CHAPTER 5

CONCLUSIONS

5.1 GENERAL

The present study investigated the application of copper slag as a substitute for fine aggregate in High Strength Concrete. The mechanical properties, durability related properties and structural behaviour in reinforced concrete under flexural, shear and repeated loadings were studied.

5.2 MECHANICAL PROPERTIES OF CSHSC

1. The fineness modulus (FM) of fine aggregate consists of CS and sand, for all combinations found above 3, which ensured the highly workable mixture at very low w/b ratio.

2. As the percentage of copper slag increases, the workability of concrete increased well and found no segregation.

3. Visual examination of the failure plane of tested specimen showed that the most of the aggregates were cracked with bursting noise particularly when copper slag percentage was increased.

4. The strength of HSC was not affected by the addition of CS. For every increment of CS, there is increase in strength. The increase in compressive strength of concrete with various CS content is more than the control mix, for all ages of testing, hence delay in strength gaining was not observed.
5. The ratio between split tensile and compressive strength is lower than the medium strength concrete, which indicates that the higher the value of compressive strength, lower the value of tensile strength.

6. CSHSC shows better modulus of rupture value than the control concrete. The addition of copper slag invariably improves the tensile strength and it is more than the permissible values in accordance with the design specifications.

7. From the cylinder compressive test results, the $Ec$ obtained for mixes with 10% to 100% of copper slag has not affected the $Ec$ value of CSHSC.

8. The bond strength arrived from pull-out test on M40 grade trial mixes exhibits about 50% of improvement over the control concrete, 60% and 70% by M60 and M80, respectively, which reflects that the bond strength improves with the increase of cube compressive strength of concrete.

9. From ultrasonic pulse velocity test results, the M40 grade CSHSC concrete is superior to the concrete without copper slag. But in higher grades, i.e., in M60 and M80 grades of CSHSC, all the trial mixes are found to be excellent.

5.3 DURABILITY CHARACTERISTICS

1. The density of all three grades was increased due to higher specific gravity of copper slag.

2. In the permeability test conducted on the M40, M60 and M80 grades of HSC containing no copper slag, the depth of penetration was apparently high when compared with the
CSHSC of all replacement levels. Under the designated test pressure no percolation was observed.

3. Water absorption test results show that the addition of CS leads to refinement of pore structures due to the presence of finer particle sizes.

4. The porosity value in the present study could be considered to be reasonable and it proves the superior durability characteristics of the copper slag concrete mixes.

5. From the impact test results, it is observed that the impact resistance of the CSHSC mixes containing copper slag is more than that of HSC mixes without copper slag.

5.4 FLEXURAL BEHAVIOUR OF CSHSC BEAMS

1. M40 grade CSHSC beams showed the same first crack load and load at yield for all CSHSC beams. The load at control deflection increased with percentage of CS replacement. For 100% CS replacement, the load at control deflection was increased by 45%. Load at failure of 0 & 25% of CS replacement found same, but 50, 75 and 100% CS replacement was 10% more than 0 and 25% of CS replacement. The deflection ductility of all combinations is above 2. However, 100% replacement of CS was 13% less than the control beam. The deflection at ultimate load reduced with increase in content of CS. The energy ductility ratio was found to be less in case of increase in copper slag content. The curvature ductility of the beams was found to be increased with increase in CS content.

2. M60 grade CSHSC beams were showed the same first crack load and load at yield for all CSHSC beams. The load at control deflection was found to be increased with percentage of
CS replacement. For 100% CS replacement, the load at control deflection was found decreased by 4.8%. Load at failure of 50, 75% CS replacement was 10% more than 0 and 25% of CS replacement and 100% replacement of CS increased by 20%. The deflection ductility of all combinations is above 1.3. However, 100% replacement of CS was found the same like control beam. The deflection at ultimate load was found almost the same, with increase in strength, the energy ductility ratio was found to be more with increase in copper slag content. The curvature ductility of the beams was found to be increased with increase in CS content.

3. M80 grade CSHSC beams showed the same first crack load but 10% more than M40 & M60 and also load at yield for 100% CS replacement found 10% higher than the other combinations of CS. The load at control deflection was found to be decreased by 14.6% with 100% of CS replacement, however no appreciable change in the other replacement. For 100% CS replacement, the load at control deflection was found increased by 4%. Load at failure of 50, 75 and 100% CS replacement was 10% more than other replacement level. The deflection ductility of all combinations is above 2. However, 100% replacement of CS was found 18% more than the control beam. The deflection at ultimate load was found almost same. With increase in strength, the energy ductility ratio was found to be more with increase in copper slag content. The curvature ductility of the beams was found to be increased with increase in CS content.
5.5 SHEAR BEHAVIOUR CSHSC BEAMS

1. M40 grade CSHSC, the yield and ultimate load carried by control beam and 25% CS are the same and behaved in a similar manner, but the reduction in load level is 10% of yield and ultimate load for 50 and 75% CS. It further reduced to 20% in case of 100% CS. It is important to note that though the capacity at ultimate load level decline, the service load level has found not changed. The loads at control deflection for all CSHSC beams are above the control beam. The energy ductility of CSHSC beams under shear is increased by 4%, 11%, 56% and 84% in case of M1S25, M1S50, M1S75 and M1S100, respectively, when compared with M1S0. The curvature ductility of M40 grade CSHSC beams under shear are increased by 32%, 57%, 71% and 76%, respectively, in case of 25, 50, 75 and 100% CS, respectively, when compared with control beam.

