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Experimental Investigation On Mechanical Properties Of Concrete With Partial Replacement Of Fine Aggregate

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Abstract

Industrial by-product materials are the most significant partially or fully substitute of fine aggregate in construction industries in these decades. This research investigates the workability and strengths of M-sand-50%, Copper slag-30%, Bottom ash-20%, and Steel slag-20% partially replaced by fine aggregate in concrete. The M-30 grade of concrete was prepared by single, binary & ternary combinations of a total of thirteen different mixes. Ordinary Portland Cement OPC 53 Grade, adopting a water-cement ratio of 0.42 constant, and Superplasticizer Conplast SP-430 were used for better workability and to maintain a slump of 50-75mm for all concrete mixes. The properties examined in the study are workability by using slump test and Mechanical properties such as Compressive, split tensile, flexural strength, and modulus of elasticity of concrete. The result shows that the concrete mixes with M-sand, Copper slag, and Steel slag had better workability, and all the Bottom ash concrete mixes had higher water demand adjusted with a Superplasticizer. The concrete with Copper slag-30% single combination mix had the optimum strength of compressive, split tensile, flexural, and modulus of elasticity compared to the conventional concrete and all other combination mixes.

Keywords: M-sand, Copper slag, Bottom ash, Steel slag, Workability

1. Introduction

Aggregates influence on both the mechanical and rheological properties of concrete and mortars. Their specific gravity, shape, surface texture, and particle size distribution, influence the fresh state properties of concrete and mortars. The mineralogical composition, elastic modulus, degree of alteration, and toughness of aggregates are found to affect the hardened properties of concrete and mortars Goncalves et al. (2007). Concrete is the most broadly used construction material aggregate making 70% of its volume the principal component material in concrete production Devi and Gnanavel (2014). The natural sand consumption is more, due to concrete and mortar usage. Hence the developing countries' rapid infrastructure growth natural sand demand is very high. The shortage of natural sand of good quality in developing countries like India and natural sand deposits are being raised and causing seriously affecting the environment and also society. River sand excavation rapidly from the river beds causes deepening, losing water retaining strata and river bank slides Sankh et al. (2014). Therefore, the developing countries are difficult to identify alternative river sand for reducing the demand. The natural aggregate uses to be reduced as the prime source of the fine aggregates in concrete. Manufactured sand obtained from industrial by-products on alternative material for the concrete in construction Muralikrishnan et al. (2018).

Some alternative materials have already been used in place of natural river sand. For example, M-sand, copper slag, steel slag, bottom ash, rock dust, quarry waste, etc., were used in concrete as a partial or full replacement for natural sand.

2. Literature reviews

Bottom ash has been used to substitute fine aggregate in concrete, according to **Dilip Kumar et al. (2014)**. M30 grade of concrete the fine aggregate, 10%, 20%, 30%, 40%, and 50% of bottom ash is used. They discovered that when 40% of bottom ash is replaced in concrete, the compressive and flexural strengths are greater at 7 days, 14 days, 28 days, and 56 days. Compressive and flexural strength was observed to be reduced after 40% replacement of bottom ash in the concrete.

Bottom ash was substituted by 0, 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 percent by weight since water consumption was high to obtain the needed slump of 100mm, according to **Kadam and Patil (2013)** Compared to control concrete, compressive, split, and flexural strength decreased as the percentage replacement of bottom ash increased. 30% replacement compressive, flexural, split, and water permeability tests are performed the same as that of control concrete.

Muralikrishnan et al. (2018) used produced sand as fine aggregate to determine the characteristics of concrete. As a replacement for sand used in concrete M 60 grade, the percentage of M-sand added by weight was 0, 25, 50, and 75 percent, and cement was replaced by adding GGBS with 0, 5, 10, and 15%, and the dosage of superplasticizer was added 0, 1, 1.3 percent by the weight of cement. They discovered that when natural sand was substituted with 50% M-sand, the optimal percentage of M-sand to achieve high flexural strength was 50%.

Qasrawi et al. (2009) investigated the use of untreated steel slag with a low CaO content as a fine aggregate in concrete. Steel slag was utilized as a fine aggregate in the mixes, partially or completely replacing sand in the ratios of 0 percent, 15%, 30%, 50 percent, and 100 percent. They concluded that when fine aggregates were replaced by steel slag between 15 and 30 percent, compressive strength was improved; however, beyond the 30 percent replacement level, the concrete mix has lower compressive strength than the reference concrete mix at the ages of 28 days, 90 days, and 180 days. The flexural, tensile strength of concrete was maximum with 50 percent steel slag replacement but flexural, tensile strength was higher than the control mix but less than the strength produced at 50 percent replacement at all curing ages.

