MECHANICAL PROPERTIES AND MICROSTRUCTURAL ANALYSIS OF COPPER SLAG IN CONCRETE

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Abstract

In this research results showed that the partial replacement of copper slag had enhanced the properties of concrete. The partially replaced concrete was having good workable condition rather than without super plasticizer. Later, with increase in percentage of copper slag the slump value decreased. It was observed that the addition of copper slag slightly increases the compressive strength copper slag concrete than conventional one and the maximum compressive strength of concrete when 40% of copper slag added the maximum compressive strength obtained is 37.51Mpa The addition of copper slag will slightly increase the tensile strength of concrete. The maximum strength of concrete achieved when 40% of copper slag the maximum tensile strength obtained is 3.8Mpa. Toughness of concrete also increases by the addition of copper slag. After the addition of copper slag will increases the flexural strength of concrete. The maximum strength of concrete achieved when 40% of copper slag added then the flexural strength is 4.3Mpa. As the percentage of copper slag is increased by more than 40%, there will be decrease in workability is observed. When the percentage of copper slag is added between 0%-40% there will be increase in workability but it was observed that reduction in workability when addition of copper slag exceeds more than 40%. Slag concrete retains a denser, more cohesive structure with fewer cracks and refined pores. *The pozzolanic activity of copper slag contributes to additional binding phases and better matrix cohesion*. *Overall, 40% copper slag replacement improves thermal resistance, structural stability, and durability compared to conventional concrete.*

Key words: Copper Slag, Mechanical Properties, Partial Replacement, XRD, SEM

1. INTRODUCTION

The ease with which structural concrete elements can be formed into a variety of shapes and sizes has been a reason for its success. It is usually the cheapest and most readily available material on the job. Their strong point is maintenance, concrete does not corode, needs any surface treatment, and its strength increases with time; therefore, concrete structures requires essentially no maintenance. The fire resistance of concrete is perhaps the most important single aspect of offshore safety and, at the same time, the area in which the advantages of concrete are most evident. In most codes of practice, the allowable concrete stresses are limited to about 50 percent of the ultimate strength; thus, the fatigue strength of concrete is generally not a problem. This is due not only to the wide range of applications that concrete offers, but also its great strength, affordability, durability, and versatility. Concrete is the only major building material that can be delivered to the job site in a plastic state. This unique quality makes concrete desirable as a building material because it can be moulded to virtually any form or shape. Concrete is also designed to permit reliable and high quality fast-track construction. Structures built with concrete are more durable and can be engineered to withstand earthquakes, hurricane, typhoons and tornadoes. With growing population, industrialization, urbanization and globalization there will be a corresponding growth in the worlds demand for clean water, clean air, waste disposal, safe and rapid transport of people and goods, residential and industrial buildings, and sources of energy. It is not surprising, therefore, that the concrete industry today is the largest consumer of natural resources, such as water, sand, gravel, and crushed rock.

The technical feasibility of industrial by-products such as copper slag and ferrous slag to replace the fine aggregate in concrete by evaluating the workability, strength and durability characteristics of concrete. The test results indicate that the strength properties are not affected by 40% or 100% replacement of quarry sand with iron slag or copper slag. However, 40% replacement of quarry sand with iron slag or copper slag in concrete is recommended considering the durability aspects of concrete. The objective of this study is to evaluate the technical feasibility of using materials such as copper slag and ferrous slag to replace manufactured sand fine aggregates in concrete. The workability, strength and durability of concrete made with copper slag fine aggregates and ferrous slag fine aggregates are evaluated in this paper. It was reported that there was no significant effect on the strength of concrete whereas the durability was found to be similar to or better than the control mix in some cases. The mixes for M40 grade with copper slag replacement were designated as M40 CS40 and M40 CS100 with 40% and 100% replacement of fine aggregate respectively. The first term in the designation denotes the grade of concrete, the second term denotes the material used for replacement and the percentage of fine aggregate replaced. The current Indian standard code IS: 383 (2016) allows fine aggregate replacement of up to 15% using ferrous slag and up to 35% using copper slag for RCC construction. The results of this study show that up to 40% fine aggregates in concrete can be safely replaced with copper slag or ferrous slag. Replacement of up to 40% by weight of fine aggregate in concrete can be recommended in moderate exposure conditions.

