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Experimental Study on Concrete Using Copper Slag as Replacement Material of Fine Aggregate

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Abstract

This paper reports the effect of concrete using copper slag as fine aggregate replacement. In this project work, the concrete grade M40 was selected and IS method was used for mix design. The properties of material for cement, fine aggregate, coarse aggregate and copper slag were studied for mix design. The various strength of concrete like compressive, flexural and split tensile were studied and non-destructive test such as rebound hammer test and ultrasonic pulse velocity measurement were studied for various replacements of fine aggregate using copper slag that are 0%, 20%, 40%, 60%, 80% and 100%. The maximum compressive strength of concrete attained at 40% replacement of fine aggregate at 7 and 28 days. The split tensile strength and the flexural strength were also obtained higher strength at 40% replacement level at 28 days. The rebound hammer test showed higher compressive strength at 40% fine aggregate replacement, this is due to uniformity of concrete. The pulse wave velocity is higher for the 40% fine aggregate replacement, it is understood that the density of the mix is high and free from pores.

Keywords: Copper slag; Waste material; Replacement of fine aggregate; Concrete; Properties of materials; Workability; Compressive strength; Split tensile strength; Flexural strength; Rebound hammer test; Ultrasonic pulse velocity measurement

Introduction

Concrete is a composite material composed of water, coarse granular material (the fine and coarse aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space among the aggregate particles and glues them together. Concrete is widely used for making architectural structures, foundations, brick or block walls, pavements, bridges or overpasses, highways, runways, parking structures, dams, pools/reservoirs, pipes, footings for gates, fences and poles and even boats. Concrete is used in large quantities almost everywhere mankind has a need for infrastructure [1].

The amount of concrete used worldwide, ton for ton, is twice that of steel, wood, plastics, and aluminum combined. Concrete's use in the modern world is exceeded only by that of naturally occurring water. Concrete is also the basis of a large commercial industry. Globally, the ready-mix concrete industry, the largest segment of the concrete market, is projected to exceed $100 billion in revenue by 2015. In the United States alone, concrete production is a $30-billion-per-year industry, considering only the value of the ready-mixed concrete sold each year. Given the size of the concrete industry, and the fundamental way concrete is used to shape the infrastructure of the modern world, it is difficult to overstate the role this material plays today [2,3].

Copper slag is used in the concrete as one of the alternative materials. It is the waste product of copper from Sterlite Industries India Ltd, Tuticorin. 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.

However, further additions of copper slag caused reduction in the strength due to an increase of the free water content in the mix. Mixes with 80% and 100% copper slag replacement gave the lowest compressive strength value of approximately 80 MPa, which is almost 16% lower than the strength of the control mix. The results also demonstrated that the surface water absorption decreased as copper slag quantity increases up to 40% replacement; beyond that level of replacement, the absorption rate increases rapidly. Therefore, it is recommended that 40 wt% of copper slag can used as replacement of sand in order to obtain HPC with good strength and durability properties [4,5].

Materials and Methods

Materials

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 and thermal resistance properties.

Aggregate: Aggregate consists of large chunks of material in a concrete mix, generally a coarse gravel or crushed rocks such as limestone, or granite, along with finer materials such as sand. The fine aggregate used in this study is river sand conforming to grading zone II Table 1 of IS 383 [6]. The coarse aggregate used in this study is of angular in shape and the maximum nominal size of coarse aggregate is 20 mm and it is Conforming to Table 2 of IS 383 [6].

Test	Cement
Specific gravity	3.09
Fineness modulus (%)	1.4
Standard consistency (%)	31.5
Initial setting time (minutes)	100
Final setting time (minutes)	240

Table 1: Properties of cement.

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Test	Fine aggregate	Copper slag	Coarse aggregate
Specific gravity	2.47	3.45	2.68
Fineness modulus	2.89	3.84	7.09
Moisture content (%)	0.1	0.1	0.1
Water absorption (%)	1.2	0.4	1.0
Density (loose state) (kg/m^3)	1700.67	2197	1513

Table 2: Properties of fine aggregate, copper slag and coarse aggregate.

