Effect of Industrial Wastes on Mechanical Properties of Concrete with Partial Replacement on Cement and Fine Aggregate

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Abstract: Concrete is the globally used construction material for various sustainable infrastructures. It is assure that for eco-friendly and sustainable development, several industrial wastes are being utilized in concrete as a alternative for either cement or fine aggregate. This study investigates the effect of using industrial wastes such as copper slag, steel slag and GGBS as a partial replacement for fine aggregate and cement. Initially fine aggregate was replaced by varying proportions (0%, 10%, 20%, 30%, 40%, 50%) of copper slag and steel slag separately. Then an experimental study was conducted on these varying mixes to reveal the compressive strength of the concrete. From the test results, optimum percentage of copper slag and steel slag was determined and optimum mixes were prepared by replacing 20% of cement with GGBS together with optimum replacement level of copper slag and steel slag on fine aggregate respectively. Tests on compressive strength, splitting tensile strength, flexural strength and Elastic modulus of concrete for the optimum mixes were determined and compared with the conventional concrete.

Introduction:

In order to achieve economic growth and development of the country, establishment of various industries are unavoidable. Industries provide employment to the many people and help to improve the economic growth rate of the country. At the same time, wastes or by-products from the several industries produce harmful damage to the environment where it is dumped or deposited. The solid waste from the industries polluted the soil and provides adverse effect to the plants and vegetation. Reuse of industrial waste material or waste by-product in construction sector plays a vital role in minimizing the solid waste disposal an also it was suitable, effective and act as a alternate material for replacing fine and coarse aggregates in concrete. Hence this study deals about the industrial waste materials as alternative for fine aggregate and cement respectively. Utilizing industrial wastes as alternative is not a new thing to literature, but this study compares two slag material as fine aggregate replacement and one more slag material in cement replacement. Copper slag is a by-product of the waste produced during pyrometallurgical extraction or through smelting of copper from sulphide ore at very high temperature. In India, copper slag was generated nearly 22.17 million tons per annum. Due to its inert nature, high stability and poor leachability, it does not pose any harmful impact on the environment and ground water resources. The constituents of copper slag are CaO, Al_2O_3, SiO_2 and Fe_2O_3

which was in very less percentage possess pozzolanic reaction and high sound value.

Various investigations have performed on concrete containing copper slag and the results show that value of workability improved with an increase in copper slag content. Many researchers have reported a systematic increment in compressive strength with an increase in copper slag replacement [19] .Steel slag is an another industrial by product obtained from the conversion of iron to steel in a furnace. Studies on steel slag utilized as fine aggregate in concrete reveals that compressive strength of concrete increases with increase in percentage of steel slag [20]. Ground Granulated Blast Furnace (GGBS) is generated during the process of extraction of iron from it ore. GGBS shows pozzolanic properties and can be utilized as a partial replacement material for cement as a binder. In this present study, copper slag and steel slag are utilized as fine aggregate in various replacement levels of concrete and 20% cement was replaced by GGBS in optimum mixes.

Materials:

Cement: In this study Dalmia 53 grade ordinary Portland cement (OPC) which confirms to IS 12269:1987 was used. The specific gravity of cement was determined as per IS 4031 part 11. The physical properties of cement was mentioned in table 1.

Fine Aggregate: River sand as used as a fine aggregate and its physical properties such as specific gravity and fineness modulus was determined. The sand was well graded and confirms to zone III as per IS 383- 1970.

Coarse Aggregate: coarse aggregate of 20mm size has been used for this study and its specific gravity determination and sieve analysis for coarse aggregate was performed. As per code IS 383-1970 the aggregate as confirmed as single sized aggregate of nominal size.

Copper Slag: copper slag used in this present study was obtained from SIPCOT industries, Chennai. The slag was black in color, glassy texture and abrasive in nature. The density of copper slag was more than the river sand so that the specific gravity also shows high value of 3.52. copper slag shows better mechanical and chemical characteristics that makes the material to be used in concrete as a partial replacement for sand.

Fig.1 steel slag

Fig. 2 copper slag

Steel Slag: steel slag is a non-metallic industrial byproduct, consisting of calcium silicates and ferrites. Steel slag used in this study was obtained from Rambo industries, Coimbatore, Tamilnadu.

