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Analysis of Strength Performance in M30 Concrete with Copper Slag Serving as a Partial Fine-Aggregate Replacement

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KEYWORDS

ABSTRACT

Natural resources are depleting worldwide while at the same time the generated wastes from the industries are increasing substantially. The sustainable development for construction involves the use of non-conventional and innovative materials such as recycling of waste materials and using them in order to compensate the lack of natural resources and to find alternative ways for conserving the environment. Some of the industrial by-products have been used in construction industry for the production of concrete.

Copper slag is one of the waste materials which can be used in Construction industry as partial replacement of fine aggregate (river sand). In the present work, M30 grade of concrete will be used as reference mix. The fine aggregate is replaced with 10%, 20% and 30% of copper slag by weight and optimum dosage is found out at 20% replacement of copper slag and then decreased. Compressive strength, flexural strength and split tensile strength were determined at the ages of 7, 28, 56 and 91 days respectively.

INTRODUCTION

Concrete is the man-made material widely used for construction purposes. The usual ingredients in concrete are cement, fine aggregate, coarse aggregate, and water. Aggregates are considered as one of the main constituents of concrete since they occupy 70-80% of the volume of concrete. In many countries, there is scarcity of natural aggregates that are suitable for construction. While in other countries, there is an increase in the consumption of aggregates due to the greater demand by the construction industry. In order to reduce dependence on natural aggregates as the main source of aggregate in concrete, artificially manufactured aggregates and artificial aggregates generated from industrial wastes provides an alternative for the construction industry. Therefore, industrial wastes should be used as an alternative to naturally available aggregates. Aggregates used in the construction industry globally are projected at an increase of more than 51 billion metric tons by 2022. Such large consumption of natural aggregates will cause destruction to the environment. The beneficial use of industrial by-products in concrete is well known for many years and significant research has been published with regard to the use of materials such as coal ash, fly ash, pulverized fuel ash, bottom ash, blast furnace slag and silica fume as partial replacement for Portland cement or as fine aggregate. In India, there is great demand of aggregates mainly from civil engineering industry for road and concrete constructions. But, now a days it has become a very difficult problem regarding availability of fine aggregate. So researchers developed waste management strategies to apply for replacement of fine aggregate for specific need. Natural resources are depleting worldwide while at the same time the generated wastes from the industry are increasing substantially. The sustainable development for construction involves the use of non-conventional and innovative materials. This can be achieved by recycling of waste materials in order to compensate the lack of natural resources and to find alternative ways for conserving the environment.

Need for replacement of natural sand in Concrete

In concrete, the cement with water forms a binder phase while the aggregate phase is mainly a filler phase which occupies about 70-80% of volume of concrete in which the fine aggregate is about 28-40 % of its volume. In construction, usually the prime source of fine aggregate is naturally available river sand which possess a problem of its non-availability during floods and in rainy reasons as well as due to huge need of construction industry. In order to solve this problem reliable source and continuous supply of an alternative material for these ingredients should be thought of and their use should be recommended. It is essential that this recommended alternative material should be eco-friendly and they should be available at cheaper cost without an interrupted supply on to the construction sites. In Indian scenario, it is observed that at very few places good quality of sand may be available in plenty. All metro and mega cities in India are facing acute) shortages of good quality of sand. At some places, sand available is coarser than Zone I sand and hence not suitable for construction work Copper slag is considered as one of the waste materials, which could have promising future construction industry as partial or full substitute of either cement or aggregates. It is a by-product obtained during the matte smelting and refining of copper. To produce every ton of copper, approximately 2.2-3.0 tons copper slag is generated as a by- product material. In India approximately around 16-18 million metric tons of copper slag is produced every year.

