

Properties of Concrete Partially Replaced with Copper Slag as Fine Aggregate and Ceramic Tile Waste as Coarse Aggregate

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Abstract

Background: The present study has investigated the properties of concrete with copper slag replacing fine aggregate and ceramic tile waste partially replacing coarse aggregate. **Methods:** Experimental mixes of concrete with copper slag replacing fine aggregate in 0%, 20%, 40% and 60% was casted and tested. Followed by casting and testing experimental concrete mixes by maintaining 40% of copper slag as fine aggregate while, coarse aggregate was replaced with ceramic tile waste at 10%, 20% and 30%. The specimens were tested for compressive, split tensile and flexural strength in the 7th, 14th and 28th day. The durability of the specimens was assessed by conducting Sorptivity and Rapid Chloride Penetration Test (RCPT) on 28th day. **Findings:** It was found that concrete with 40% Copper Slag content as fine aggregate and 10% Ceramic tile waste yielded best results both in strength and durability. **Application:** A Sustainable Concrete mix can be made by using copper slag and ceramic tile waste which could be used in beams, columns, slabs and other structural elements. Thus mitigating need for natural raw materials like river sand and gravel leading the path to “sustainability”.

Keywords: Copper Slag, Ceramic Tile Waste, Concrete, Partial Replacement

1. Introduction

Concrete an artificial composite material made cement/binder, aggregates (course and fine) and water. Concrete known for its versatility and wide application in infrastructure development. Though widely adopted the material has been notoriously known for its ever increasing carbon footprint. Studies say that Concrete industry contributes to about 5% of global CO₂ emissions. To give a better picture of the scenario for every one tons of cement produced 1 tons of CO₂ is generated and released to the atmosphere contributing to global warming¹. Along with this demand for raw material like river sand and gravel continues to increase it is estimated that the global needs of aggregate was around 25.9 to 29.6 billion tones for the year 2012². Being a non-renewable resource this puts in a huge crunch if not used judiciously. Attempts have been made to look for “greener” alternatives for

cement, sand and aggregate. Researchers have replaced cement with various binders like flyash, silica fume, rice husk ash, and saw dust. Additionally, fine aggregate has been replaced with copper slag, rubber crumb waste and steel slag. Al-Jabri et al., has studied the effect of copper slag as fine aggregate in high performance. Eight concrete mixes with copper slag content varying from 0 % to 100 % Also, coarse aggregate replaced with cockle shell, expanded polystyrene beads, ceramic tiles. The concrete mixes were investigated in terms of density, compressive, tensile, flexural strength and durability. They have suggested that 40% of replacement yielded best results in terms of strength and durability³. Matheswaran et al., investigated the possibility of copper slag as an alternative to fine aggregate in construction industry. They studies revealed that for plastering and flooring fine aggregate can be replaced upto 50% by copper slag and for brick and wall masonry upto 25% can be replaced⁴. Khanzadi and

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Behnood investigated the mechanical behavior of high strength concrete with copper slag as coarse aggregate. The test was carried out with water to cementitious ratio of 0.40, 0.35 and 0.30 along with limestone replacing cement in 0%, 6%, 10%. The compressive split tensile and rebound hammer values were computed on 28th day. It was revealed that compressive strength increased by 10-15% and split tensile increase by 10-18%⁵. Pacheco-Torgal and Jaalai investigated the compressive strength of concrete and durability of concrete with cement replaced with ceramic waste. The results indicate that though the initial strength gain was low the results are comparable to the control concrete⁶. Vanitha et al., studied the effect of waste plastics as coarse aggregate in concrete paver blocks. The waste plastics were added incremental with percentage of replacement varying from 0 to 10% and tested for compression on 7th, 14th and 28th day. It was concluded that best results were obtained with 4% and 2% in solid blocks and paver blocks respectively⁷. Though, all these investigations have yielded positive results. Researchers are yet to realize the possibility of replacing two components of concrete at the same time. This paper deals with the behavior of concrete when the constituents both fine and coarse aggregate are replaced by copper slag and ceramic tile waste respectively.

