both the setting times significantly at 1 g/L and 1.5 g/L concentrations. Workability decreased with the increase in concentration of magnesium sulphate. No significant change is observed at 7 days, whereas at 28 days and 90 days, significant change is observed at 1.5 g/l concentrations of MgSO$_4$ in the case of all the three HPCs. But the strengths of HPC with metakaolin are higher when compared with other two HPCs. From the results of XRD and SEM tests the formation of Sepiolite compound is identified which may be responsible for the above changes.

- HCl present in the deionised water retarded both the setting times significantly at 400 mg/L and 800 mg/L concentrations. Workability decreased with the increase in concentration of HCl. It is observed that there is significant decrease in both the strengths of all the three HPCs from 100 mg/l concentration of HCl at 7 days, 28 days and 90 days respectively. From the results of XRD and SEM tests the
formation of Jennite compound is identified which may be responsible for the above changes.

- $\text{H}_2\text{SO}_4$ present in the deionised water retarded both the setting times significantly at 400 mg/L and 800 mg/L concentrations. Workability decreased with the increase in concentration of $\text{H}_2\text{SO}_4$ in mixing water. It is observed that significant decrease in both the strengths is observed from 100 mg/l concentration of $\text{H}_2\text{SO}_4$ for all the three HPCs at 7, 28 and 90 days respectively. From results of XRD and SEM tests the formation of Thaumasite compound is identified which may be responsible for the above changes.

- From the above conclusions it can be concluded that NaCl, KCl and CaCl$_2$ affect positively, where as other salts affect negatively.

- By comparing all the three HPCs it is observed that compressive and split tensile strengths are more for HPC with Metakaolin. And also the strengths of HPC with phosphogypsum are high when compared with HPC with OPC.

- The addition of phosphogypsum and metakaolin has reduced the negative effect and increased the positive effect on the properties of HPC.

### 9.3 Safe Limits for Various Chemicals

- The presence of NaCl up to 30 g/L in mixing and curing water is safe for concreting works with HPC produced with OPC, OPC + 20% phosphogypsum and OPC + 20% metakaolin.

- The presence of KCl up to 5 g/L in mixing and curing water is safe for concreting works with HPC with OPC, HPC with phosphogypsum and HPC with metakaolin.
- The presence of $\text{Na}_2\text{SO}_4$ up to 10 g/L in mixing and curing water is safe for concreting works with HPC with OPC, HPC with phosphogypsum and HPC with metakaolin. Though workability decreases with increase in $\text{Na}_2\text{SO}_4$ concentration up to 10 g/L, the minimum value observed is 0.90 which is sufficient workability for all normal concrete works.

- The presence of $\text{CaCO}_3$ up to 0.3 g/L in mixing and curing water is safe for concreting works with HPC with OPC, HPC with phosphogypsum and HPC with metakaolin.

- The presence of $\text{Na}_2\text{CO}_3$ up to 10 g/L in mixing and curing water is safe for concreting works with HPC with OPC, HPC with phosphogypsum and HPC with metakaolin. Though workability decreases with increase in $\text{Na}_2\text{CO}_3$ concentration up to 10 g/L, the minimum value observed is 0.88 which is sufficient workability for all normal concrete works.

- The presence of $\text{NaHCO}_3$ up to 10 g/L in mixing and curing water is safe for concreting works with HPC with OPC, HPC with phosphogypsum and HPC with metakaolin. Though workability decreases with increase in $\text{NaHCO}_3$ concentration up to 10 g/L, the minimum value observed is 0.89 which is sufficient workability for all normal concrete works.

- The presence of $\text{CaCl}_2$ up to 2 g/L in mixing and curing water is safe for concreting works with HPC with OPC, HPC with phosphogypsum and HPC with metakaolin.

- The presence of $\text{MgSO}_4$ up to 1.5 g/L in mixing and curing water is safe for concreting works with HPC with OPC, HPC with phosphogypsum and HPC with metakaolin. Though workability decreases with increase in $\text{MgSO}_4$ concentration
up to 1.5 g/L, the minimum value observed is 0.87 which is sufficient workability for all normal concrete works.

- The presence of HCl up to 100 mg/L in mixing and curing water is safe for concreting works with HPC with OPC, HPC with phosphogypsum and HPC with metakaolin. Though workability decreases with increase in HCl concentration up to 100 mg/L, the minimum value observed is 0.92 which is sufficient workability for all normal concrete works.

- The presence of H₂SO₄ up to 50 mg/L in mixing and curing water is safe for concreting works with HPC with OPC, HPC with phosphogypsum and HPC with metakaolin. Though significant decrease in strengths are observed at 100 mg/L; 50 mg/L is recommended keeping workability consideration in mind.

**9.4 SCOPE FOR FUTURE WORK**

The following aspects can be taken up for further investigation:

- In the present work investigations have been carried out to assess the effect of various chemicals on setting times, workability and strength properties of High-Performance-Concrete. However there is need to conduct durability studies so that the safe limits for various chemicals can be worked out.

- In the present work phosphogypsum and metakaolin have been used as admixtures. Further studies can be carried out by using mineral admixtures such as silica fume, rice husk ash, ground granulated blast furnace slag etc. The possible chemical reactions for these admixtures may be standardized.

- In the present work High-Performance-Concretes have been produced without using any fibre reinforcement. Long-term studies may be carried out to assess the
effect of various chemicals in water on High-Performance-Concretes produced with different types of fibres.

- The effect of various compounds present in water on the corrosion of reinforced cement concrete can be investigated in order to formulate the standards and limitations for the use of mixing water in construction.

- Studies may be carried out to explore the possibility of using treated effluents of various industries for preparing High-Performance-Concrete.