Copper slag

Copper slag is produced as a by-product of metallurgical operations in reverberator furnaces. For every ton of copper production, about 2.2 tonnes of copper slag is generated. Earlier copper slag was used as an abrasive material for removing rust and marine deposits from ships through sand blasting. After repetitive recycling and reuse, the copper slag lost its original abrasive property and with no good use thereafter, it was disposed in landfills. However, there were environmental concerns about the leaching of heavy metals into soil and ground-water, and hence were dumped in landfill sites. Industries found a novel way of encapsulating this waste into concrete thereby not only removing the environmental concern also finding a value-added and meaningful substitute for natural sand. Copper slag is totally inert material and its physical properties are similar to natural sand. Copper slag when grounded fine can be used as a replacement for sand in concrete which provides potential, environmental as well as economic benefits for all related. industries. Particularly in areas where a considerable amount of copper slag is produced. The major constituent of a smelting charge are sulphides and oxides of iron and copper. The charge also contains oxides such as SiO_2 , Al2O3,CaO and MgO which are either present in original concentrate or added as flux. It is Iron, Copper, Sulphur, Oxygen and their oxides which largely control the chemistry and physical constitution of smelting system. A further important factor is the oxidation/reduction potential of the gases which are used to heat and melt. As a result of this process copper-rich matte (sulphides) and copper slag (oxides) are formed as two separate liquid phases. The addition of silica during smelting process forms strongly bonded silicate anions by combining with the oxides. This reaction produces copper slag phase, whereas sulphide from matte phase, due to low tendency forms the anion complexes. Silica is added directly for the most complete isolation of copper in matte which occurs near saturation concentration with SiO_2. The slag structure is stabilized with the addition of lime and alumina. The molten slag is discharged from the furnace at 1000-1300 °C. When liquid is cooled slowly, it forms a dense, hard crystalline product, while a granulated amorphous slag is formed through quick solidification by pouring molten slag.

LITERATURE REVIEW

Byung Sik Chun et al (2005) conducted several laboratory tests and evaluated the applicability of copper slag as partial replacement of sand. From the various tests performed, the strength of composite concrete was compared, studied and analysed by monitoring the stress and ground settlement of clay, sand compaction pile and copper slag compaction pile.

Shanmuganathan et al (2007) reviewed and mentioned that large amounts of copper slag concretes are generated as waste products worldwide during the copper smelting process. Copper slag concrete can be used in many applications such as concrete, landfills, Ballasts bituminous pavements tiles etc. The characteristics and utilization of copper slag concrete has been reviewed (Gorai et Al 2003). The apprehension of environmental hazard from the view point of leaching of heavy metals from the slag and its long term stability in extreme environmental conditions were studied by shanmuganathan et Al and reported from their sulphuric acid leaching results that the heavy metals present in slag are very stable and have poor leaching ability. They considered that the slag was safe to be considered for use in a variety of applications such as for replacement of sand and replacement of cement in case of ggbs. The slag samples are nontoxic and pose no environmental hazard.

Al-Jabri et al (2009) investigated the performance of high strength concrete made with copper slag as replacement for fine aggregate at constant workability and Studied the effect of super plasticizer addition on properties of high strength concrete made with copper slag. They observed the water demand reduced by about 22% for 100% copper slag replacement the strength durability of high strength concrete is improved with increase on content of slag up to 50%. However, further increase of copper slag reduce the strength due to increase in free water content in mix. Also , the strength and durability characteristics of high strength concrete were adversely affected by the absence of the super plasticizer from the concrete paste despite the improvement in the concrete strength with the increase of copper content. The test results also show that there is also slight increase in density of nearly 5% with addition of copper slag, workability increased rapidly with increase of copper slag percentage.

MosafaKhanzadi and Ali Behnood (2009) investigated the feasibility of using copper slag as coarse aggregates in high strength concrete. The effects of replacing lime stone coarse aggregates by copper slag coarse aggregates, the compressive strength ,Split tensile strength and rebound hammer values of high strength concrete are evaluated in his work. The use of copper slag aggregate showed an Increase of about 10-15% Compressive strength and an increase of 10-18% splitting tensile strength compared to some stone aggregate indicating that using copper slag as coarse aggregate in high strength concrete is suitable.

Brindha et al (2010) studied that the potential use of granulated copper slag from Sterlite Industries as a replacement for sand in concrete mixes. The effect of replacing fine aggregate by copper slag on the compressive strength and split tensile strength were attempted in this work. Leaching studies demonstrate that granulated copper slag does not pave way for leaching of harmful elements like copper and iron present in slag. The percentage replacement of sand by granulated copper slag were 0%, 5%, 10%, 15%, 20%, 30%, 40%, and 50%. The compressive strength was observed to increase by about 35-40% and split tensile strength by 30-35%. The experimental investigation showed that percentage replacement of sand by copper slag shall be up to 40%. Addition of slag in concrete increases the density thereby the self-weight of the concrete. The results of compression & split-tensile test indicated that the strength of concrete increases with respect to the percentage of slag added by weight of fine aggregate up to 40% of additions. The recommended percentage replacement of sand by copper slag is 40%.