An investigation is carried out for M-40 grade of concrete mixes with partial replacement of Fine Aggregate (Sand) by Copper Slag in proportions of 0%, 10%, 20%, 30%, 40% and 50%. Compressive Strength, Split Tensile Strength and Flexural Strength at the ages of 28 days for various combinations of Copper Slag and Sand were investigated The main aim of this study is to find the strength and durability properties of concrete in which fine aggregate replaced with Copper slag partially by 10%, 20%, 30%, 40%. They concluded that the addition of copper slag in concrete increases the density of the concrete. The results of compressive tests show that the strength of the concrete increases with respect to the percentage of copper slag added by weight of fine aggregate up to 30% of replacement of copper slag strength was found to be 45.42 N/mm2 for a design mix 1: 1.4: 2.6 keeping w/c ratio as 0.4.For M30 grade concrete, the highest compressive strength was achieved at 7days by 50% replacement of copper slag is39.105Mpa and the maximum compressive strength was achieved at 28days by 10% replacement of copper slag and which was found about 44.66MPa, compared with nominal mix (29.87N/mm2 and 41.65N/mm2) and for M40 grade concrete, the maximum compressive strength was achieved at 7days by 20% replacement of copper slag is 44.44MPa and the highest compressive strength was achieved at 28days by 50% replacement of copper slag and which was found about 53.105MPa, compared with nominal mix (32.33N/mm2 and 47.11N/mm2).The maximum strength was achieved for 40 % replacement of fine aggregate with copper slag Further addition of copper slag reduces the strength.

Here the fine aggregate partially replaced by copper slag (CS) in 20%,30%,40% and 50%by weight of sand. Mix design was prepared for M30 grade of concrete. The strength has been increased by 46% by replacement of 40%fine aggregate with C S. As copper slag increases, the water absorption in concrete decreases. By replacement of copper slag as fine aggregate we can reduce the digging of river sand which affects the hydraulic structures such as piers, bridges etc. In this study mix design of M30 is prepared as per IS: 10262(2009) and proportion is 1:1.5:2.5 having water-cement ratio of 0.45 ratio. According to IS: 456-2000 [11] the minimum water cement ratio is 0.45. Five different mix proportions are prepared i.e., 0%, 20%, 30%, 40%, and 50% as partial replacement of fine aggregate. The workability of the concrete increases with the increase in replacement of CS with water cement ratio. Replacement of CS in fine aggregate reduces the cost of making concrete. The strength has been increased by 40% replacement of CS.

Using copper slag as a partial replacement to fine aggregates in concrete, in which cubes were casted for various grades of concrete and for various proportions of sand replacement with copper slag ranging from 20% to 50%. Obtained results on different parameters like strength, workability and density were compared with those of control concrete made with ordinary Portland cement and sand. Aggregates considered as one of the main constituent of concrete and occupy more than 70% of concrete mix. As so much fight is going on for obtaining Fine aggregates we have to find different alternative to this. Copper slag used as a partial or full substitute for fine aggregates were prepared in order to investigate the effect of Copper slag substitution on the strength normal concrete. Concrete mixtures were prepared with different proportions of Copper slag. Proportions (by weight) of Copper slag added to concrete mixtures were as follows: 0% (for the control mix), 20%, 25%, 30%, 35%, 40%, 45% and 50%. The control mixture was designed to have a target 28 day compressive strength of 20N/mm^2(M- 20) and 30 N/mm2 (M-30), using a water cement ratio of 0.55 and 0.45. For lower grade of concrete for 30% replacement of sand results into 35% more dense concrete. This percentage lowers down up to 32% in case of higher grade of concrete, From the observations and results obtained 40% replacement of copper slag gives highest strength in lower grade of concrete. Further increase in percentage of replacement copper slag reduces strength in lower as well as higher grade of concrete.

2. MATERIALS

3.1 MATERIALS USED IN CONCRETE

There are many types of concrete available, created by varying the proportions of the main ingredients below. In this way or by substitution for the cementitious and aggregate phases, the finished product can be tailored to its application with varying strength, density, or chemical properties.

2.1 Cement

In this project work 33, grades Ordinary Portland Cement are used. The tests of cement are conducted to the properties of cement as per IS 12269-1987. Density of cement =1400Kg/M^3

Fig: 2.1Cement

2.2 Fine aggregate

Aggregate is the granular material used to produce concrete or mortar and when the particles of the granular material are so fine that they pass through a 4.75mm sieve, it is called fine aggregate the used in this study is river sand. It passing through IS sieves of size 4.75mm.Density of fine aggregate = 1650kg/m^3

Fig: 2.2 Fine Aggregate

2.3Coarse aggregate

Gravels constitute the majority of coarse aggregate used in concrete with crushed stone making up most of the remainder Locally available crushed granite coarse aggregate are used in this study, having the maximum size of 20mm. Density of course aggregate20mm size=2350kg/m^3