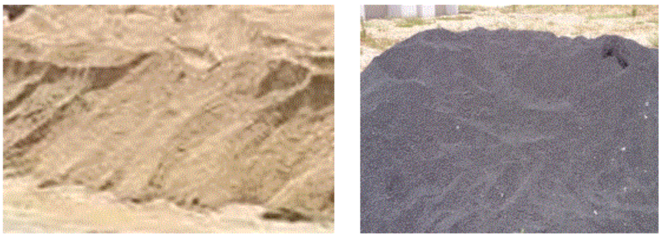

Figure 1: Fine aggregate and copper slag used in the study.

Cement: Cement, commonly Portland cement, and other cementitious materials such as fly ash and slag cement, serve as a binder for the aggregate. The cement used in this study is of OPC 53 grade conforming to IS 12269 [7].

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.

Copper slag: Copper slag is an irregular, black, glassy and granular in nature and its properties are similar to the river sand. In this project, Copper slag used is brought from Sterile Industries India Ltd, Tuticorin. Every ton of copper will generate approximately 2.2-3 tons of copper slag [8,9]. Sterlite Industries India Ltd produces 400,000t/year of copper and during the process, around 800,000t of copper slag is generated in a year. The chemical traces such as copper, sulphate and alumina present in the slag are not harmful (Figure 1).

Objective of this study

Many researchers had already found, copper slag possible to use as a material in concrete. In this experimental study copper slag is used in concrete as replacement material of fine aggregate. For this study, M40 grade of concrete is used and the tests are conducted for various replacement of fine aggregate using copper slag as 0%, 20%, 40%, 60%, 80% and 100% in concrete. The obtained results are compared with those of control concrete made with fine aggregate [10].

Properties of materials

The preliminary tests were carried out for finding the materials properties of cement, fine aggregate and coarse aggregate as per IS 12269 [7] and IS 383 [6]. The studied properties are given in Tables 1 and 2.

Methodology

In fresh state; the workability parameters such as slump value and compacting factor were studied. In hardened state; the strength tests such as compressive strength, split tensile strength and flexural strength were studied and the Non-destructive tests such as rebound hammer test and ultrasonic pulse velocity test were conducted for each mix. The obtained results are tabulated. The conclusions were made from the results and discussions (Table 3).

Mix Design and Experimental Work

Mix design

An integral part of concrete mix proportioning is the preparation of trial mixes and effect adjustments to such trials to strike a balance between the requirements of placement, that is, workability and strength, concomitantly satisfying durability requirements 4 [11]. As per IS 10262 [12], the method is adopted for finding the proportion of M40 grade concrete and the arrived mix ratio was 1:1.36:2.52:0.41 (Tables 4 and 5).

Experimental work

Workability: Workability is a measure of the ease with which a fresh mix of concrete or mortar can be handled and placed. For various mixes the concrete were prepared. In the fresh concrete, the slump cone test and compaction factor test were carried out (Figure 2).

- **Slump cone test:** The slump test result is a measure of the behaviour of a compacted inverted cone of concrete under the action of gravity as per IS 1199 [13]. It measures the consistency or the wetness of concrete.
- **Compacting factor test:** Compacting factor of fresh concrete is done to determine the workability of fresh concrete by compacting factor test as per IS 1199 [13]. The apparatus used is Compacting factor apparatus (Table 6).

Strength test	Compression test	Split tensile strength	Flexural strength
Sample type	cube	cylinder	beam
Sample size (mm)	150×150 × 150	150×300	100×100×500
Days of testing	7 & 28	28	28
Total no. of samples for one series	6	3	3

Table 3: Details of specimen used in the study.

Cement	Fine aggregate	Coarse aggregate	w/c ratio
450	610.49	1132.06	186
1	1.36	2.52	0.41

Table 4: Mix proportions (kg/m^3) and mix ratio.

S.No	% of replacement of fine aggregate	Cement (kg/m^3)	Fine aggregate (kg/m^3)	Copper Slag (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)
1	0	450	610.49	0	1132.06	186
2	20	450	488.40	122.10	1132.06	186
3	40	450	366.30	244.20	1132.06	186
4	60	450	244.20	366.30	1132.06	186
5	80	450	122.10	488.40	1132.06	186
6	100	450	0	610.49	1132.06	186

Table 5: Various concrete mix details.

Figure 2: Slump cone and compacting factor test of fresh concrete.