2. In case of M60 grade CSHSC beams, the yield and ultimate load carried by 0, 25 and 50% CS are the same and behaved in a similar manner, but 75 and 100% CS, the improvement in load level is 10% for yield load and in case of ultimate load, 0, 25 and 50% CS carried 196.2 kN, 75 and 100% CS carried 10% more than the other beams. In case of 75 and 100% CS, the increase in yield load significantly reveals the improvement in the tensile strength of CSHSC beams at higher grades. The energy ductility of CSHSC beams under shear is decreased by 15% in case of M2S25, and M2S50, but increased by 10% and 18% in case of M2S75 and M2S100, respectively, when compared with M1S0. The curvature ductility of CSHSC
beams under shear are decreased by 10% in case of 25% CS but increased by 18%, 15%, and 11%, respectively in case of 50, 75 and 100% CS, when compared with control beam.

3. In case of M80 grade CSHSC beams, the stiffness was not lost with increase in copper slag content. Deflection ductility of the beams is the same in case of M3S25, slightly reduced (9%) in case of M3S50, but 30% and 16% more in case of M3S75 and M3S100 respectively. The deflection ductility of M2S25 and M2S50 is 6% and 14% less than the control concrete but for M2S75 and M2S100 it is 5% and 17% more than at the ultimate load of control concrete. The yield and ultimate load carried by 0, 25, 50 and 75% CS are the same and behaved in a similar manner, but for 100% CS the improvement in load level is 10% for yield and ultimate load. The energy ductility of M80 grade CSHSC beams under shear is almost the same in case of M3S25, M3S50, and M3S75 and 4% less in case of M3S100, when compared with M3S0. In case of M80 grade CSHSC beams the curvature ductility of CSHSC beams under shear is increased by 4%, 21%, 39%, and 44%, respectively, in case of 25, 50, 75 and 100% CS, when compared with control concrete.

4. The number of cracks decreased with increase in grade of concrete and with increase in percentage of copper slag content. However, no significant difference in pattern was noticed between the control concrete and concrete with copper slag. Failures of beams of all three grades were not associated with a loss of cover concrete.
5.6 EFFECT OF COPPER SLAG ON CSHSC BEAMS UNDER REPEATED LOADING

From the experiment results it is clear that the stiffness of beam increases with increase in copper slag content. It again proves that the increase in compressive strength of concrete results in improved flexural behaviour and energy absorption of copper slag replaced beams than the control beams.

In case of M40 grade CSHSC beams, M1C0, M1C25 and M1C50 failed at 196.2 kN, but resulted in reduced deflection at the same load. However, M1C75 and M1C100 carried 10% more than the other beams and resulted in almost the same deflection with 3% difference. It has been well demonstrated by this experiment that the CSHSC beams are capable of carrying more load and their energy absorption level is 18% more in case of M1C100, when compared with the control beam of same grade, i.e., M1C0.

In case of M60 grade CSHSC, M2C0 and M2C25 failed at 196.2 kN, but resulted in reduced deflection at the same load. However, M2C50, M2C75 and M2C100 carried 10% more than the other beams and resulted in reduced deflection of 20% and 9%, respectively, less compared with M2C50. When compared with the load carried by CSHSC under monotonic loading, the M2C0 carried the same load at ultimate level but reduced deflection in case of repeated loading.

In case of M80 grade CSHSC, M3C0, M3C25 and M3C50 failed at 196.2 kN, but resulted in reduced deflection at the same load. However, M3C75 and M3C100 carried 10% more than the other beams and resulted in increased deflection of 4% more than M3C75. When compared with the load carried by CSHSC under monotonic loading, the M3C0 and M3C25 carried 10% less than the load at ultimate level under repeated loading condition. The
M3C50 beams carried 20% less than the load carried by the beams under monotonic loading. M3C75 and M3C100 carried 10% less load under repeated loading, when compared with the same beam under monotonic loading.

5.7 RESEARCH CONTRIBUTION

The durability of copper slag high strength concrete under normal environment found improved when compared with control concrete.

Copper Slag which threatens the environment, has found a suitable way of safe disposal by its application in modern concrete

Sustainability of construction industry amidst the depleting natural resources is ensured, and this paving the way for green technology.

5.8 SCOPE FOR FUTURE WORK

Studies are to be made for still higher grades of concrete

The micro structure studies of CSHSC may also be taken for further investigation.

The HSC studied in this research can further be investigated for bond strength with ribbed bar, carbonation resistance, long-term behaviour such as creep and shrinkage, effect of addition of fibres, application of pre-stressing techniques.

Investigation can be made on the mechanical and durability-related properties of HSC mixer containing blended cements and these results can be compared with those of a blend of OPC and mineral admixtures.