Wei Wu et al (2010) investigated the mechanical properties of high strength concrete replacing fine aggregate with copper slag. Micro silica was also used to supplement the cementitious content on the mix for high strength requirement. They observed that when copper slag was used to replace fine aggregate up to 40% the strength of concrete increases while the surface water absorption decreases. They also observed that when more than 40% of copper slag is used micro structure of concrete contains more voids, micro cracks, and capillary channels which accelerate the damage of concrete during loading.

PRELIMINARY INVESTIGATION

Cement type

43 Grade Ordinary Portland cement (SAGAR CEMENT) is used.

Fine Aggregate

River sand conforming to zone-II is used as fine aggregate.

Coarse Aggregate

Crushed granite material with 60% passing 20mm and retained on 10mm sieve, 40% passing 10mm and retained on 4.75mm sieve having a specific gravity of 2.74 is used.

Water

Potable fresh water available at Andhra University, Visakhapatnam, which is free from concentration of acid or organic substances was used for mixing the concrete.

Copper slag

Copper slag is a by-product obtained during the matte smelting and refining of copper. Copper slag is also called as Ferro sand. Copper slag used in this work is brought from Sterlite Industries Ltd (SIL), SIPCOT Industrial Complex Madurai Bypass Road, Thoothuudi, Tamilnadu, India. SIL is producing copper slag during the manufacturing of copper metal. Currently in SIL itself 2600 tons of copper slag is produced per day and the total accumulation is around 1.5 million tons. Copper slag is a black glassy and granular in nature and has similar particle size range like sand. The specific gravity of the slag lies between 3.4 and 3.98. It is also found that the copper slag has less moisture content so it has less heat of hydration.

Table 1: Physical Properties of Fine aggregates (IS 383, IS 2386 Part II)

S.NO	PROPERTY	VALUE
1	Zone of sand	Zone II as per IS 383
2	Specific gravity	2.63
3	Bulk density a) Loose state b) Compacted state	2250kg/m^3 2400kg/m^3
4	Fineness modulus	2.66
5	Silt content	1 %
6	Surface moisture	0.7 %

Physical properties of copper slag (as suggested by the supplier)

S.NO	Physical properties	Suggested values by supplier
1	Colour	Black
2	Specific gravity	3.77
3	Fineness Modulus	3.44

Sieve analysis of Copper slag : Total weight of sample taken =1000 grams

S.NO	IS Sieve	Weight retained	% weight retained	% cumulative weight retained	% Finer
1	80mm	0	0	0	100
2	40mm	0	0	0	100
3	20mm	0	0	0	100
4	10mm	4	0.4	0.4%	99.6
5	4.75mm	6	0.6	1%	99
6	2.36mm	112	11.2	12.2%	87.8
7	1.18mm	394	39.4	51.6%	48.4
8	600µm	322	32.2	83.8%	16.2
9	300µm	130	13	96.8%	3.2
10	150µm	18	1.8	98.6%	1.4
Fineness modulus =∑% cumulative weight retained /100 =344.4/100 =3.44					

Chemical properties of copper slag (as suggested by the supplier)

S.NO	Chemical component	% of chemical component
1	SiO2	25.42
2	Fe2	68.79
3	Al2O3	0.21
4	CaO	0.14
5	Na2O	0.55
6	K2O	0.22
7	MnO3	0.24
8	TiO2	0.39
9	SO3	14.38
10	CuO	6.53

Details of mix proportions of various mixes.

SN O	Description	**MIX PROPORTIONS kg/m³**			
1	Constituent	0% CS M30	10% CS M30	20% CS M30	30% CS M30
2	OPC43	400	400	400	400
3	Water(litres)	176	176	176	176
4	W/C Ratio	0.44	0.44	0.44	0.44
5	Sand	661.56	595.404	529.25	463.1
6	Copper slag	0	66.156	132.31	198.46
7	Coarse aggregate 10 mm	489.20	489.20	489.20	489.20
8	Coarse aggregate 20 mm	734.34	734.34	734.34	734.34

RESULTS AND DISCUSSIONS

WORKABILITY

The workability of concrete is determined by compaction factor test, as this test is suitable for low workable mixes also. Before casting the specimens only the workability is measured, if the does not have required slump of 25-50 mm then the mix would be made again with superplasticizer. It can be observed that as the percentage of the replacement of fine aggregate with copper slag increases the slump is decreasing, as the water absorption capacity of copper slag is more as compared to river sand. Hence the workability decreases.