Replacement of fine aggregate (%)	Slump (mm)	Compacting factor	Degree of workability
0	26	0.82	Low
20	27.5	0.86	Low
40	30	0.88	Low
60	32.5	0.90	Low
80	34.5	0.92	Low
100	36	0.96	Low

Table 6: Slump and compacting factor value.

Preparation of sample: The moulds were prepared as per IS 10086 [14] and the samples were prepared and cured as per IS 516 [15]. For compression test 6 cubes of size 150×150×150 mm were cast and carried out test at 7 and 28 days for each mix. For Split tensile test and Flexure test 3 cylinders of size 150×300 mm and 18 beams of size 100×100×500 mm were cast and carried out test at 28 days for each mix. The Rebound hammer test and the Ultrasonic Pulse Velocity test are carried out for concrete cubes before carrying out strength tests.

Strength tests: In the hardened concrete, the Semi-destructive tests like Compressive strength test, Split tensile strength test and flexural strength test were carried out as per IS 516 [15].

Compressive strength: Compressive strength is often measured on a universal testing machine. By definition, the ultimate compressive strength of a material is that value of uniaxial compressive stress reached when the material fails completely. The compressive strength (N/mm^2) is calculated by using the formula,

$$\text{Compressive strength } = \frac{\text{Ultimate load } (\text{N})}{\text{Area of cross section } \left(\text{mm}^2\right)}$$

Split tensile strength: Ultimate tensile strength (UTS), often shortened to tensile strength (TS) or ultimate strength, is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. Tensile strength is not the same as compressive strength and the values can be quite different [16]. The split tensile strength (N/mm^2) is calculated by using the formula,

$$\text{Split tensile strength } = \frac{2\text{P}}{\pi \text{LD}}$$

Where, P=Ultimate load at failure (N), L=Length of specimen (mm) and D=Diameter of specimen (mm)

Flexural strength: Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The flexural strength represents the highest stress experienced within the material at its moment of rupture (Figure 3 and Tables 7-9). The flexural strength (N/mm^2) of rectangular cross-section using a three point flexural test technique is obtained by the formula,

$$\text{Flexural strength } = \frac{\text{PL}}{\text{BD}^2}$$

Where, P=Ultimate load at failure (N), L=Length of specimen (mm), B=Breadth of specimen (mm) and D=Depth of specimen (mm)

Non-destructive test: In the hardened concrete, the Non-destructive tests like Rebound hammer test & Ultrasonic pulse velocity test were carried out as per IS 13311 [17,18].

Rebound hammer test: A Schmidt hammer, also known as a Swiss hammer or a rebound hammer, is a device to measure the elastic properties or strength of concrete or rock, mainly surface hardness and penetration resistance. The hammer measures the rebound of a spring-loaded mass impacting against the surface of the sample. By reference to the conversion chart, the rebound value can be used to determine the compressive strength.

Ultrasonic pulse velocity test: Ultrasonic Pulse Velocity (UPV) testing of concrete is based on the pulse velocity method to provide information on the uniformity of concrete, cavities, cracks and defects. The test equipment must provide a means of generating a pulse, transmitting this to the concrete, receiving and amplifying the

Figure 3: Compressive strength, split tensile strength and flexural strength test of specimen.

Replacement of fine aggregate (%)	Weight of the cube (kg)		
	Before curing	7 days curing	28 days curing
0	8.037	8.309	8.494
20	8.407	8.797	8.907
40	8.699	8.852	9.059
60	9.107	9.163	9.437
80	9.326	9.443	9.726
100	9.631	9.525	9.819

Table 7: Average weight of the cube.

Replacement of fine aggregate (%)	7th day Compressive strength (N/mm^2)	28th day Compressive strength (N/mm^2)
0	29.50	38.80
20	33.72	40.70
40	38.37	42.95
60	30.88	34.44
80	29.65	31.39
100	26.87	27.66

Table 8: Average compressive strength of the specimen.

Replacement of fine aggregate (%)	Average split tensile strength (N/mm^2)	Average flexural strength (N/mm^2)
0	2.45	4.79
20	2.68	7.00
40	3.09	7.73
60	2.43	6.27
80	2.22	5.46
100	1.85	4.42

Table 9: Average split tensile strength and flexural strength of the specimen.

pulse and measuring and displaying the time taken (Figure 4, Tables 10 and 11).

