Flexural Behavior of Concrete with Partial Replacement of Cement with Marble Powder and Fine Aggregate with Copper Slag

Seethal J Sasi, Aneena Babu

Abstract— To protect the depleting natural sand source and limit the use of cement it is essential to find an alternative solution for the preparation of concrete. Sustainability can be achieved only by using suitable techniques of substitution and waste management. Marble powder and copper slag are such materials which are the byproducts of manufacturing industries. These can be used either as a filler material in cement or fine aggregate. This work focuses on replacement of cement with marble powder and fine aggregate with copper slag in M30 grade concrete. Here marble powder is added at an increasing percentage of 5% by weight of cement and copper slag at 10% by weight of fine aggregate up to the optimum value. The concrete mixes were prepared, tested and compared in terms of compressive strength, split tensile strength, modulus of elasticity and modulus of rupture with the conventional concrete. The flexural strength is studied under two point loading and various properties are studied. The resultant in terms of load deflection graph and moment curvature relationship is also studied. The durability properties of the concrete replaced with marble powder and copper slag is found to be in agreement with conventional concrete.

Index Terms—Compressive strength, Copper slag, Durability properties, Flexural strength, Marble powder, Modulus of elasticity, Modulus of rupture, Split tensile strength

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1 Introduction

In the construction world, concrete is an inevitable component. The impact of concrete on environment is complex. Producing cement in huge amounts in factories directly influences the greenhouse gases emission and environmental pollution. It is estimated that 1 tone clinker production releases 1 tone CO_2 gas. Similarly the fine and coarse aggregates generally occupy 60% to 75% of the concrete volume. Fine aggregate has become the most widely consumed natural resource on the earth after fresh water. The annual world consumption of sand is estimated to be 15 billion tons.

Marble powder is a byproduct obtained from the marble industry during sawing, processing and shaping. Marble powder is one such waste material which can be used as a substitute for cement or fine aggregate. Due to its fineness it can show the property same as that of the cement. Also, marble powder will easily mix with aggregates giving a perfect bonding due to its fineness. It will fill the voids present in concrete thereby imparting sufficient compressive strength when compared to the ordinary concrete. The marble powder has high degree of fineness; it was proved to be very effective in bonding of mortar and concrete [1]. Marble dust concrete and lime stone dust concrete when compared with same water cement ratio and mix proportion found that marble dust concrete have less water permeability compared to lime stone dust concrete [2].

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Copper slag is considered as a waste material which could have a promising future in construction sites as a partial or full substitute of either cement or fine aggregates. It is a by- product derived from smelting and refining of copper. For every ton of copper produced, approximately 2.2–3.0 tons copper slag is generated as a by-product material mixture. In order to reduce the accumulation of copper slag and also to provide an alternate material for sand, it is proposed to study the potential of copper slag as replacement for fine aggregate in cement concrete.

2 Methodology

- Procurement of materials
- Determination of material properties
- Preparation of mixes
- Determination of fresh and hardened properties
- Durability properties
- Casting and testing of beams

3 Materials Used

Portland Pozzolana cement (PPC), Manufactured sand (M sand) passing through 4.75mm sieve, coarse aggregate of 20mm size, water, super plasticizer (Cera Hyperplast), marble powder, copper slag and steel reinforcement were used for the study. Reinforcement steel of grade 500 was used. 10mm dia bars are used as tension reinforcement, 8mm dia as compression reinforcement and 6mm dia as stirrup holders. Water used for the work was potable water from the college supply system. All the materials used was tested as per IS specification and all the results obtained conforms to IS specifications.

M30 grade concrete was used for the preparation of specimens. Mix was designed as per IS 10262:2009 [3]. Mix proportion adopted was 1:1.472:2.995. The cement content used was 420 Kg/m^3 and water cement ratio adopted was 0.45 with the addition of super plasticizer of about 0.1%. The compressive strength obtained after 28 days was found to be 39.45 N/mm^2.

4 Experimental Investigation

4.1 Fresh Properties of Concrete

The fresh property conducted is the slump test. Slump of concrete is measured according to IS 1199 – 1959 (Reaffirmed 2004).

