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Research paper

Experimental Behaviour of Sandwich Panels Using Copper Slag Mortar

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Abstract

This paper presents the study to investigate the viability of using copper slag as fine aggregate in cement mortar. Two series of cement mortar mixtures were prepared with different proportion of copper slag at different workability. In the first series, various proportions of copper slag is substituted for sand ranging from 0% to 100% with constant workability. Second series consists of fully replaced copper slag for sand in the cement mortar, which was achieved by maintaining the same workability as that of the control mortar mixture from first series and a control mixture for this new workability with sand as fine aggregate. The strength of twelve trial cement mortar mixtures were tested. The results indicate high compressive strength upto 50% replacement of copper slag, after that the compressive strength decreases with increase in copper slag percentage in cement mortar. The copper slag content in the mortar adversely affected the compressive strength of the mortar mixtures as 4.2% and 21.1% improvement in the compressive strength of the cement mortar for 50% replacement compared and 100% replacement compared with the control mortar mixtures. The density of cement mortar increases with increase in copper slag. From these trial mixtures two optimized mixtures were selected and were used to cast the sandwich panels. This panels were tested for flexural behaviour and axial load compression behaviour. The behavior of sandwich panels were simulated using ANSYS and the results were compared with experimental results.

Keywords: *Industrial Waste , Cement Mortar, Copper Slag, Workability, Ferrocement Panels.*

1. Introduction

Major problems during the construction of a structure are the availability of the building materials. These building materials were non-renewable resources, which include sand, gravels, etc. Hence, it is necessary to explore other resources that have similar properties as fine aggregate. In India, about 6-6.5 million tons of copper slag are generated annually. Copper slag is a by-product obtained from the copper refining industry. The disposal of copper slag in landfills is not a correct option due to environmental problems, lack of land, etc. Copper slag as a partial and full substitution for fine aggregate and coarse aggregate have been mentioned in many works [1,3,4,5]. Many researchers have been carries out to investigate the usage of copper slag as fine aggregate and coarse aggregate in mortar and concrete. The mechanical properties of mortar and concrete are also investigated in several research works. Previous researches also suggest that copper slag is a beneficial utilization of industrial by-product in improvement of properties of mortar and concrete. Cement mortar shows a continuous increase in the density as the copper slag content increases. In this paper, copper slag was used as a substitution for sand. As the copper slag percentage increases, the workability also increases. Some researchers showed that a substitution of 50% copper slag yielded more compressive strength than the other mixtures and control mortar mixtures. The water absorption rate of copper slag is less compared to the sand. Several studies proved that copper slag can be used as a substitution for fine aggregate in order to achieve mortar with better mechanical and durability properties. This paper presents the effect of using copper slag as fine aggregate in cement mortar for developing ferrocement sandwich panels. Another series of cement mortar is prepared by maintaining the workability as that of the control mixture. Ferrocement is a versatile form of reinforced concrete, made up of meshes, cement, sand and finally water that shows unique qualities of strength, serviceability and durability. Ferrocement techniques relatively allow us to have slender size components and can be done by the unskilled labour. Sandwich ferrocement panels are eco-friendly, sound insulation, fire resistance, and less wastage of material during construction compared to conventional reinforced concrete. In this study, sandwich panels where cast using the optimized mixtures. The experimental investigation showed that the behaviour of panels developed by 50% substitution of copper slag shows better results than the control mixture panel.

2. Objective

In previous research work [1, 3, 4, 5, 7, 8, 11, 15] the authors discusses the performance of copper slag substitution as fine aggregate on the compressive strength, durability, and workability of concrete. Concrete of different mixture proportions of copper slag were prepared and the specimens were tested to know the characteristics of the concrete at different curing ages. The investigation showed that the density of concrete increases. The main objective of this paper is to prepare panels using a mortar mixture, where the natural resources were 100% replaced by the industrial waste copper slag. That helps in fast construction of low cost construction buildings.

3. Materials

3.1. Cement

The cement used in the study was Portland pozzolana cement (PPC) purchased from Ultratech Company. This cement is the most widely used in the construction industry in India.

3.2. Fine Aggregate

River sand is used as fine aggregate in this work. Sand is used normally as fine aggregate in mortar and concrete. Sand and Copper slag used were tested for gradation and they met specification requirements. The sand used in this project were sieved through 4.75mm sieve.