Results and Discussions

Study on fresh concrete

Based on the observations from the experimental work, the following results and discussions are presented in this chapter. For workability study, the slump and compacting factor test were conducted on fresh concrete for different proportions as mentioned in Table 5.

Slump value: From Figure 5 it was noted that the slump value increased with the percentage of copper slag increases in concrete. The measured slump was 26 mm for the control mixture whereas 36 mm with 100% replacement of fine aggregate using copper slag. This considerable increase is due to the low water absorption characteristics of copper slag and its glassy surface compared with sand which caused surplus quantity of free water to remain after the absorption and hydration processes have completed. It should be noted that mixes with high contents of copper slag showed signs of bleeding and segregation which can have detrimental effects on concrete performance [19].

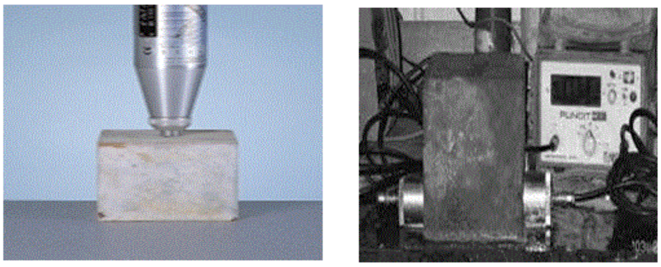

Figure 4: Rebound hammer and ultrasonic pulse velocity test for cube.

Replacement of fine aggregate (%)	7th day Compressive strength (N/mm²)	28th day Compressive strength (N/mm²)
0	9.81	10.00
20	16.19	25.75
40	26.49	35.64
60	22.72	30.43
80	19.98	24.32
100	14.73	20.08

Table 10: Average compressive strength of cube by rebound hammer test.

Replacement of fine aggregate (%)	7th day		28th day	
	velocity (km/sec)	Concrete quality	velocity (km/sec)	Concrete quality
0	3.95	Good	4.26	Good
20	3.68	Good	4.54	Excellent
40	4.52	Excellent	5.21	Excellent
60	4.21	Good	4.83	Excellent
80	3.86	Good	4.54	Excellent
100	3.79	Good	4.23	Good

Table 11: Ultrasonic pulse velocity test of cube.

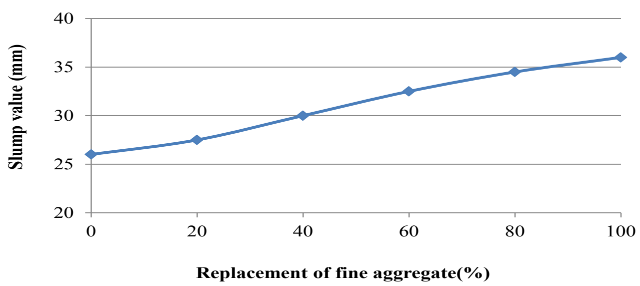

Figure 5: Relationship of slump value and percentage of replacement of fine aggregate.

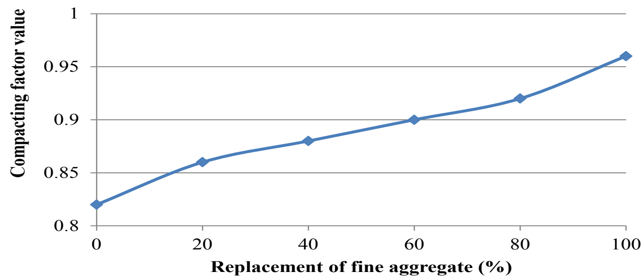

Figure 6: Relationship of compacting factor value and percentage of replacement of fine aggregate.

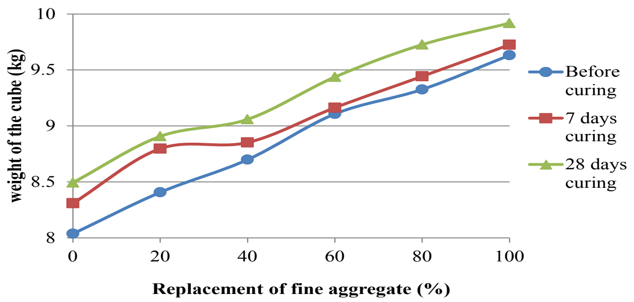

Figure 7: Relationship of weight of the cube and percentage replacement of fine aggregate.