2. Experimental Program

2.1 Materials Used

The Copper slag was used as a partial replacement for sand and ceramic tiles used as replacement for coarse aggregate in concrete. The OPC 53 grade cement locally available cement confirming to IS-12269:2013⁸ was used for the used as this is the most commonly available cement in Chennai. River sand and gravel were used as fine aggregate and coarse aggregate. The physical properties of the raw materials are enlisted in Table 1. Figure 1 shows the particle size distribution of aggregates used. The water cement ratio was maintained at 0.4 for the entire investigation.

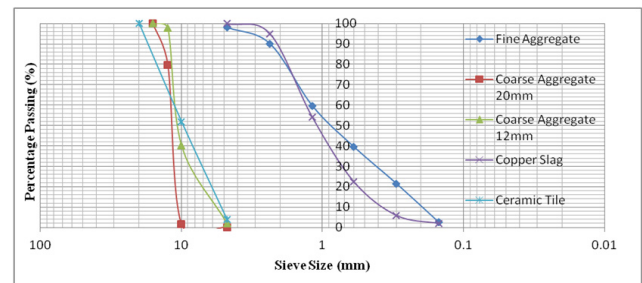


Figure 1. Particle size distribution of aggregates.

Table 1. Physical properties of materials used

Properties	Cement	Coarse Aggregate		Fine Aggregate	Copper Slag	Ceramic Tile Waste
		20 mm	12 mm			
Specific Gravity	3.157	2.71	2.68	2.5	3.56	2.71
Fineness Modulus	-	-	-	3.98	4.16	3.42
Water Absorption (%)	-	0.87	1.69	1.69	0.5	8.49
Surface Texture	Fine	Rough	Rough	Granular	Rough	Smooth
Bulk density	-	1612.67	1438	1736.67	2200	1612.63

Table 2. Mix proportioning of experimental mixes

Specimen Designation	Percentage of Replacement		Water Cement Ratio	Cement Content (kg/m³)	Water in Litres	Fine Aggregate (Kg/m³)	Copper Slag (Kg/m³)	Coarse Aggregate (Kg/m³)		Ceramic Tile Waste (Kg/m³)
	Copper Slag as F.A	Ceramic Tile Waste (C.W)						20 mm	10 mm	
M1	0	0	0.4	370	148	793.4	-	713.16	475.44	-
M2	20	0	0.4	370	148	634.72	158.68	713.16	475.44	-
M3	40	0	0.4	370	148	476.04	317.36	713.16	475.44	-
M4	60	0	0.4	370	148	317.36	476.04	713.16	475.44	-
M5	40	10	0.4	370	148	476.04	317.36	641.86	475.44	71.3
M6	40	20	0.4	370	148	476.04	317.36	570.53	475.44	142.63
M7	40	30	0.4	370	148	476.04	317.36	499.22	475.44	213.94

2.2 Mix Design

The Constituents of control concrete and concrete partially replacing fine aggregate with copper slag/coarse aggregate with ceramic tile are as shown in Table 2. The different mixes were labeled as M1, M2, M3, M4, M5, M6 and M7. The Control Mix (M1) was proportioned in accordance to IS 10262: 2009⁹ to have a characteristic compressive strength of 40 N/mm². The performance of the experimental mixes was compared with that of the control mix.