3.3. Copper Slag

Copper slag was brought from Sterlite industry. The copper slag used was sieved through 4.75mm sieve. Sieve analysis for both sand and copper slag were conducted in accordance with IS 383-1970. Specific gravity and water absorption tested were conducted in accordance with IS 2386(part 3)-1963. The gradation curves for both sand and copper slag are presented in Fig.1. Both sand and copper slag satisfies the grading limit zone II. Properties of fine aggregate are presented in Table 1.

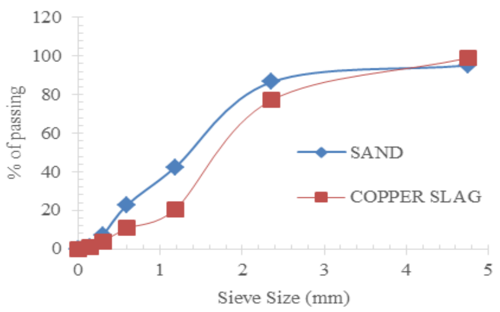

Fig. 1. Gradation curve of fine aggregate

Table 1: Properties of sand and copper slag

Property	Material		Value
Specific gravity	Sand		2.66
	Copper slag		3.50
Bulk density	Sand		1647 kg/m^3
	Copper slag		2197 kg/m^3
Water absorption	Sand		3.25%
	Copper slag		1.395%
Fineness modulus	Sand		2.55
	Copper slag		2.12

4. Experimental Investigation

4.1. Cement Mortar

The mix proportion chosen for this work is 1:2 cement mortar. The effect of using copper slag as a replacement of sand can be studied by preparing specimen of different proportions of copper slag ranging from 0% to 100% as shown in Table 2. Total of nine specimens of size 100X100X100mm dimensions cast for each proportion and three samples for each mixture were tested after the curing ages of 7, 14 and 28th day. The slump value of the cement mortar was determined to ensure the workability of the cement mortar. For the binder part, cement was used. The slump values of cement mortar are presented in Table 3.

Table 2: Mixture proportion

Sample ID	Mix ratio		Sand	Copper slag		w/b ratio
A0	1:2		100%	-		0.4
A1	1:2		90%	10%		0.4
A2	1:2		80%	20%		0.4
A3	1:2		70%	30%		0.4
A4	1:2		60%	40%		0.4
A5	1:2		50%	50%		0.4
A6	1:2		40%	60%		0.4
A7	1:2		30%	70%		0.4
A8	1:2		20%	80%		0.4
A9	1:2		10%	90%		0.4
A10	1:2		-	100%		0.4
B1	1:2		100%	-		0.37
B2	1:2		-	100%		0.37

Table 3: Slump value

Sample ID	Water binder ratio	Slump value
A0	0.4	60 mm
A5	0.4	Collapse
B1	0.37	True slump
B2	0.37	62 mm

4.2. Sample Preparation

All the dry ingredients required for the mixtures were taken by weight basis and are kept in an individual container. Normal tilting type mixture machine of capacity 80 Kg was used for preparation of mortar mixtures. The weighed ingredients were dry mixed thoroughly, the required water quantity as poured into the mixture. Mixtures were mixed to get uniform color and consistency. The workability of the mixtures was checked using the slump cone test. Test specimens of size 100X100X100mm were selected. Cement mortar specimens were compacted in three layers using tamping rod. Specimen were removed after 24 hours of room temperature drying from moulds and cured in the water tanks for testing ages of 7, 14 and 28th day. Another mixture B2 is prepared with maintaining the slump value same as that of the A0 mixture and the water cement ratio found to be of 0.37. To compare the B2 mixture another control mixture of 0.37 water cement ratio is also prepared.

4.3. Testing Procedure.

Compressive strength test was carried out on 100mm cube specimen in UTM. All the specimens were tested in saturated surface dry condition before conducting the test. Compressive strength test was conducted on cement mortar cubes at 7, 14 and 28th day. Based on the test result of trial mixtures, three mixtures were optimized (A0, A5 and B2) were used to cast the panels. The compressive strength of trial mixtures were shown in Table 4.
From the above result, it is clear that A5 mixture shows 4.4% higher value than the A0 mixture. B2 mixture shows 26.7% & 7.5% higher value than that of A0 mixture and B1 mixture. Hence, the mixtures A5 and B2 were optimized to cast panels.