Compacting factor: From Figure 6 it was noted that the value of compacting factor slightly increased with the replacement of copper slag in concrete. The calculated value of compacting factor was 0.82 for the control mixture whereas 0.96 with the 100% replacement of copper slag. This is mainly due to the higher specific gravity of copper slag which was 3.45 compared with sand which has a specific gravity of 2.47.

Study on hardened concrete

In this section, based on the experimental results of the compressive strength, split tensile strength, flexural strength, rebound hammer test and ultrasonic pulse velocity measurement discussions are made as follows.

Compressive strength: From the Figure 7 it was found that the weight of the cube showed lowest value in control concrete at before curing, 7 days curing and 28 days curing were 8.037 kg, 8.309 kg and 8.494 kg respectively whereas in concrete with 100% fine aggregate replacement using copper slag, the weight of the concrete value found the highest at before curing, 7 days curing and 28 days curing were 9.631 kg, 9.725 kg and 9.918 kg. The weight of specimen increased with the addition of copper slag into concrete. This is because of higher density of copper slag which was 2197 Kg/m³ compared with density of sand which was 1700.67 Kg/m³.

Figure 8 showed that the compressive strength of cube was found to be 29.50 N/mm² at 0% fine aggregate replacement and of 38.88 N/mm² at 100% fine aggregate replacement of 7 days. And the compressive strength of cube at 28 days was found to be 26.87 N/mm² at 0% fine aggregate replacement and of 27.66 N/mm² at 100% fine aggregate replacement. The maximum compressive strength was found to be at 40% fine aggregate replacement of about 38.37 N/mm² at 7 days and of 42.97 N/mm² at 28 days. The compressive strength of concrete at 7 and 28 days increased gradually up to 40% fine aggregate replacement and then decreased with increase in percentage of replacement.

Split tensile strength: Figure 9 showed that the split tensile strength of cylinder was found to be 2.45 N/mm² at 0% fine aggregate replacement and of 1.85 N/mm² at 100% fine aggregate replacement. The maximum split tensile strength was found to be at 40% fine aggregate replacement of about 3.09 N/mm². The split tensile strength of copper slag added concrete was gradually increased up to 40% replacement and then decreased with further fine aggregate replacement. The split tensile strength of cylinder showed a similar behaviour to the compressive strength of the cube for all mixtures.

Flexural strength: Figure 10 showed that the flexural strength of beam was found to be 4.79 N/mm² at 0% fine aggregate replacement and of 4.42 N/mm² at 100% fine aggregate replacement. The maximum flexural strength of beam was found to be at 40% fine aggregate replacement of about 7.73 N/mm². The flexural strength of beam showed higher strength at 40% fine aggregate replacement. The flexural strength of all mixtures showed a similar behaviour to the compressive strength results.

Rebound hammer test: From the Figure 11 it is noted that the compressive strength was found to be 9.81 N/mm² at 0% fine aggregate replacement and of 14.73 N/mm² at 100% fine aggregate replacement of 7 days. And the compressive strength at 28 days was found to be 10 N/mm² at 0% fine aggregate replacement and of 20.08 N/mm² at 100% fine aggregate replacement. The maximum compressive strength was found to be at 40% fine aggregate replacement of about

26.49 N/mm² at 7 days and 35.64 N/mm² at 28 days. The compressive strength of concrete at 7 and 28 days obtained with the rebound number was increased gradually up to 40% fine aggregate replacement and then decreased with increase replacement. This is due to homogeneity of concrete and the strengths were lie in between ± 15% and ± 20% of compressive strength of compression test.

Ultrasonic pulse velocity measurement: The ultrasonic pulse velocity measurement is the measure of quality of concrete. It is mainly related to its density and modulus of elasticity which in turn, depends upon the materials and mix proportions used in making concrete as well as the method of placing, compaction and curing of concrete. From Figure 12 it was observed that the pulse wave velocity showed above 4.5 km/sec at 7th day measurement and above 5.2 km/sec at 28th day measurement. This is due to the density of the mix is high and free from pores. It is also observed that the concrete at 40% replacement level showed excellent quality and good quality for other percentages at 7th day measurement [20]. At 28th day measurement, the concrete showed excellent quality for 20%, 40%, 60% and 80% replacement of fine aggregate and showed good quality for 0% and 100% replacement of fine aggregate. The important observation was that the addition of copper slag definitely reduced the pores of concrete and made the concrete impermeable (Figure 13).