WORKABILITY IN TERMS OF SLUMP

Slump cone test performed for the concrete with copper slag showed very low slump values. So to obtain the results precisely, compaction factor test is done for the copper slag concrete.

Slump for M30 grade of concrete with different replacement percentages of fine aggregate by copper slag by 0.5% of admixture (Aura mix 300+)

S.NO	**Type of mix+0.5%Admixture**	**Slump (mm)**
1	0% CS M30	95
2	10% CS M30	82
3	20% CS M30	75
4	30% CS M30	69

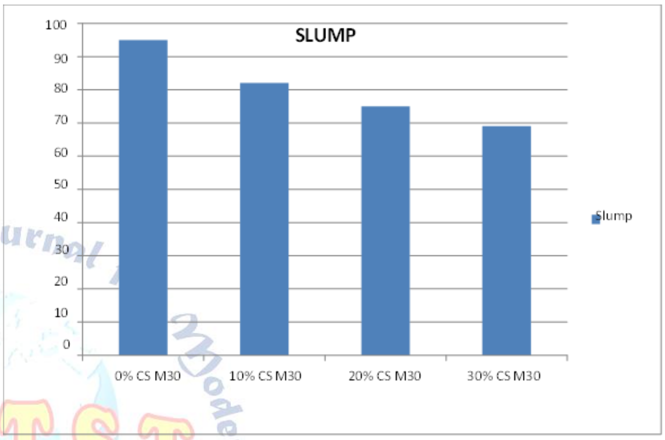

Fig: Variation of Slump for M30 Grade of Concrete With Increase in Percentage

WORKABILITY IN TERMS OF COMPACTION FACTOR

The values of compaction factor obtained in the present investigation for various percentages of replacement of fine aggregate with copper slag are shown in table 4.2 it can be observed that as the percentage of the replacement of fine aggregate with copper slag increases the compaction factor decreases. Hence it can be concluded that as the percentage of copper slag increases the workability decreases.

Compaction factor for M30 grade concrete with different replacement percentages of fine aggregate by copper slag

S.NO	Grade of concrete	M30			
1	Type of mix	0% CS M30	10% CS M30	20% CS M30	30% CS M30
2	Compaction factor	0.89	0.88	0.87	0.85

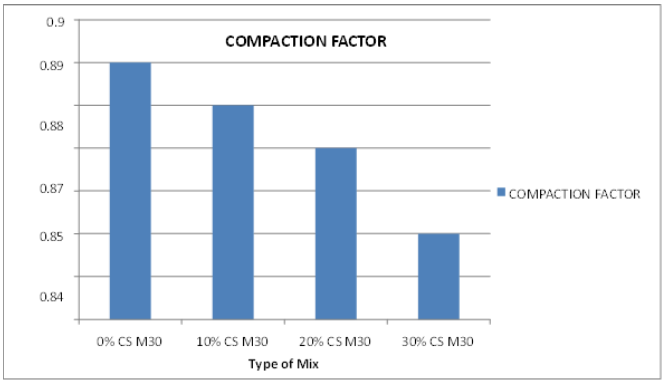

Fig: Variation of Compaction factor for M30 grade of concrete With Increase in Percentage

WORKABILITY IN TERMS OF VEE-BEE TIME

Vee-Bee time for M30 grade of concrete with different replacement percentages of fine aggregate by copper slag.

S.NO	Type of Mix	Vee –Bee Time (Sec)
1	0% CS M30	10.2
2	10% CS M30	11.5
3	20% CS M30	12.3
4	30% CS M30	14.2

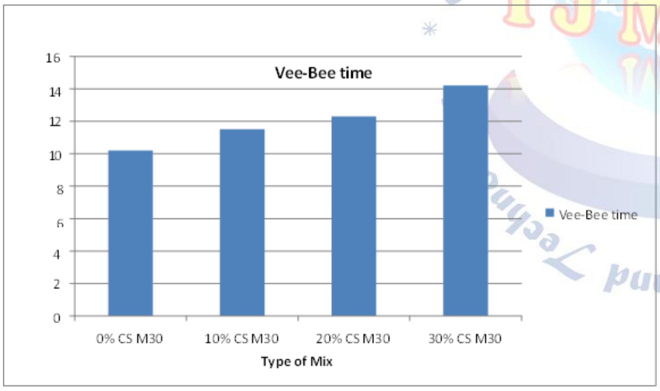

Fig: Variation of Vee-Bee time for M30 grade of concrete With Increase Percentage

COMPRESSIVE STRENGTH

Compressive strength test has been conducted on cubes of standard size 150 mm x 150 mm x 150 mm for all mixes and resulting compressive strength obtained at the age 7, 28, 56 and 91 days for M30 grade concrete were tabulated in the Table 5.4 and Fig.4.6. It can be seen that the compressive strength of concrete with fine aggregate replaced by copper slag is more than the conventional concrete mix at all ages.