Fig: 2.3 Coarse Aggregate

2.4 Copper slag

Copper slag is the material which is considered as a waste material, which can have a bright future in construction industry as partial replacement of either fine aggregates. It is a by- product obtained during the matte smelting and refining of copper. The safe disposal of this waste is a lack, costly and causes environmental pollution. The construction industry is the only area where the safe use of waste material (copper slag) is possible. When it is introduced in concrete as a replacement material, it reduces the environmental pollution, space problem and also reduces the cost of concrete. In production of every ton of copper, approximately 2.2–3.0 tons' copper slag is generated as a by-product material. Currently, about 2600 tons of Copper slag is produced per day and a total accumulation of around 1.5 million tons. If we are able to use the copper slag in place of natural sand then we can successively obtain a material to replace the sand, which is eco-friendly and cost effective. Density of copper slag 2.31 g/cc

Fig: 2.4 Copper Slag

Table: 2.1 Physical Properties of Copper Slag

Physical properties	**Copper slag**
Appearance	Black glassy granules
Colour	Black
Grain shape	Granular
ph	6.6 – 7.2
Water soluble chloride content	11 PPM
Specific gravity	3.5 – 3.8
Bulk density	1.9 gm/cc
Hardness	6 – 7 MOH

Table: 2.2. Chemical Properties of Copper Slag

Sio_2	33.05
Al_2O_3	2.79
Fe_2O_3	53.45
Ca O	6.06
Mg O	1.56
SO_3	1.89
K_2O	0.61
Na_2O_3	0.28
TiO_2	0
Mn_2O_3	0.06
CI	0.01
Loss of ignition	0
IR	0

2.5 Water

Water is then mixed with this dry composite, which produces a semi-liquid that workers can shape (typically by pouring it into a form). The concrete solidifies and hardens to rock-hard strength through a chemical process called hydration. The water reacts with the cement, which bonds the other components together, creating a robust stone-like material. The good quality water is used in this study.

3. METHODOLOGY

The methodology explains about the step by step procedure that is going to be done in the project.

Table 3.1 Number of Specimens in triplicate for Different % Replacements

SL NO	DESCRIPTION	NO OF CUBES	NO OF BEAMS	NO OF CYCLINDER
1	30% replacement of fine aggregate with copper slag	3	3	3
2	40% replacement of fine aggregate with copper slag	3	3	3
3	50% replacement of fine aggregate with copper slag	3	3	3
	TOTAL	9	9	9

- The study includes casting of 3 cubes, 3 beams and 3 cylinders for comparing mechanical of concrete with % replacement of copper slag as fine aggregate.
- Workability was checked using slump cone test to study ease of mixing, placing, compacting and transporting.
- To know the compressive strength of cubes, flexural strength using beams and split tensile strength of concrete specimens using cylinders were tested and noted concordant values.

Finally, the fresh and hardened properties were compared with normal concrete for analysing the maximum increase in properties such specimens

3.1TEST DATA FOR MATERIALS

- Cement used - OPC
- Specific gravity of cement - 3.12
- Specific gravity of Course aggregate - 2.72
- Fine aggregate - 2.63

3.2 SIEVE ANALYSIS

- Coarse aggregate - Confirming to Table-2 of IS 383
- Fine aggregate - Confirming to Grading Zone 2 of Table-4 of IS 383

3.3 TRIAL MIX PROPORTIONS

The following table shows the trial mixes for 0%, 30%, 40%and 50% copper slag addition

Table 3.2 Trial mixes proportions of 0%, 30%, 40%and 50% copper slag addition

%age of copper slag addition	Moulds	Number of moulds	Cement (Kg)	Fine aggregate (Kg)	Coarse aggregate (Kg)	Copper slag (kg)	Water (liters)
0%	Cube	3	5.37	8.162	10.74	-	2.148
	Cylinder	3	8.43	12.81	16.86	-	3.372
	Beam	3	7.95	12.09	15.9	-	3.18
30%	Cube	3	5.37	5.712	10.74	2.45	2.148
	Cylinder	3	8.43	8.967	16.86	3.843	3.372
	Beam	3	7.95	8.463	15.9	3.627	3.18
40%	Cube	3	5.37	4.896	10.74	3.264	2.148
	Cylinder	3	8.43	7.686	16.86	5.124	3.372
	Beam	3	7.95	7.254	15.9	4.836	3.18
50%	Cube	3	5.37	4.08	10.74	4.08	2.148
	Cylinder	3	8.43	6.405	16.86	6.405	3.372
	Beam	3	7.95	6.045	15.9	6.045	3.18

4. TEST RESULTS AND DISCUSSIONS

4.1 Slump Test Results

From the Fig. 4.1, the slump value for the conventional concrete is 90 mm, with the addition of copper slag of 30%, 40% and 50% correspondingly slump values are 90, 95 and 87mm respectively. For 50% addition of copper slag there is reduction in slump value to 87 mm, due of the increase in the specific surface area of the copper slag results in increase in the water absorption. Hence there is decrease in the workability.