GGBS: Ground granulated blast furnace slag was much finer than cement in its particle size, so it was used as a cementious material in concrete. It was procured from astraa chemicals, Chennai and its properties complied with BS: 6699.

Super Plasticizer: super plasticizers are high range water reducers used to improve workability and compaction of concrete. Conplast – SP 430 is the admixture used in this study.

Fig. 3 GGBS

Fig. 4 Slump cone Test

Testing of materials

Specific gravity: It is defined as the ratio of weight of given volume of the material to the eight of an equal volume of distilled water at a stated temperature. As per Indian standard code, IS 2720-1980 part 3, the specific gravity for cement, sand, copper slag, steel slag and coarse aggregate are determined and shown in table 1.

Sieve analysis: sieve analysis also called grain size analysis as performed on river sand, copper slag, and steel slag to determine the particle size distribution and fineness modulus. As per IS code 2386-1963 part I, gradation means the distribution of particle sizes within the total range of size. Well graded means small amount of largest and smallest particles, uniform graded means a large percentage of particles are of same size and gap graded means that most of particles are large in size or small in size with very few particles of an intermediate size. Fig 1 shows the graph of gradation for sand, copper slag and steel slag. From the graph it is found that the river sand, copper slag and steel slag are well graded.

Table 1. Physical properties of river sand, copper slag and steel slag.

Sl. No	Material properties	River sand	Copper slag	Steel slag
1.	Bulk density	1678 g/m^3	3460 g/m^3	3265 g/m^3
2.	Specific gravity	2.52	3.52	3.26
3.	Fineness modulus	2.23	3.14	2.96
4.	Type of fine aggregate	Fine	coarser	Medium
5.	Zone	III	I	II
6.	Color	Brown	Black	Black
7.	Texture	Granular	Glassy texture	Rough surface
8.	Size	0.3 - 0.6 mm	0.6 – 1 mm	0.3 – 1 mm

Slump cone Test: Slump cone test was conducted on fresh concrete to determine the workability of concrete. In this study to keep water cement ratio a constant value, chemical admixture was used and its dosage was determined by using slump value. The apparatus for this test is in the form of frustum cone having height 30cm, bottom diameter 20cm and top diameter 10cm. The slump value maintained throughout this study was in the range of 50mm -75mm as shown in fig.4

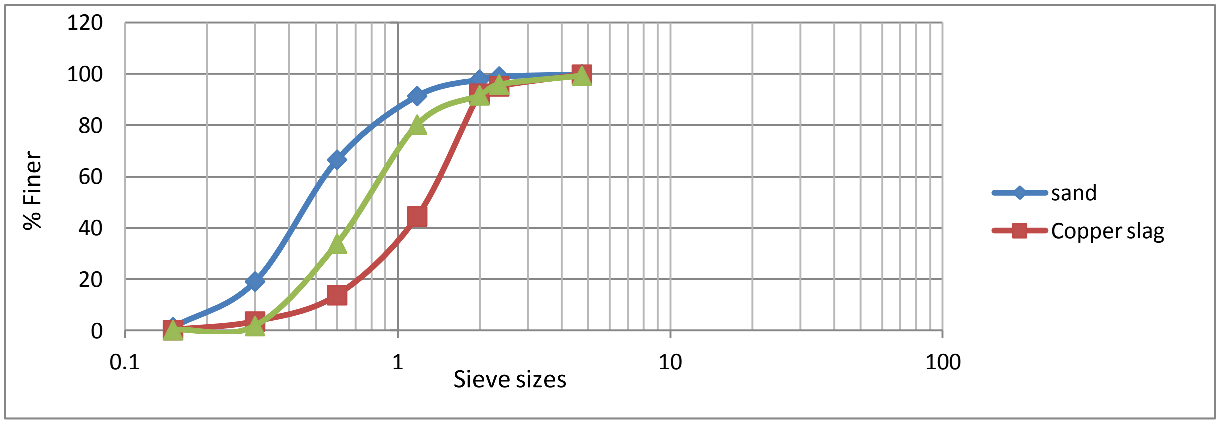

Fig.7 Particle size distribution graph for sand, copperslag and steel slag

3. Experimental Study

3.1 Mix design

The concrete mix design was prepared for M30 grade concrete as per IS10262-2009. The water cement ratio is taken as 0.4 and it was maintained throughout the study by using different percentages of chemical admixture superplasticizer conplast 430 as water reducer. The mix proportion was shown in table 2.