Table 4: Compressive strength of trial mixtures

Mix id	Compressive strength			Density Kg/m^3
	7th day	14th day	28th day	
A0	22.6	29.0	38.6	2168
A1	21.6	31.5	39.2	2170
A2	18.5	26.5	32.3	2195
A3	16.7	21.1	28.4	2347
A4	19.5	22.4	28.3	2494
A5	21.4	36.7	40.3	2545
A6	20.7	26.3	30.4	2571
A7	19.4	21.4	28.3	2653
A8	18.5	20.5	24.1	2673
A9	11.7	20.0	23.0	2710
A10	11.8	17.7	22.5	2745

B1	29.5	31.2	45.5	2174
B2	26.1	34.2	48.9	2737

5. Panels

5.1. Introduction

Many researches [2, 6, 9, and 16] have studied the behaviour of panels and the dimension selected for this work is 900X600X100mm. Two different meshes of grid size 60X60mm and galvanized mesh of size 12mmX12mm were tied together using binding wire in a box shaped structure, which act as a reinforcement. This wire mesh were bent at the edges to the dimension of 870X570X70mm. thermocol of the same size were kept inside this reinforcement. A U-bend shaped meshes was provided at the center which connects the bottom meshes with top meshes to act as single unit as shown in Fig 2.

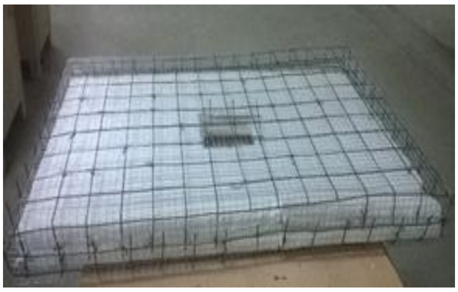

Fig. 2. Mesh reinforcement

In the wooden mould of dimension 900X600X100mm, a cover block of 15mm thickness was used. The mortar was poured upto 15mm as bottom layer. This mortar is well compacted manually. The bottom layer mesh was kept on this cement mortar and compacted uniformly, thermocol was inserted into the bottom layer mesh. Care was taken to flow mortar at the sides to form a single box unit. The top layer mesh is tied together with the bottom layer using binding wire. The top surface is smoothly finished. After 24 hours the panels was demoulded from the wooden mould and cured using gunny bags for 28 days.

5.2. Test Setup

After 28 days of curing, panels were surface dried and were whitewashed. Marking were drawn to the center of panels along length and breadth directions and a span of 800mm were marked. A roller of width length 600mm was kept at the centerline. The flexural strength test setup is shown in Fig 3. LVDT and demec gauge were used to calculate deflection and strain in the panels. Load was applied gradually in control manner. Demec points were used to measure the strain on the test specimens at 5mm from top surface and 5mm from bottom surface. The flexural strength of panels can be seen in Table 5.

Table 5: Flexural strength of panels

Mix id	Average load (KN)	Average Flexural strength (N/mm^2)
A0	21.5	4.3
A5	30.2	6.0
B2	32.0	6.4

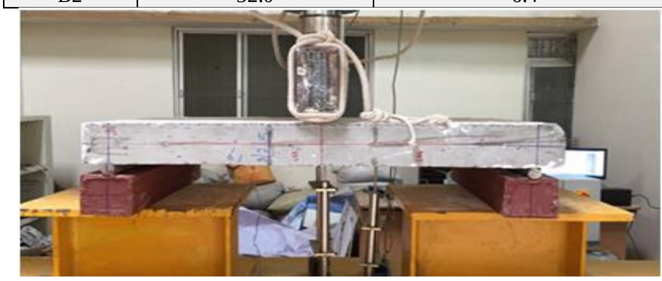

Fig. 3. Flexural strength test setup

It is interesting to note that the flexural strength of A5 mixture shows 40.2% higher value than the A0 mixture. B2 mixture shows 48.8% higher value than the A0 mixture.