2.3 Specimen Preparation and Test Procedure

63 specimens of 15 x 15 x 15 cm³ were casted in accordance to IS 516-1959¹⁰ to assess the average compressive strength of the experimental mixes. The specimens were demoulded after 24 hrs and stored in water at 27°C until the day of testing. The compression test was conducted on 7th, 14th and 28th Day. A total of 21 specimens of 15 x 15 x 70 cm³ size were casted to estimate the flexural behavior. The test specimens were stored at 24°-30°C for 48 hours before testing and immediately tested while still in wet condition to determine its flexural strength on the 28th day. Also, 21 cylindrical specimens of 150 mm diameter and 300 mm depth were casted as per IS 5816: 1999¹¹ to investigate the split tensile strength on the 28th day. The durability of the concrete was estimated by Rapid Chloride Penetration and Sorptivity Test. The specimens, for Rapid Chloride Penetration were prepared by making samples of 50 mm thick and 100 mm diameter. The test is performed by keeping one end of the specimen in 3% Sodium Chloride Solution (NaCl) and other end in 0.3 M Sodium Hydroxide (NaOH) while maintaining a potential difference of 60 V DC forcing the chloride ions to penetrate the concrete for a duration of 6 hrs the amount of charge passed was noted every 30 min. The sorptivity test on the other hand was performed by making specimens of 200 mm height and 100 mm diameter. The specimens were cured in water for 28 days. Before testing the specimens were dried in oven at 110°C and placed in 5 mm high water level from the base of the specimens. The capillary action of the water from the side was prevented by sealing off with epoxy coating. The quantity of water absorbed was measured in 30 minutes by top hold weigh balance.

3. Results and Discussion

3.1 Strength Characteristics

3.1.1 Compressive Strength

The compressive test was conducted on the cubical specimens tested on a universal testing machine of 2000 kN capacity. The test was carried out on 7th, 14th and 28th day of curing. Out of entire experimental M1, M2, M3 and M4 which contained only Copper slag as fine aggregates replacement in 0, 20, 40 and 60%. On the 7th day of Testing best results were obtained in M3 of 31.52 N/mm² which was 5.91% higher than the Control Mix. On the 14th day the average compressive strength of M3 (40% copper slag) was obtained as 50.07 N/mm² compared to the control mix this was 18.50% higher. Finally, on the 28th day again M3 yielded a 58.53 N/mm² which was 18.93% higher than the control mix.

From the results obtained from the mixes M1, M2, M3 and M4. It was decided to continue investigation with Concrete's fine aggregate 40% replaced by Copper Slag and replace coarse aggregate in 10%, 20%, 30% by ceramic tile waste these mixes were labeled as M4, M5, M6 and M7. The Specimens M4-M7 was in 7th, 14th and 28th day. At 7 day M6 had strength of 31.67 N/mm² which was 5.4% higher than control mix. At 14th day M5 compressive strength was 51.2 N/mm² which was 21.18% higher than conventional concrete. At 28th day the M5 had 21.62% higher than conventional concrete. Table 3 shows the compressive strength results of the specimens casted. The Compressive test results of the specimens are plotted graphically in Figures 2 and 3.

Table 3. Experimental results

Specimen Designation	Average Compressive Strength (N/mm ²)			Flexural Strength (N/mm ²)	Split Tensile Strength (N/mm ²)
	7 Days	14 Days	28 Days	28 Days	28 Days
M1	29.76	42.25	49.2	8.5	4.97
M2	29.92	42.94	54.3	8.52	4.973
M3	31.52	50.07	58.53	8.58	4.98
M4	31.1	46.69	52.65	8.32	4.718
M5	29.36	51.2	59.84	8.45	4.93
M6	31.37	47.3	55.18	7.8	4.4
M7	27.99	46.75	50.09	7.61	4.34

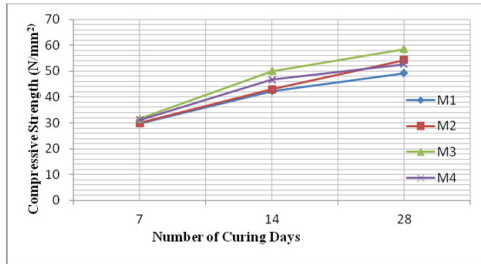


Figure 2. Compressive strength of concrete partially replacing fine aggregate with copper slag.

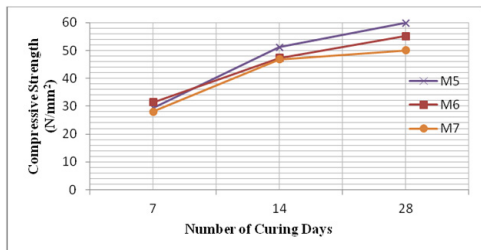


Figure 3. Compressive strength of 40% copper slag concrete and ceramic tile replacing coarse aggregate.