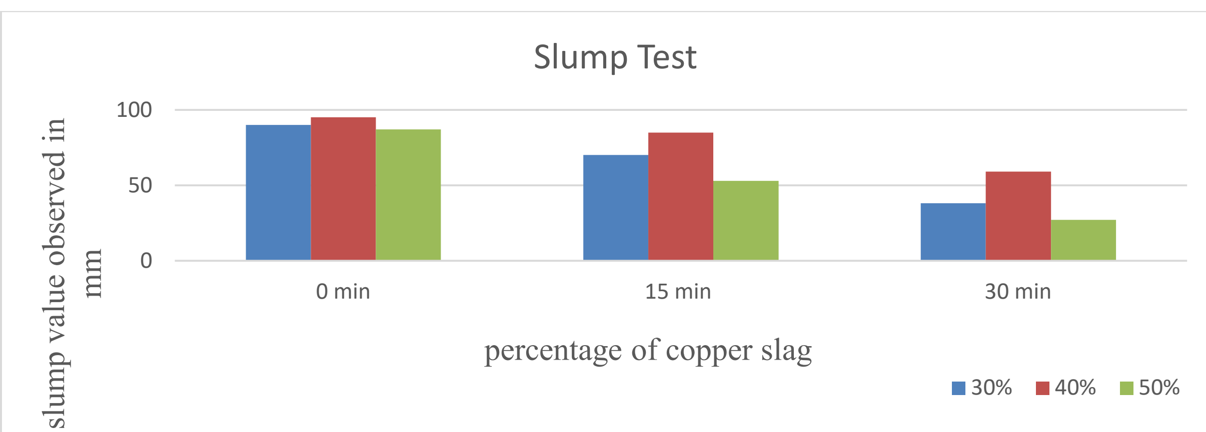

Fig. 4.1 Slump Value for 30%, 40%, 50% of Copper Slag Replaced

4.2 Compressive Strength Test Results of Elevated Temperatures After 28 Day Cured Specimen

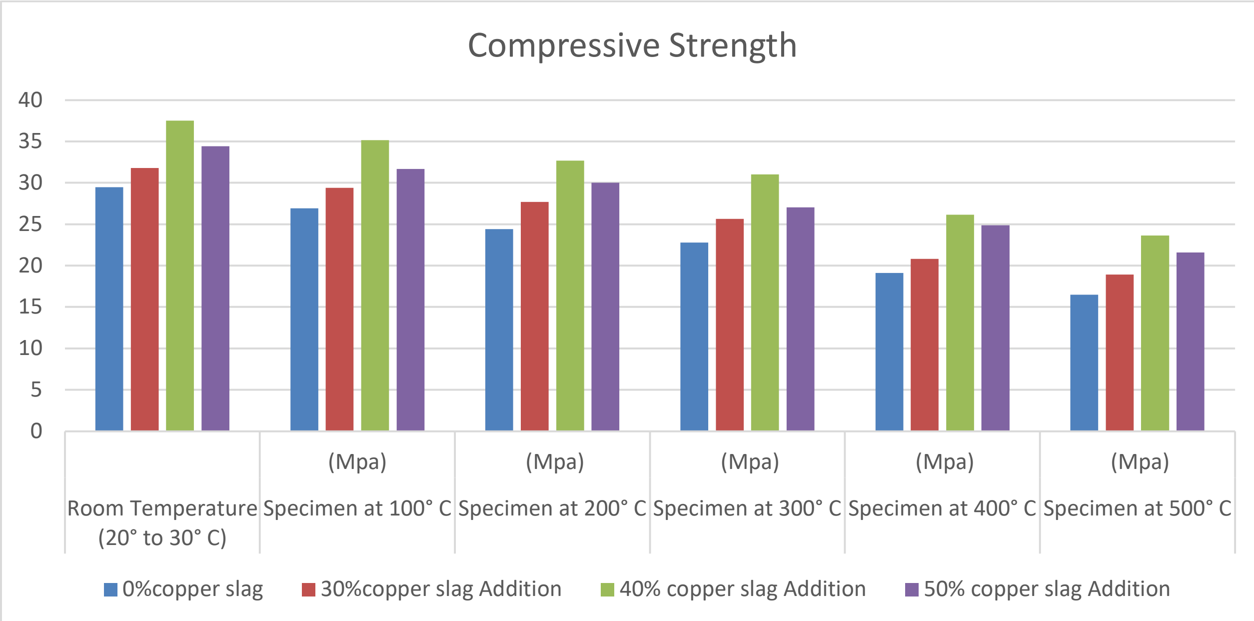

Fig. 4.2 Compressive Strength Test Results

At the end of 28th day Compressive Strength Results obtained from Fig. 4.2 it can be observed that the tensile strength of the concrete increased with increase in copper slag volume up to 40% and declined with the increase in % replacement and temperature.