Compressive strength of M30 grade concrete Effect of addition of copper slag

From the optimum dosage bar charts we can observe that he 20% replacement of natural sand by copper slag gives more strength than any other replacement. For M30 grade of concrete the compressive strength at optimum dosage 20% is of order 16.39%, 23.16%, 19.01% and 16.49% at the ages of 7, 28, 56 and 91 days.

Table : Compressive strength (MPa) of M30 grade concrete with different proportions of copper slag

Days	0% CS M30	10% CS M30	20% CS M30	30% CS M30
7 days	30.2	32.85	35.5	33.1
28 days	42.22	47.56	52.0	48.44
56 days	44.44	48.44	52.89	49.3
91 days	45.78	49.78	53.33	50.22

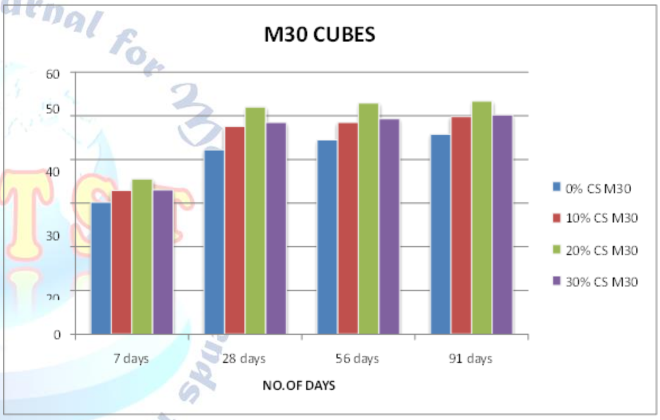

Fig: Variation of compressive strength for M30 grade of concrete With 7,28,56,91days

Split Tensile strength test

Split tensile strength test has been conducted on cylinders of size 150mm x 300mm for all mixes and resulting split tensile strength obtained at the age of 7, 28, 56 and 91 days for M30 grade of concrete were tabulated in the table 5.5 and Fig.4.7. It can be seen that the split tensile strength of concrete with fine aggregate replaced by copper slag is more than the conventional concrete mix at all ages.

Effect of addition on copper slag

From the optimum dosage bars we can observe that the 20% replacement of natural sand by copper slag gives more split tensile strength than any other replacement. For M30 grade of concrete the Split tensile strength for optimum dosage 20% is order 23.91%, 29.61%, 20.61%, 17.52% at the ages of 7, 28, 56 and 91 days.

Split tensile strength of M30 grade concrete with different proportions of copper slag.

S.NO	Days	0% CSM30	10% CS M30	20% CS M30	30% CS M30
1	7days	2.30	2.59	2.85	2.63
2	28days	2.87	3.53	3.72	3.60
3	56days	3.25	3.66	3.92	3.70
4	91days	3.71	4.14	4.36	4.24

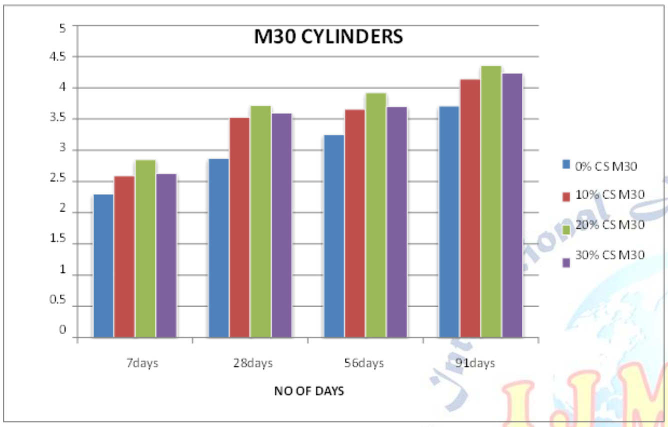

Fig: Variation of Split tensile strength for M30 grade of concrete With Increase in days

Flexural Strength test

Flexural strength test has been conducted on beams of size 100mm x 100mm x 500mm for all mixes and resulting flexural strength obtained at the age of 7, 28, 56 and 91 days for M30 grade of concrete were tabulated in table 5.6 and Figure 4.8. It can be seen that the flexural strength of concrete with fine aggregate replaced by copper slag is more than the conventional concrete mix at later ages.