4.2 Hardened Properties of Concrete

Various hardened properties like cube compressive strength, split tensile strength, cylinder compressive strength, modulus of elasticity and modulus of rupture were studied for both conventional concrete and concrete replaced with marble powder and copper slag. Splitting tensile strength was done as per IS 5816-1999 (Reaffirmed 2004) in a universal testing machine having 1000kN capacity. All the remaining tests were performed as per IS 516-1959 (Reaffirmed 2004).

4.3 Durability Properties

Durability is one of the most important properties of concrete. Durability is defined as the resistance to weathering, chemical attack, penetration of chlorides, corrosion of reinforcement etc. The various tests conducted are:

4.3.1 Water Absorption

Water absorption in concrete was determined by ASTM C 642 (2006). The specimens were dried in an oven at a temperature of 100^{0}C for 24 hours. After taking specimens from the oven, it is allowed to cool in ambient temperature. The weight was denoted as 'A'. The specimen is cooled and dried and weight was determined. Then it is immersed in water for 24 hours. The weight was taken at 60 minutes, 120 minutes and 24 hours. This weight is denoted as 'B'. The water absorption was calculated using (1)

$$\% \ Absorption = [(B – A)/A] \ X \ 100 \qquad\qquad (1)$$

4.3.2 Sorptivity

The test was done according to ASTM C 1585 (2004) [4], to measure the capillary absorption of water. The specimens were placed in an oven for 24 hours at 100°C. After that it is cooled for 24 hours and weight is noted. Then the specimens were put on a weld mesh such that the bottom surface was freely accessible to water. The water level was kept at not more than five mm above the base of the specimen. The weight was noted at 0, 5, 10, 20, 30, 60, 120, 240 and 300 minutes after wiping off the excess water from the surface of the specimens. The quantity of water absorbed during each time interval is calculated from (2).

$$I = m_t / (a \times d) \hspace{3cm} (2)$$

Where,
I = Absorption in mm
m_t = change in specimen mass in grams at the time t
 = exposed area of specimens through which water   penetrates in mm^2
 = density of water in g/mm^3
t = elapsed time in minutes

Fig. 1 Test Setup for Sorptivity

A graph was plotted for I versus square root of time in   seconds. The slope of best fit curve was taken as the sorptivity in mm/s$^{1/2}$.

4.3.3 Rapid Chloride Penetration Test (RCPT)

Calculations were done according to ASTM C 1202 [5].   Specimens of 100 mm diameter and 50 mm height were cast for NC and MCC. All the specimens were cured for 28 days. After 28 days, the surface water is wiped off and is coated with sealant.
          The test specimens were kept for vacuum curing. They were placed in the vacuum dessicator and then connected to the vacuum pump via moisture trap. The   dessicator has a valve which has to be kept in such a way that the dessicator was connected only to the moisture trap and pump. It should not have any contact with the atmosphere. Fig. 2 shows the test setup for vacuum curing.

Fig. 2 Set up for vacuum curing

Vacuum was maintained for three hours. Petroleum jelly was used to minimize the leakage of air. After three hours, the valve of the vacuum dessicator was turned and cooled de-aerated water was allowed to enter the dessicator, which is called vacuum soaking. De-aerated water was prepared by boiling water in a beaker and allowing it to cool in a closed vessel. Once the specimens are immersed in water, the valve was turned to previous position. The pump was kept running during this stage, and vacuum was maintained for one more hour. After one hour, the valve was removed from the vacuum decsicator and air was allowed to enter the dessicator. The specimens were left in water for 18 hours.

The current passed through the specimen was measured from the supply unit. Readings were taken in every half hour, for a period of 6 hours. Calculations were done according to ASTM C 1202.

The current passed though the specimens for a period of 6 hours was noted. The amount of charge was calculated as the area under the curve, by the trapezoidal formulae (3) and corrected charge was calculated as per (4).