3.2 Mix proportion

The first part of this study is the partial replacement of river sand by copper slag and steel slag separately with varying percentage (0%,10%,20%,30%,40% and 50%). This first part which includes to determine the optimum percentage of copper slag and steel slag replacement level.

The second part is to keep the optimum percentage of copper slag and steel slag as constant and replacing cement by 20% GGBS. OM0 denotes the control mix, OM1 denote the optimum mix 1 (copper slag 40% and GGBS 20%), OM2 denotes the optimum mix 2 (steel slag 30% and GGBS20%).

Table. 2 mix proportion

Sl. No	Mix	Cement kg/m	GGBS kg/m	Sand kg/m	Copper slag kg/m	Steel slag kg/m	Coarse aggregate kg/m	Admixture litre/m	Water litre/m
1.	M_{CC}	383	-	634	-	-	1299	3.064	153
2.	M_1	383	-	570.7	88.58	-	1299	3.064	153

3.	M_2	383	-	507.4	177.1	-	1299	2.681	153
4.	M_3	383	-	444.1	265.68	-	1299	2.298	153
5.	M_4	383	-	380.8	354.26	-	1299	1.915	153
6.	M_5	383	-	317.5	442.84	-	1299	1.532	153
7.	M_6	383	-	570.7	-	82.03	1299	3.064	153
8.	M_7	383	-	507.4	-	164.06	1299	3.064	153
9.	M_8	383	-	444.1	-	246.09	1299	3.830	153
10.	M_9	383	-	380.8	-	328.12	1299	3.830	153
11.	M_{10}	383	-	317.5	-	410.15	1299	3.830	153
12.	OM_{CC}	306.48	76.62	634	-	-	1299	2.298	153
13.	OM_1	306.48	76.62	380.8	354.26	-	1299	1.149	153
14.	OM_2	306.48	76.62	444.1	-	246.09	1299	3.064	153

3.3 Preparation of specimens

The cement and fine aggregate were first mixed together without any lumps and two-third of the required water was first added to the mix and mixed thoroughly then the remaining water was added to get a uniform and homogeneous concrete mix. The chemical admixture, conplast sp 430 was added to the mix as water reducing agent. The admixture dosage as gradually increased from 0 to 1% of cement content to obtain the required workability and the slump value is measured.


Fig.8 casting of specimens

Each mix of varying replacement levels and control concrete was cast in 150mm x 150mm x 150mm cubes to determine compressive strength, 150mm x 300mm cylinders for split tensile and modulus of elasticity test and 100mm x100mm x 500mm prisms for flexural test. All specimens are compacted well in table vibrator and demoulded after 24 hrs and cured by immersion in water for 28 days.

4. Results and Discussions

The test results on mechanical properties of hardened concrete such as compressive strength, split tensile strength, flexural strength and modulus of elasticity determined from the experimental study are discussed below.

4.1 Compressive Strength

Initially compressive strength test was determined to find the optimum percentage replacement of copper slag and steel slag in river sand. From that results, copper slag of 40% and steel slag of 30% replacement in river sand shows more strength than control concrete and it will be taken as the optimum percentage replacement for further tests.