4.3 Split Tensile Strength Test Results of Elevated Temperatures After 28 Day Cured Specimen

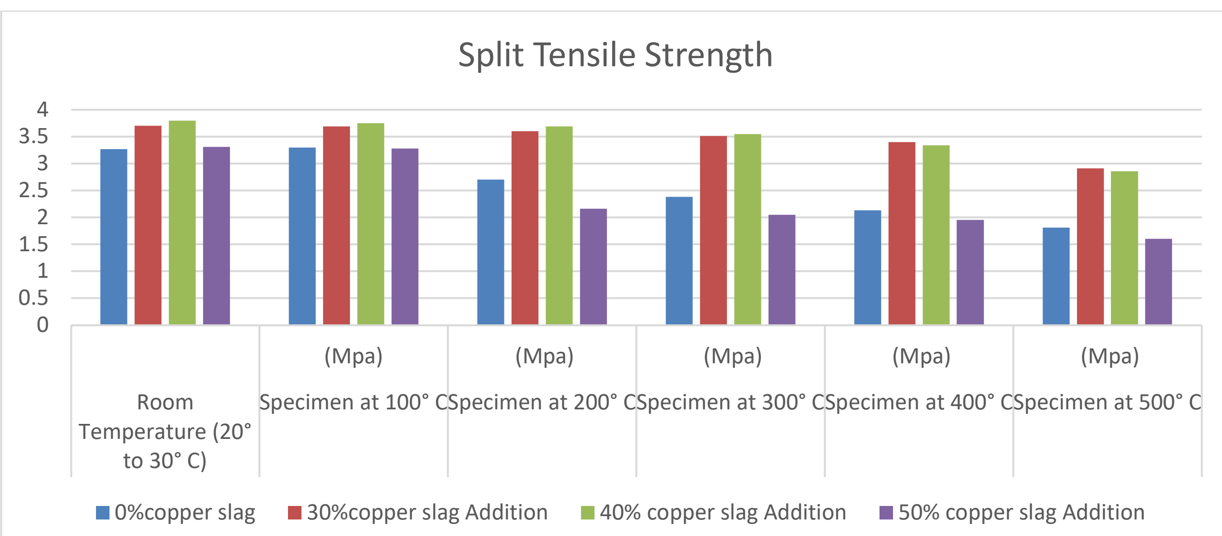

Fig. 4.3 Split Tensile Test Results

At the end of 28th day Tensile Strength Results obtained from Fig. 4.3 it can be observed that the tensile strength of the concrete increased with increase in copper slag volume up to 40% and

declined with the increase in % replacement and temperature.