5.3. Load – Deflection Behaviour

The average load delfection curve for A0 and A5 mixture with water cement ratio of 0.4 is shown in Fig 4. The load deflection curve for B2 mixture with water cement ratio 0.37 is represented in Fig 5.

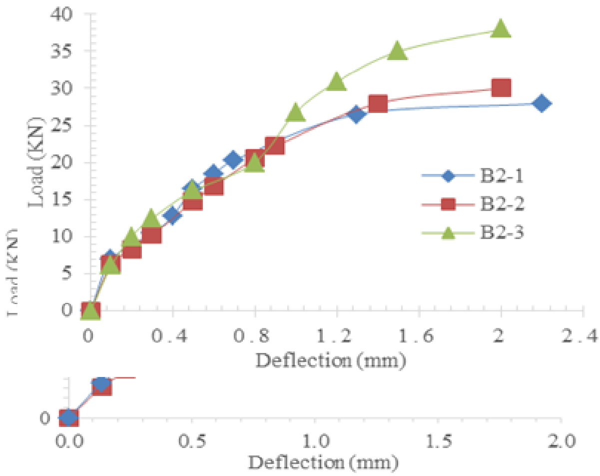

Fig. 4. Load deflection curve of A0 and A5 mixtures

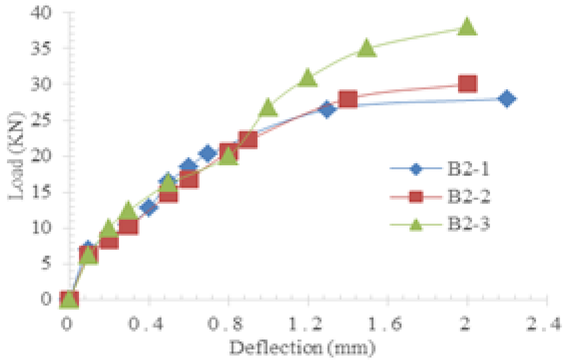

Fig. 5. Load deflection curve of B2 mixtures

5.4. Moment Curvature

A comparative moment curvature diagram for slab panels with A5 and B2 mixture with control mixture are shown in Fig 6& 7. The loads were applied gradually in a controlled manner. Demec gauge is used to measure the strain value along the compression and tension z

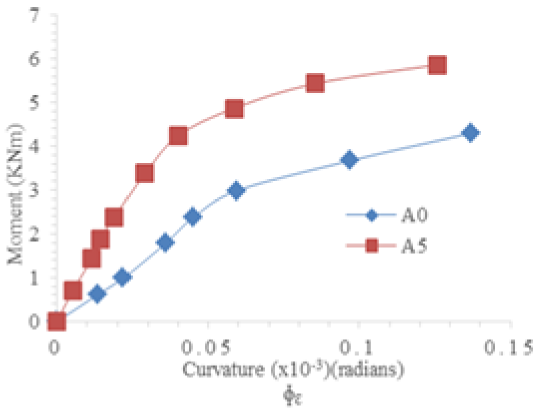

Fig. 6. Moment curvature for slab panels A0 and A5 mixtures

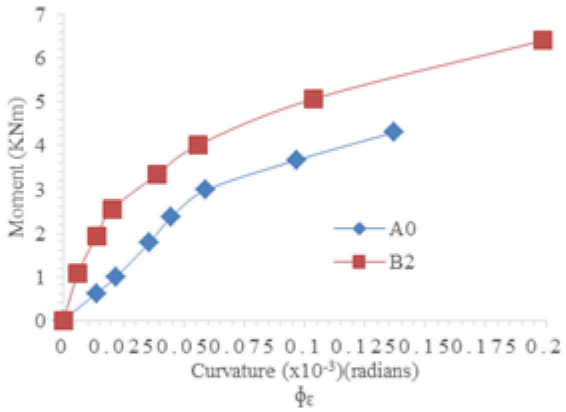

Fig. 7. Moment curvature for slab panels A0 and B2 mixtures

5.5. Stress-Strain Behaviour of Panels

Strains on the panels were measured using demec gauge. The load is applied gradually on the panels. The stress-strain behavior of panels for A0 and A5 mixture is shown in Fig 8. The stress-strain behavior of panels of A0 and B2 mixtures is presented in Fig 9.