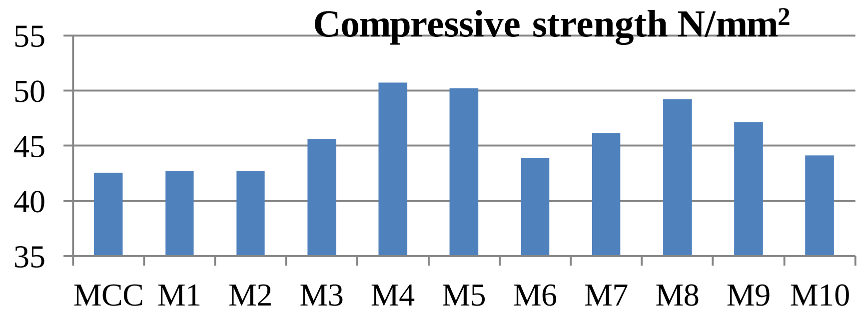

Fig.6 Compressive test results to determine optimum percentage replacement

The cube compressive strength of conventional and replacement concrete for three various Mix with 20% GGBS as cement replacement was determined. It was observed that strength increases throughout all the mixes at 28 days when compared to the conventional concrete. At 40% of copper slag and 30% of steel slag replacement in fine aggregate shows higher compressive strength than conventional concrete. Angular shape and glassy particles of copper slag with fine powder form of GGBS improves cohesion of cement matrix and increase the strength of concrete. Steel slag consists of active C_2S and C_3S, which can react in the hydration process and improves the strength of concrete.

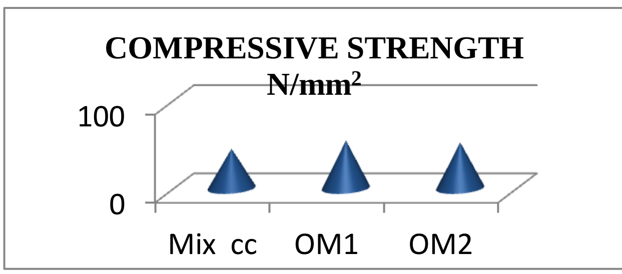

Fig.9 compressive strength results for optimum mixes

Table 3. Compressive strength results

S.NO	MIX	COMPRESSIVE STRENGTH N/mm^2
1	Mix cc	44.79
2	OM1	54.1
3	OM2	51.92

4.2 Split Tensile Strength

The test was carried out as per IS 5816-1999 to determine the tensile strength of the concrete at 28 days on 150mm diameter and 300mm height cylinder. The addition of Copper slag and steel slag in concrete as fine aggregate enhances the split tensile strength of concrete compared to the conventional concrete. At 40% of copper slag and 30% of steel slag replacement in M-sand shows slightly high strength than natural river sand. Steel slag has a rougher surface than natural sand, resulting in a higher bonding strength with cement paste.

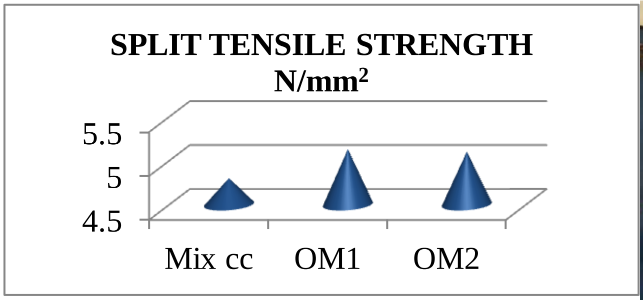

Fig.10 split tensile strength results for optimum mixes

Table 4. Split tensile strength results

S.NO	MIX	SPLIT TENSILE STRENGTH N/mm^2
1	Mix cc	4.8
2	OM1	5.13
3	OM2	5.1

4.3 Flexural Strength: Flexural strength is defined as a material's ability to resist deformation under load. The determination of flexural strength is important to estimate the load at which the concrete members may crack. The flexural strength (Modulus of rupture) was moderately increased when the river sand and M-sand was replaced by copper slag and steel slag. The flexural strength increases with increase in percentage of copper slag and steel slag up to 40% and 30% of fine aggregate. The enhancement in flexural strength is about 19% on copper slag and 17% on steel slag for 28 days curing.