Calculated charge,

$$Q_x = 900 \, (I_0 + 2I_{30} + 2I_{60} + 2I_{90} + \ldots\ldots + 2I_{300} + 2I_{330} + I_{360}) \qquad (3)$$

Corrected charge,

$$Q_s = Q_x \, (3.75/x)^2 \qquad (4)$$

x = diameter of the specimen

The total charge from RCPT test, Q_s was substituted in Berkes equation Eqn. (5) to obtain the chloride diffusion coefficient D_c.

$$D_c = 0.0103 \times 10^{-12} \times Q_s^{0.84} \qquad (5)$$

4.4 Flexural Strength Test

Mix	Cube strength N/mm²	Cylinder strength N/mm²	Split tensile strength N/mm²	Modulus of elasticity N/mm²	Modulus of rupture N/mm²

NC	39.45	33.55	3.8	2.417×10^4	4.6
MCC	40.55	36.90	3.9	2.51×10^4	4.4

Beams of 100 mm x 150mm x 1000mm size are subjected to two point loading in an Universal Testing Machine of 1000 kN capacity. Dial gauges were used to measure the deflection values and the resultant were used to plot the load – deflection graph. LVDT's were used to measure the strain values and used to plot the moment – curvature relationship. Fig. 3   represents the detailing of beam.
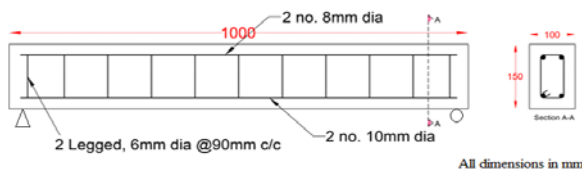

Fig. 3 Beam detailing

5 Results and discussions

- **Mix proportion**

5.1.1 Replacement of cement with marble powder

Fig. 4 Optimum % of marble powder in cement

5.1.2 Replacement of fine aggregate with copper slag

Fig. 5 Optimum % of copper slag in fine aggregate

- **Mechanical Properties**

Table 1 Mechanical properties

- **Durability Test Results**

- *Water absorption result*

Table 2 Water absorption test results

Specimen	Oven dried weight, A Kg	Weight after 24 hours of immersion in water, B Kg	Water absorption %
NC	2.4	2.491	3.79
MCC	2.503	2.596	3.71

5.3.2 Sorptivity

Fig. 6 Sorptivity curve for specimens

The sorptivity of concrete replaced with marble powder and copper slag was less than that of normal concrete. The slopes of the best fitting curve gave the values for sorptivity as 0.01032 and 0.00818 mm/sec$^{1/2}$. The addition of marble   powder and copper slag decrease the capillary absorption of the control mixes.

- RCPT

Table 3 RCPT results

Specimen	Q (Coulombs)	Qs (coulombs)	Chloride ion penetration	Diffusion coefficient, Dc
NC	1554.3	1408	Low	4.54 x10^{-12}
MCC	1285.5	1156.95	Low	3.85 x10^{-12}

Table 3 represents RCPT results. All the specimens indicated low chloride penetration as per the specifications laid down by ASTM C-1202. However MCC has a slight decrease of 15 % in diffusion coefficient than NC. But the penetration rate was observed to be low. The MCC mix is less permeable than NC mix making them more durable.

5.4 FLEXURAL BEHAVIOR OF RC BEAMS

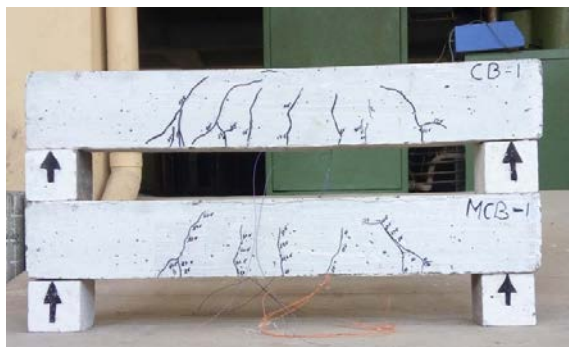*5.4.1 Crack pattern and failure mode*

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Fig. 7 Crack pattern

Fig. 7 shows the crack pattern of concrete replaced with marble powder and copper slag and normal concrete. Cracks were not seen during the beginning of the test. Further when the load was increased, cracks start to propagate. Most of the cracks initiated from the bottom of the beam and propagated to the top of the beam. The mode of failure was almost same. The crack spacing was less in concrete replaced with marble powder and copper slag than normal concrete.