4.4 Flexural Strength Test Results of Elevated Temperatures After 28 Day Cured Specimen

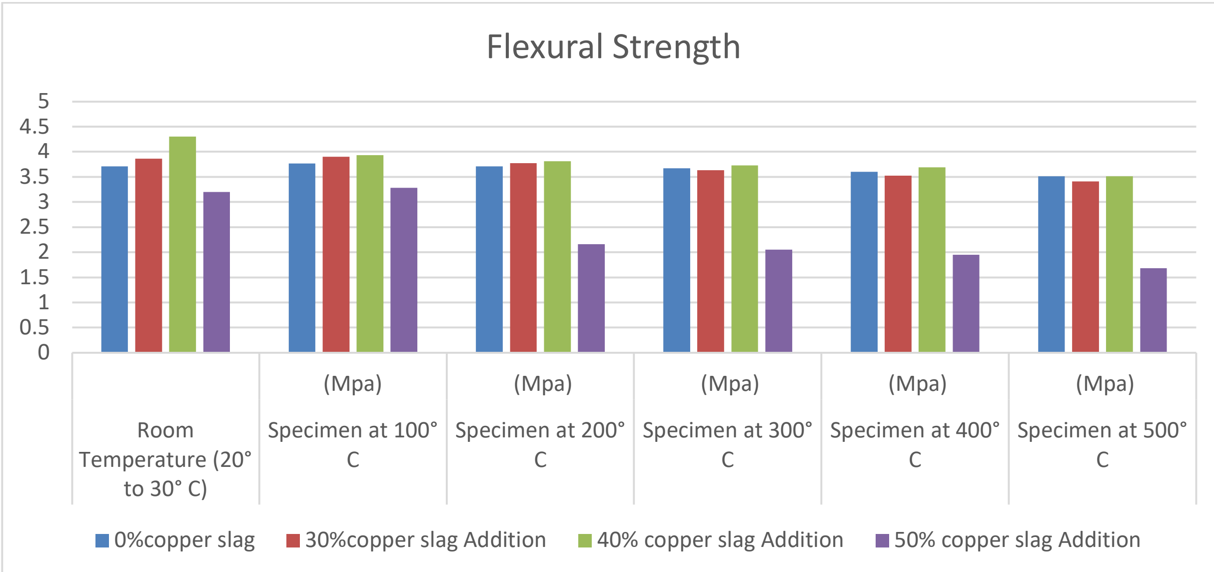

Fig. 4.4 Flexural Strength Test Results

At the end of 28th day Flexural Strength Results obtained from Fig. 4.4 it can be observed that the tensile strength of the concrete increased with increase in copper slag volume up to 40% and declined with the increase in % replacement and temperature.

4.5 XRD of CM and 40% Replaced Copper Slag at 400⁰C

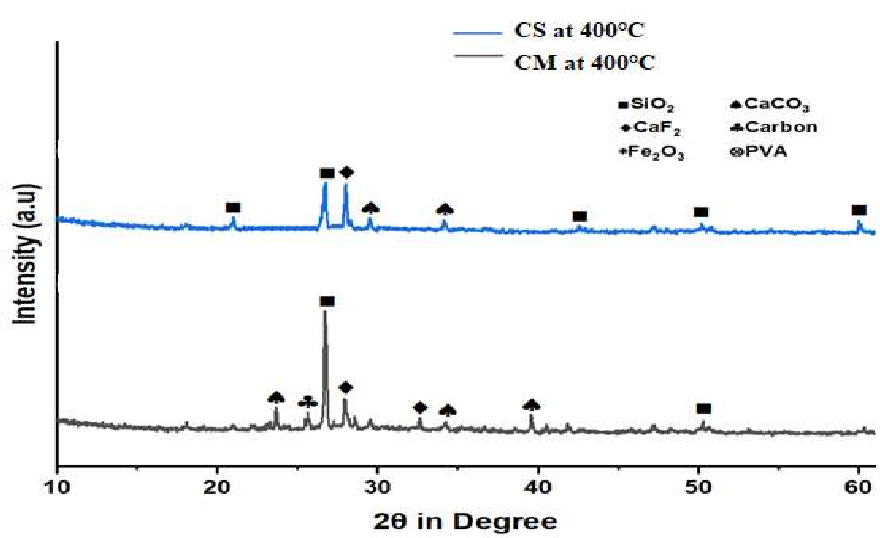

Figure 4.5: XRD of CM and 40% Replaced Copper Slag at 400⁰C

The X-ray diffraction (XRD) analysis of conventional concrete (CM) and concrete containing 40% copper slag replacement, both subjected to a temperature of 400°C, reveals notable differences in their phase compositions and thermal stability. The XRD patterns, observed over a 2θ range of 10° to 65°, indicate the presence of key crystalline phases including silica (SiO_2), iron oxide (Fe_2O_3), calcium carbonate ($CaCO_3$), and calcium fluoride (CaF_2). Silica peaks are evident in both samples, with the copper slag mix displaying sharper and more intense peaks, particularly between 27° and 30°, reflecting the higher crystalline silica content contributed by the copper slag. Iron oxide phases remain prominent in the slag-containing concrete, with distinct peaks around 24° to 28° and near 36°, while these are barely detectable or absent in the conventional concrete.

Calcium carbonate peaks, which appear near 29.5°, show a marked reduction in intensity at 400°C for both samples, indicating partial thermal decomposition. However, the conventional mix still exhibits slightly higher $CaCO_3$ peak intensity, suggesting a greater amount of residual calcium carbonate compared to the slag mix. Calcium fluoride peaks are observed in both concretes but are more noticeable in the copper slag blend, likely due to minor impurities from the slag material. Carbon-related signals, which had been observed at lower temperatures especially in the conventional mix, are almost completely absent at 400°C in both samples, demonstrating extensive thermal degradation of organic compounds.