Effect of addition of copper slag

From the optimum dosage bars we can observe that the 20% replacement of natural sand by copper slag gives more flexural strength than any other replacement. For M30 grade of concrete the flexural strength for optimum dosage 20% is of order 12.19%, 16.15%, 15.2%, 13.16% at the ages of 7, 28, 56 and 91 days.

Flexural strength of M30 grade concrete with different proportions of copper slag

S.NO	Days	0% CS M30	10% CS M30	20% CS M30	30% CS M30
1	7days	5.25	5.54	5.89	5.64
2	28days	6.19	6.46	7.19	6.79
3	56days	6.48	6.98	7.47	7.23
4	91days	6.76	7.11	7.65	7.34

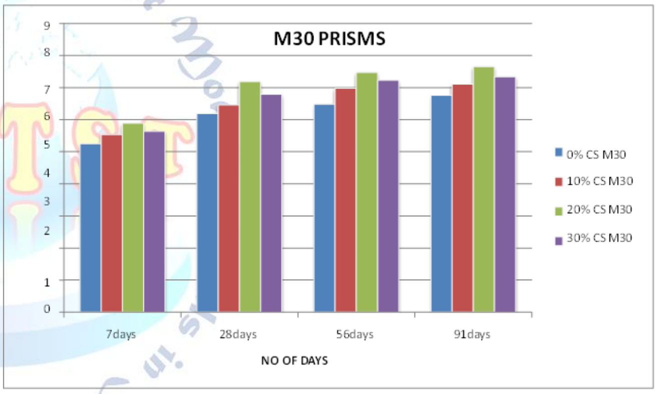

Fig: Variation of Flexural strength for M30 grade of concrete

With Increase in days increase in compressive strength, split tensile strength, flexural strength for M30 grade conventional concrete and concrete with 20% copper slag at different ages.

S.NO	Age (days)	Compressive Strength (MPa)		Increase in compressive strength (%)	Split tensile Strength (MPa)		Increase in split tensile strength (%)	Flexural strength (MPa)		Increase in flexural strength (%)
		0% CS M30	20% CS M30		0% CS M30	20% CS M30		0% CS M30	20% CS M30	
1	7	30.2	35.5	16.39	2.30	2.85	23.91	5.25	5.89	12.19
2	28	42.22	52.0	23.16	2.87	3.72	29.61	6.19	7.19	16.15
3	56	44.44	52.89	19.01	3.25	3.92	20.61	6.48	7.47	15.2
4	91	45.78	53.33	16.49	3.71	4.36	17.52	6.76	7.65	13.16

CONCLUSIONS

Results were analysed to derive useful conclusions regarding the workability, strength characteristics of concrete on replacing natural sand with copper slag in different proportions for M30 grade concrete. The following conclusions were drawn from study.

1. The Compaction factor values of concrete with copper slag are observed to be relatively less when compared to conventional concrete, as copper slag has more water absorption capacity compared to the river sand. Therefore, workability of concrete decreases significantly with the increase of copper slag percentage in concrete.
2. It can be concluded that copper slag can be used as alternative material for natural sand in M30 grade concrete which gives more strength than conventional concrete.
3. It is observed that 20% replacement of natural sand by copper slag is giving better compressive strength when compared to other proportions (0%, 10%, 30%) of mixes for 7,28,56 and 91 days.
4. It is observed that 20% replacement of natural sand by copper slag is giving better split tensile strength when compared to other proportions of mixes for all ages (7, 28, 56 and 91 days).
5. It is observed that 20% replacement of natural sand by copper slag is giving better flexural strength when compared to other proportions of mixes for later ages (7, 28, 56 and 91 days).
6. The compressive strength of copper slag concrete is of order 16.39%, 23.16%, 19.01%, 16.49% for 7, 28, 56 and 91 days respectively when compared with conventional concrete.
7. The split tensile strength of copper slag concrete is of order 23.91%, 29.61%, 20.61%, 17.52% for 7, 28, 56 and 91 days respectively when compared with conventional concrete.
8. The flexural strength of copper slag concrete is order 12.19%, 16.15%, 15.2%, 13.16% for 7, 28, 56 and 91 days respectively when compared with conventional concrete.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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