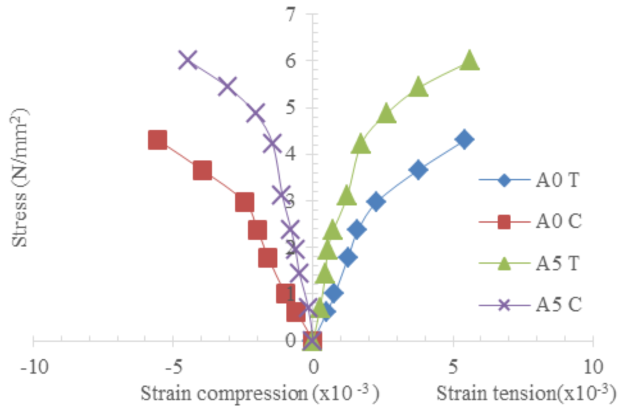

Fig. 8. Stress – Strain behavior of A0 and A5 mixtures

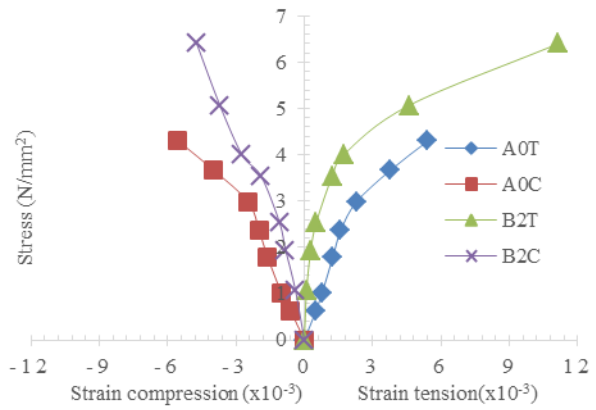

Fig. 9. Stress – Strain behavior of A0 and B2 mixtures

6. Wall Panel

6.1. Wall Panel Preparation

Wall panel were prepared using A0, A5 and B2 mixtures. Wooden moulds of internal dimension 450X300X100mm were used. Panels were cast in horizontal direction; one layer of welded wire mesh of grid opening 60X60mm was tied with one layer of galvanized mesh of 1mm diameter and grid opening of 12X12mm. the ends of the reinforcement were prepared for one panel. Mortar mixture was prepared, poured into the wooden mould upto height of 15mm, and well compacted manually and levelled. One layer of combined mesh and galvanized mesh was placed over the mixture allowing equal distance in the sides of the mould. Another reinforcement of combined layer of welded mesh and galvanized mesh was placed above thermocol layer. Mortar mixture again poured into this mesh, compacted properly, and finished smoothly. The panel was demoulded after 24 hours and kept in the curing tank for 28 days.

6.2. Specimen Preparation

Panels were taken from the curing tank after 28 days and surfaces were dried. Whitewash was done and specimen details were marked. Markings were done in front and back portion of the panels. Panels were tested in UTM.Plaster of paris was provided at the top and bottom surface of the panels.

6.3. Uniaxial Load Test on Wall Panels

Wall panel was kept on UTM bottom vertically by checking verticality and horizontal by using sprit level. I-steel section was placed on the top of the panels to full width of the panels. Dial gauge were fixed to calculate the lateral and horizontal deformation. The test setup for axial load presented in Fig 10.

Fig. 10. Axial load test setup

Three panels from each mixtures A0, A5 and B2 were tested by applying UDL on wall panels, vertical, lateral deformation and strain were recorded at different load intervals upto failure load. The compressive strength of panels were represented in Table 6. The compressive stress strain behavior of panels were shown in Fig 11 and 12.

Table 6: Compressive strength of the panels

Mix id	Average load (KN)	Average Compressive strength (N/mm²)
A0	356.0	11.9
A5	481.3	16.0
B2	519.0	17.3