4.6 SEM of CM and 40% Replaced Copper Slag at 400^0C

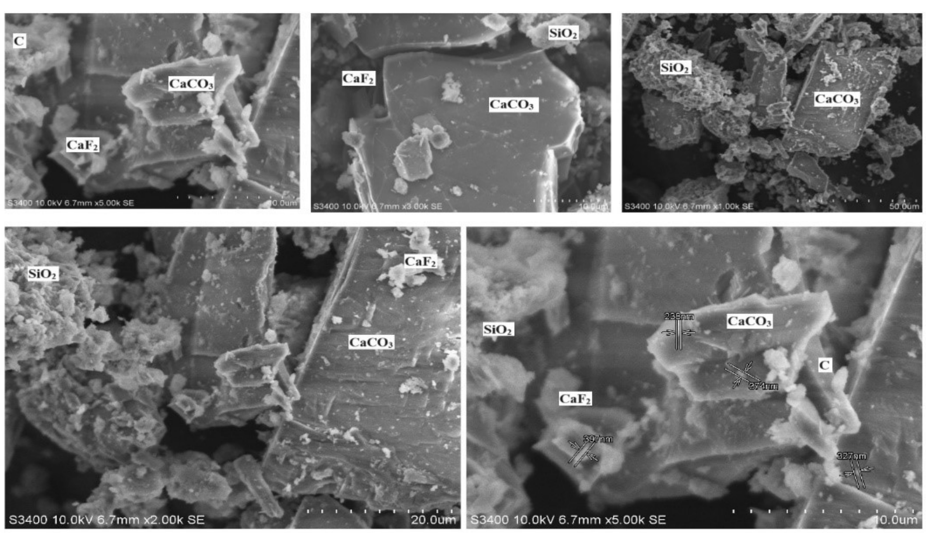

Figure 4.6 (A) : SEM image of CM at 400^0C

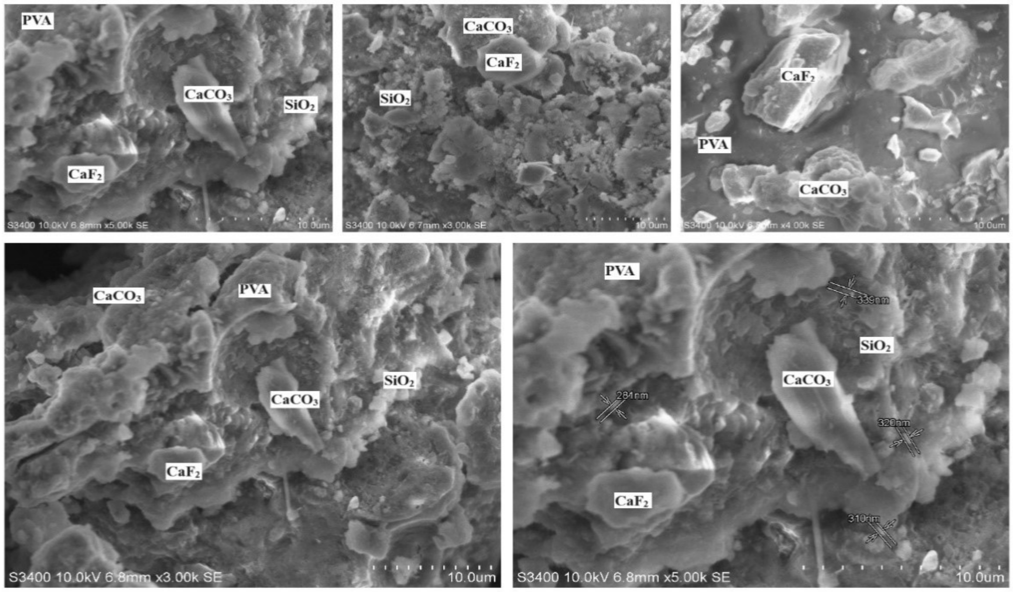

Figure 4.6 (B) : SEM image of 40% Replaced Copper Slag at 400^0C

The scanning electron microscopy (SEM) analysis of conventional concrete (CM) and concrete containing 40% copper slag replacement after exposure to 400°C reveals significant differences in their microstructural condition. At this elevated temperature, the CM sample exhibits extensive microstructural damage, including widespread micro-cracking, increased porosity, and evident deterioration of the cementitious matrix. The thermal exposure causes further dehydration of calcium silicate hydrates and other hydration products, leading to loss of cohesion between the cement paste and aggregates. These microstructural changes reduce the overall integrity and durability of the conventional concrete, making it more susceptible to mechanical failure.