According to **Bhavagna and Lalitha (2017),** an experimental investigation on concrete (M30) by partial substitution of fine aggregate with copper slag was conducted. Copper slag (CS) was used to substitute fine aggregate in percentages of 20%, 30%, 40%, and 50% by weight of sand. They demonstrated that the workability of the concrete rises with the increase in the replacement of CS with water-cement ratio, and the compressive strength, split tensile strength, and flexural strength was raised by replacing 40% fine aggregate with CS at the age of 3, 7, and 28 days.

Sambhaji and Autade (2016) evaluated the properties of concrete with copper inclusion as a fine aggregate. Copper slag replacement as a fine aggregate with partially or fully using M-25 grade of concrete. They observed that the concrete workability increased at the same W/C ratio with all the percentage replacement levels of copper slag. The replacement of Copper slag has 10% - 30% less workability, 40% - 90% average, and 100% more workability of concrete. The concrete with 50% copper slag inclusion Compressive Strength was higher compared with the conventional mix.

Reddy et al. (2015) investigated the characteristics of concrete with synthetic sand as a substitute for natural sand in quantities of 0%, 20%, 40%, 60%, and 100%. They determined that manufactured sand had limited workability due to the angular particle form, which they compensated for by adding admixtures to the mix. In comparison to other proportions of mixes, replacing natural sand with 60 percent manufactured sand resulted in good compressive strength, split tensile strength, and flexural strength for M20 and M30 grade concrete.

Guo et al. (2018) carried out effects of steel slag partial replacement as fine aggregate on static and impact strength behaviours of concrete incorporated with steel slag by 0%, 10%, 20%, 30%, and 40% volume substitution of fine aggregate The results showed that the improved the compressive strength of dynamic and static at the inclusion of steel slag 20 % as fine aggregate.

3. Experimental program

3.1 Materials used

3.1.1 Cement

Ordinary Portland Cement 53 grade confirming to BIS: 12269 (1987) was used in the concrete mixture.

3.1.2 Fine aggregate

Locally available river sand was used as fine aggregate with a specific gravity of 2.63 and fineness modulus of 2.21 confirming BIS: 383 (1970).

3.1.3 Coarse aggregate

Hard blue granite crushed stone of the nominal size of 20mm was used for the concrete mix and its specific gravity was 2.73 and the fineness modulus was 7.08 confirming BIS: 383 (1970).

3.1.4 M-sand

Manufacturing sand (M-sand) used in this study was taken from Karur, Tamilnadu, India, and its specific gravity was 2.71, and fineness modulus was found 2.42.

3.1.5 Copper slag

Copper slag obtained from Thoothukudi, Tamilnadu, India was used in the investigation. The specific gravity and fineness modulus was found 3.54 and 2.84.

3.1.6 Bottom as

The Bottom ash used in this study was from Neyveli, a thermal power plant in Tamilnadu, India, and its specific gravity and fineness modulus was found 2.48 and 1.96.

3.1.7 Steel slag

Steel slag was obtained from Vedha industries private limited, Karikal, Pondicherry, India, and its specific gravity and fineness modulus was found 2.86 and 2.74.

3.1.8 Water

Water available in the laboratory as potable drinking water was used for making concrete specimens and curing purposes of concrete confirming BIS: 456 (2000).

3.1.9 Superplasticizer

Superplasticizer SP430 Fosroc chemicals confirming to BIS: 9103 (1999) was used as a water-reducing agent and required slump attained in the concrete mixture.

3.2 Mix proportions of concrete

The concrete mix design was prepared under guidelines as per BIS: 10262 (2009). The concrete mix proportion finalized 1:1.45:2.80 (C: FA: CA) with W/C 0.42. The volume of water 178.81 kg/m3, cement (C) 425.73 kg/m3, and coarse aggregate (CA) 1192.46 kg/m3 were kept constant for all the mixes. The volume of fine aggregate (FA) quantity varied from 0 to 618.58 kg/m3. M-30 Grade of concrete with a total of Thirteen mixes of conventional concrete (CC), single combination mixes, and binary and ternary mixes are considered in this investigation. The details of mix designation with mix combinations are presented in Table 1.