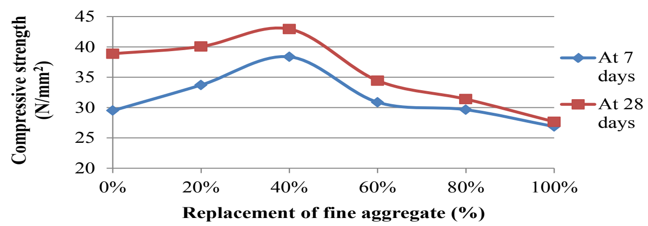

Figure 8: Relationship of compressive strength of cube and percentage of replacement of fine aggregate at 7 and 28 days.

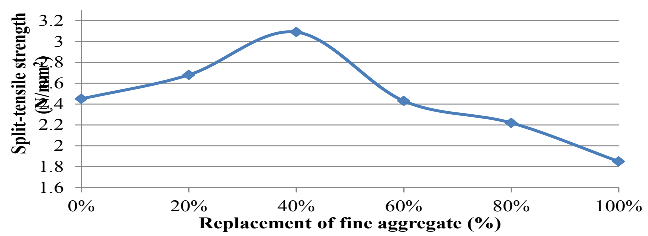

Figure 9: Relationship of split tensile strength and percentage of replacement of fine aggregate at 28 days.

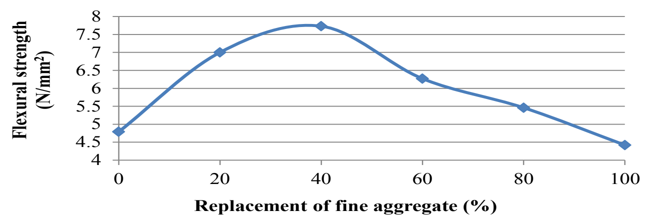

Figure 10: Relationship of flexural strength and percentage of replacement of fine aggregate at 28 days.

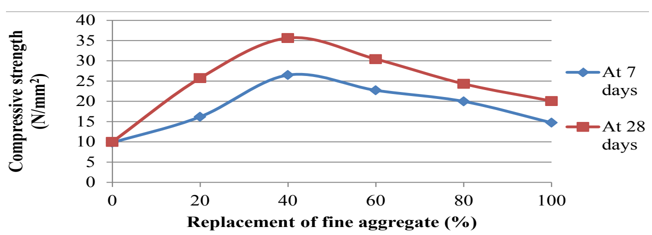

Figure 11: Relationship of compressive strength and percentage of replacement of fine aggregate at 7 and 28 days of rebound hammer test.

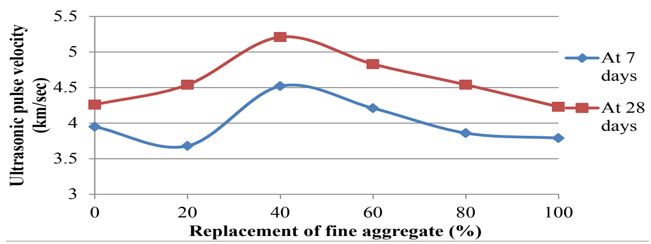

Figure 12: Relationship of pulse wave velocity and percentage of replacement of fine aggregate at 7 and 28 days.

Figure 13: Copper powder Slug.

Conclusion

From the results and discussions, the following conclusions were made

- The replacement of fine aggregate using copper slag in concrete increases the density of concrete thereby increases the self-weight of the concrete.
- The workability of concrete increased with the increase in copper slag content of fine aggregate replacements at same water-cement ratio.
- Form the results of compressive strength, split tensile strength and flexural strength, the concrete shown higher value at 40% replacement of fine aggregate using copper slag. So it is recommended that 40% of fine aggregate can be replaced by copper slag.
- The rebound hammer test revealed the uniformity of concrete and their compressive strength.
- The ultrasonic pulse velocity test indicated the excellent quality of concrete at 40% replacement level.
- The construction industry is the only area for safe use of waste materials, which reduces the environmental problems, space problems and cost of construction.

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