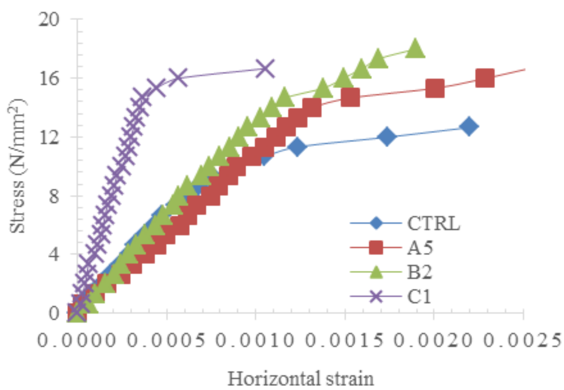

Fig. 11. Stress Vs. horizontal strain of different types of panels

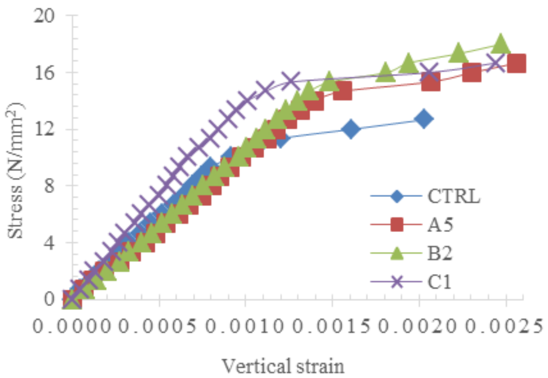

Fig. 12. Stress Vs. vertical strain of different types of panels

6.4. Load Deflection Curve

The load versus vertical deflection for the optimized mixtures of ferrocement wall panels was presented in Fig 13 and 14.

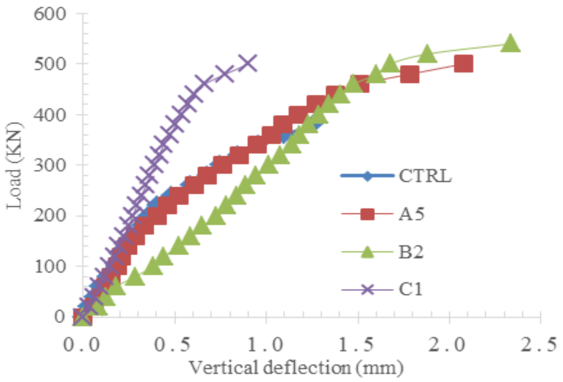

Fig. 13. Load Vs. vertical deflection of different types of panels

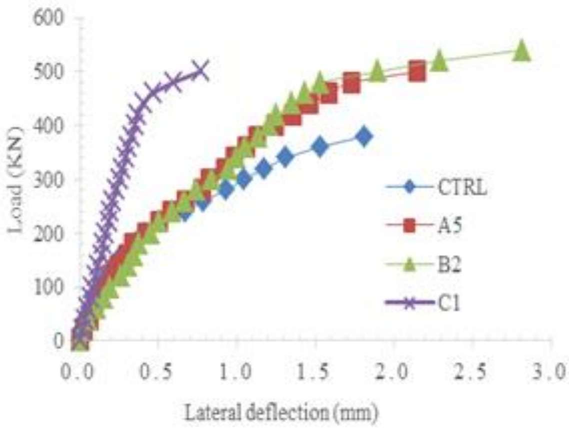

Fig. 14. Load Vs. lateral deflection of different types of panels

7. Conclusions

The following conclusions may be drawn from this investigation study:

1. Compared with the sand, specific gravity of copper slag is 31.6% higher. Water absorption of copper slag is much lesser than the sand. Density of copper slag is 33.4% higher than the density of sand.
2. Workability of cement mortar increases with increase in percentage of copper slag added to the mortar.
3. 50% of copper slag could potentially replace for sand in cement mortar mixtures.
4. Almost 8.1% reduction in water demand at 100% copper slag replacement in comparison with the control mixture with control mixture at the same workability.
5. By maintaining same workability 100%, substitution of copper slag can be made for sand.
6. The compressive strength of mortar are comparable to the control mixture upto 50% copper slag substitution for sand, but they decreased with further increase in copper slag content.
7. Panels prepared with A5, B2 and C1 mixtures performances were better compared with control mixture.
8. The sandwich panels with A5 and B2 mixtures yielded higher strength for both flexural and axial loadings than the control mixtures.
9. Crack pattern of the flexural panels and wall panels were compared with the crack pattern of control mixture.
10. This overall investigation indicates that performance of sandwich ferrocement panels, which can be used in construction merits. Therefore, further research work needs to be conducted as well through the economic feasibility.

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