5.4.2 Load – deflection graph

Fig. Fig. 8 Load – deflection graph

The loading was applied at a rate of 2.5 kN. From the graph, it can be seen that the curve is linear up to first crack load for both normal beams and beams replaced with marble powder and copper slag and further application of load makes it nonlinear until yielding. Beyond yielding, the deflection was   increased up to the ultimate load. Failure of control specimen occurs before the failure of beams replaced with marble powder and copper slag indicating that the beam replaced is more ductile ie, capable of undergoing more deflection before failure.

5.4.3 Energy absorption

Energy absorption was found out by the area under the load deflection plot. Due to the limitations in the experimental set up, the load deflection graph could be plotted only up to 80% of the peak load, in the descending portion of the curve. The energy absorption of specimens is shown in table 4.

Table 4 Energy absorption of beams

Mix	Energy absorption (kN mm)
NC	446.465
MCC	581.142

5.4.4 Stiffness and toughness

The stiffness of the beam can be calculated from the Load- deflection curve. The stiffness is the slope of the initial linear portion of the load- deflection curve. Toughness was taken as the ratio of area of the load deflection curve till the ultimate load to the area of the load deflection curve till the first crack load. The estimated values are shown in Table 5.

Table 5 Stiffness and toughness of beam specimens

Specimen	Stiffness kN/mm	Toughness
NC	63.49	28.24

MCC	69.37	29.84

5.4.5 Moment curvature relationship

Fig. 6.5 shows the moment curvature plot for the beams. The moment-curvature plot showed a similar profile for both   mixes as that of load deflection curve. It has a linear portion upto initial crack and comparatively flat after the formation of cracks and non-linear bending behaviour till the yield point and thereafter large deformations beyond yield load. From the graph it is clear that both mixes has similar moment carrying capacity.

Fig. 9 Moment curvature relationship

5.4.6 First crack, yield and ultimate load

First crack load was determined from the load deflection plot corresponding to the point at which the curve deviates from linearity. The yield moment was calculated and from the yield moment, the yield load was calculated. The ultimate load was found experimentally. The results are tabulated in Table 6.

Table 6 First crack, yield and ultimate load

Mix	First crack load kN	Yield load kN	Ultimate load kN
NC	22.5	56	69
MCC	25	59	73

5..4.7 Ductility index

Displacement ductility was calculated as the ratio between the displacements at ultimate load to the displacement at yield load. The ductility could be considered at 80 % of the peak load, because this takes into account, the softening part of load deflection curve. Hence for calculating ultimate deflection, 80% of peak load is considered. The absolute and relative values of ductility are presented in Table 7.

Table 7 Ductility index for beams

Mix	Displacement ductility		Curvature ductility	
	Absolute	Relative	Absolute	Relative
NC	2.56	1	2.03	1

MCC	2.69	0.95	2.23	1.1

6 Conclusion

- The workability of normal concrete and replaced   concrete was found to be low and to increase the workability super plasticizers was used. The dosage of   super plasticizer used was 0.1%.
- Optimum replacement of cement with marble powder is 10% and the optimum replacement of fine aggregate with copper slag is 40%.
- The cylinder compressive strength, split tensile strength and modulus of elasticity increased in MCC by 10%, 3% and 4% than NC. But modulus of rupture decreased in MCC by 5%. But the mechanical properties of both the mixes were within the   permissible limits of IS specifications.
- The durability properties such as water absorption and sorptivity were found to decrease for MCC than NC by 3% and 21% respectively.
- The diffusion coefficient of MCC decreased by 15% to that of NC using RCPT. All the specimens indicated low chloride penetration as per the ASTM C-1202 making them more durable and less permeable
- The crack pattern observed was almost similar and the number of cracks was more in MCC than NC and all the cracks appeared was flexural cracks. But the crack width was small for MCC. .
- From the flexural test, it was observed that the failure of control specimens occurs before the failure of replaced specimens.
- The type of failure observed was tension failure for all the beams and no crushing occurs before the steel yields. All the beams showed ductile behaviour.
- The ultimate load of replaced concrete increased by about 6% than the normal conventional concrete.
- The energy absorption obtained from the load   deflection curve for MCC is greater than NC by 30%. The increase in energy absorption indicates better ductility.
- The stiffness is increased for MCC by 10% than NC thus having more load carrying capacity than the conventional concrete.
- The displacement ductility and curvature ductility was increased by 5% and 10% respectively.

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