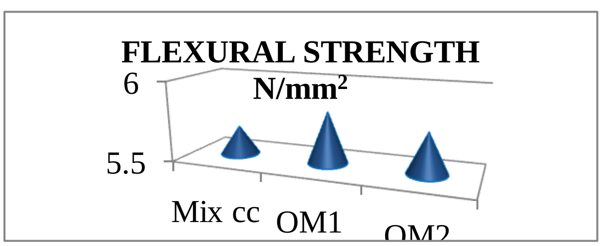

Fig.11 flexural strength results for optimum mixes

Table 5. Flexural strength results

S.NO	MIX	FLEXURAL STRENGTH N/mm²
1	Mix cc	5.68
2	OM1	5.82
3	OM2	5.75

4.4 Modulus of Elasticity

The elastic modulus of the tested specimens can be extracted from the stress-strain curve. The elastic modulus increased slightly due to the addition of 40% copper slag and 30% steel slag content, which is 21.92% and 19.28% higher than conventional concrete. This improvement can possibly be attributed to the high angularity of the both copper slag and steel slag, which resulted in an increase in the bond between the particles and the cement paste.

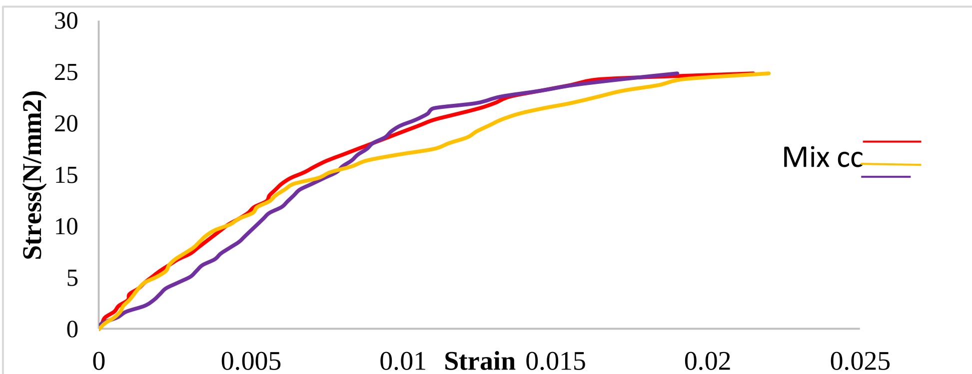

Fig.12 stress strain behavior for determining modulus of elasticity of concrete.

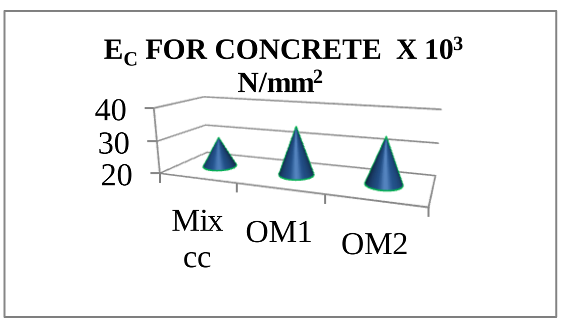

Fig.13 modulus of elasticity results for optimum mixes

Table 6. Modulus of elasticity results

S.NO	MIX	MODULUS OF ELASTICITY E_C X 10^3 N/mm²
1	Mix cc	29.3
2	OM1	34.69
3	OM2	33.75

Conclusion

- From the initial compressive strength results, the optimum percentage replacement level of copper slag and steel slag was found to be 40% and 30%.
- Copper slag of 40% and steel slag of 30% replaced in fine aggregate with 20% of GGBS in cement shows higher strength than conventional concrete for all mechanical properties of concrete.
- Surface area of GGBS is more than OPC which leads to filling of spaces between particles and increase the strength.
- The compressive strength increases upto 40% in copper slag and 30% in steel slag and the improved strength is about 20% and 16% than conventional concrete.
- The split tensile strength increases about 7% and 6% than conventional concrete.
- The flexural strength increases slightly upto 40% in copper slag and 30% in steel slag and the improved strength is about 3% and 2% than conventional concrete.
- The modulus of elasticity of concrete increases upto 40% of copper slag and 30% steel slag and the improved strength is about 18% and 15% than conventional concrete.
- Above the optimum replacement level of copper slag the strength was decreases due to less water absorption of glassy particles of copper slag and increase in bleeding.
- Steel slag of 30% replacement with GGBS gives better strength and dense particle packing structure.
- The workability of concrete decreases with increase in percentage of steel slag leads to decrease in strength above 30% replacement level.

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