3.1.2 Flexural Strength

The flexural test was conducted on the experimental mixes which were molded into $15 \times 15 \times 70 \text{ cm}^3$ specimens and cured up to 28 days. The specimens were tested on the 28 day and compiled as shown in Table 3. The results show that in terms of flexural strength the performance was appreciable only case of M2 and M3 showed mildly superior performance of 0.8% higher than M1. Whereas the mixes M4, M5, M6 and M7 showed lower performance compared to control mix. The lowest being M7 being 10.47 % lower than the control mix. The results are graphically plotted in Figure 4.

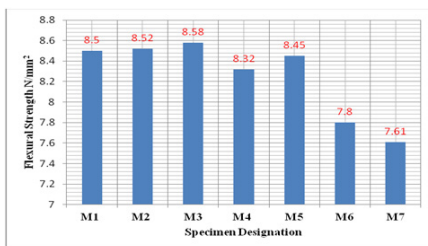


Figure 4. Flexural strength on 28th day.

3.1.3 Split Tensile Strength

The split tensile strength was conducted on 28th day the

results are as shown in Table 3. The results show that the performance of M5 on par with that of the control mix. The results are shown are graphically in Figure 5.

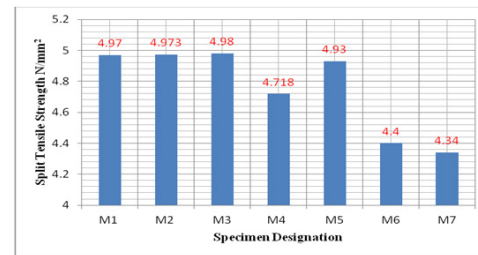


Figure 5. Split tensile strength on 28th day.

3.2 Durability Characteristics

3.2.1 Rapid Chloride Penetration Test

The test results should be understood that higher the charge coulomb passed higher is the chloride ion penetration thus lower is the durability of the specimens. The results as shown in Table 4 confirm that though all the specimens are within the Moderate Durability as per ASTM C 1202¹². The lowest charge passed was in case of M5 indicating highest durability.

Table 4. Rapid chloride penetration test on 28th day

Specimen Designation	Charge Passed Through In Coloumbs (C)	Chloride Permeability Results As Per ASTM C 1202
M1	3121.36	MODERATE
M2	3514.3	MODERATE
M3	2526.3	MODERATE
M4	3121.2	MODERATE
M5	1992.3	MODERATE
M6	3662.6	MODERATE
M7	2952.13	MODERATE

Table 5. Sorptivity test and absorption rate.

Specimen Designation	Sorptivity Value ($\times 10^{-6}$) mm/min ^{0.5}	Absorption Rate $I = S.t^{1/2}$ mm
M1	5.308	100.71
M2	5.569	105.66
M3	8.073	153.17
M4	9.759	185.16
M5	8.696	164.99
M6	9.00	170.76
M7	9.04	171.52

3.2.2 Sorptivity and Absorption Test

Sorptivity means the ingress of water through the effect of capillarity in concrete. High sorptivity indicates higher permeability of concrete. Table 5 shows M4 and M5 are the most permeable.

4. Conclusion

- In terms of Compressive Strength M5 (40% Copper Slag and 20% Ceramic Tile Waste) the initial strength gain at 7th day was marginally lower compared to control mix. But the 14th and 28th day strength was higher than control mix M1. All the experimental mixes satisfy the 28th day compressive strength expected from M40 grade of concrete.
- M3 (60% Copper Slag-0% Ceramic Tiles) and M5 (40% copper slag-10% Ceramic Tile) split tensile strength was closely similar to that of control mix.
- M3 (60% Copper Slag-0% Ceramic Tiles) had the highest flexural strength on the 28th day in the entire investigation. Closely behind was M2 (40% Copper Slag) and M5 (40% Copper Slag-20% Ceramic Tiles). The lower strength may be attributed to the presence of ceramic tiles wastes limited ability of interlocking behavior as shown by gravel.
- M5 (40% Copper Slag-0% Ceramic Tiles) had the highest chloride penetration indicating high durability.

5. References

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