On the other hand, the concrete with 40% copper slag replacement demonstrates a comparatively denser and more stable microstructure despite the thermal exposure at 400°C. The copper slag particles effectively fill voids and refine the pore structure, which limits the propagation of micro-cracks. The slag's pozzolanic reaction continues to contribute to the formation of additional binding phases, helping to maintain the matrix cohesion and structural integrity. As a result, the slag-modified concrete shows better resistance to thermal damage, with fewer and less severe micro-cracks and less porosity compared to the conventional mix.

5 CONCLUSIONS

Based on the test results, it is analysed and the following conclusions were made:

- It shows that the partially replaced concrete was having good workable condition rather than without super plasticizer. Later, with increase in percentage of copper slag the slump value decreased.
- It was observed that the addition of copper slag slightly increases the compressive strength copper slag concrete than conventional one and the maximum compressive strength of concrete when 40% of copper slag added the maximum compressive strength obtained is 37.51Mpa The addition of copper slag will slightly increase the tensile strength of concrete.
- The maximum strength of concrete achieved when 40% of copper slag the maximum tensile strength obtained is 3.8Mpa. Toughness of concrete also increases by the addition of copper slag
- Addition of copper slag will increases the flexural strength of concrete. The maximum strength of concrete achieved when 40% of copper slag added then the flexural strength is 4.3Mpa
- As the percentage of copper slag is increased by more than 40%, there will be decrease in workability is observed.
- When the percentage of copper slag is added between 0%-40%there will be increase in workability but it was observed that reduction in workability when addition of copper slag exceeds more than 40%.
- Lastly, the addition of 40% copper slag in concrete is found to be optimum as well as effective and economical as it gives good compression, tensile, and flexural strength for the concrete.
- At 400 °C, copper slag concrete shows stronger silica and iron oxide peaks than conventional concrete, indicating higher crystalline stability.
- Calcium carbonate decomposition is more pronounced in slag mix, leaving less residual $CaCO_3$ compared to CM.
- Calcium fluoride phases are more evident in slag concrete due to slag impurities.
- SEM shows conventional concrete suffers severe micro-cracking, high porosity, and matrix deterioration at 400 °C.
- Slag concrete retains a denser, more cohesive structure with fewer cracks and refined pores.
- The pozzolanic activity of copper slag contributes to additional binding phases and better matrix cohesion**.**
- Overall, 40% copper slag replacement improves thermal resistance, structural stability, and durability compared to conventional concrete.

REFERENCES

1) Alinda Dey, Deepjyoti Dev, (2014), "Use of Copper Slag as Sustainable Aggregate" ASCE India Section Oct 17-18.

2) Alaa M. Rashad (2016) " A brief review on Blast Furnace Slag and Copper Slag as Fine aggregate in mortar and Concrete based on Portland Cement" Rev. Adv. Mater. Sci. 44(2016) 221-237

3) Amarnath M.R.,Kavin R.A. (2015) "A study on effective replacement of Fine aggregateusing Copper Slag" IJSTE Volume 1: 2349-784.

4) Naveed Shaikh, Pradeep P Tapkire, "A Partial Replacement of Fine Aggregate by Copper Slag In Concrete", IJEACS, Volume 5, Issue Dec-2016 NBNSCOE, Sholapur,Maharastra,India

5) "A Study on the Partial Replacement of Fine Aggregate with Copper Slag" by Observing the Compression, Split Tensile and Flexural Properties - V. Sushma ,Dr. T. Suresh Babu,K.V.Manikanta, M Anvesh Kumar,M Praveen Kumar - July – 2015 Visvodaya engineering collage Kavali

6) Binaya Patnaik, Srinivasa Rao (2015) "Strength and Durability Properties of Copper Slag admixed Concrete" IJRET, pp.2319-1163.

7) Chavan, R. R. and Kulkarni, D.B. (2014) "Performance of copper slag on strength properties as partial replace of fine aggregate in concrete mix design".International journal of advanced engineering research and studies, pp. 95- 98.

8) Job Thomas, Nassif N. Thaickavila and Mathews P. Abrahamb, (2014) "Copper or ferrous slag as substitutes for fine aggregates in concrete", IJRET, Cochin University of Science and Technology Kochi, Kerala,India

9) Abhinav Shyam1, Abdullah Anwar, Ahmad, (2017), "Experimental Study on the Behavior of Copper Slag as Partial Replacement of Fine Aggregate in Concrete" IJRASET Volume 5

10)Ch. Sai Bhavagna,G. Lalitha, (2017),"Experimental Study On Concrete (M30) By Partial Replacement Of Fine Aggregate With Copper Slag" IJCIET, Volume 8,issue

11) Gowshik.A, Jayaprakash.J (2015) "Use of Copper Slag as a replacement for Fine Aggregate in Concrete" ISSN 0973-4562 Vol.10 No.83.