Table 1: Combination of Materials

S.No.	Mix designation		Mix combinations
1	CC	Single combination mixes	C+FA100%+CA
2	MS		C+(FA50%+MS50%)+CA
3	CS		C+(FA70%+CS 30%)+CA
4	BA		C+(FA80%+BA20%) +CA
5	SS		C+(FA80%+SS20%)+CA
6	MSCS	Binary mixes	C+(FA20%+MS50%+CS30%)+CA
7	MSBA		C+(FA30%+MS50%+BA20%+ CA
8	MSSS		C+(FA30%+MS50%+SS20%)+CA
9	CSBA		C+(FA50%+CS30%+BA20%)+CA
10	CSSS		C+(FA50%+CS30%+SS20%)+CA
11	BASS		C+(FA60%+BA20%+SS20%)+CA
12	MSCSBA	Ternary mixes	C+(FA0%+MS50%+CS30%+BA20%) +CA
13	MSCSSS		C+(FA0%+MS50%+CS30%+ SS20%)+CA

3.3 Compressive strength

The compressive strength test was conducted on 150mm x 150mm x 150mm standard size concrete cubes at a compression testing machine (CTM) Confirming as per BIS: 516 (1970). The compressive strength was found at 28 days of cured specimens. The load was applied gradually until the maximum load at which the specimen breaks was recorded. The test set up of compressive strength of concrete cube as shown in figure 1.

Figure 1: Test setup for Compressive strength

3.4 Split tensile strength

The split tensile test specimens of 150mm diameter and 300mm length cylinders were cast. This test was carried out after 28 days of curing specimens using a compression testing machine (CTM) with 3000 KN capacity by placing cylindrical specimens between the loading surfaces of the machine and the load was applied until the vertical axis of the cylinder failed values are noted, the test was conducted as per BIS: 516 (1970). The test setup of split tensile strength for the cylinder is shown in figure 2.

Figure 2: Test setup for Split tensile strength

3.5 Flexural strength

Flexural strength test carried out the beams size of 100mm x 100mm x 500mm were used and the test was conducted by standard flexural testing machine under two points loading at the rate of 1000KN capacity load applied. The failure values were recorded and flexural strength was calculated. Tests were conducted as per BIS: 516 (1970). The test setup of the flexural test beam is shown in figure 3.

Figure 3: Test setup for Flexural strength

3.6 Modulus of elasticity

Modulus of elasticity or young's modulus of the concrete test was carried out confirming as per BIS: 516 (1970). Cylinder specimens of sizes 150 mm in diameter and 300mm in height were cast and after a 28-day curing period, the test was carried out. The test setup of the Modulus of elasticity cylinder is shown in figure 4.

Figure 4: Test setup for Modulus of elasticity

4. Results and discussion

4.1 Workability on fresh concrete

The slump cone test of fresh concrete to measure the workability of concrete is given by the BIS: 1199 (1959) for each partial replacement of fine aggregate in concrete combinations, trial mixes were carried out to improve the workability of the fresh concrete by incorporating a superplasticizer Conplast SP 430. The superplasticizer had to be adjusted to get the slump of fresh concrete range of 50mm to 75mm. The workability test results slump values are presented in Table 2.

Table 2: Slump Values

S.No	Mix combinations	S.P (%)	Slump value (mm)
1.	CC	0.50	60
2.	MS	0.30	55
3.	CS	0.30	52
4.	BA	0.60	67
5.	SS	0.50	64
6.	MSCS	0.30	59
7.	MSBA	0.60	53
8.	MSSS	0.50	55
9.	CSBA	0.50	57
10.	CSSS	0.40	54
11.	BASS	0.60	55
12.	MSCSBA	0.60	61
13.	MSCSSS	0.40	56

4.2 Mechanical properties of hardened concrete

4.2.1 Compressive strength

The compressive strength was compared to the conventional concrete specimen with various combination mixes at M-30 grade of concrete after 28 days of curing. The results are shown in Table 3 and the graph is shown in figure 5.

Table 3: Mechanical properties test result

S.No	Mix combinations	Compressive Strength (MPa)	Split Tensile Strength (MPa)	Flexural strength (MPa)	Modulus of elasticity (MPa)
1.	CC	43.65	3.87	5.40	33950
2.	MS	43.73	3.89	5.53	33956
3.	CS	57.25	5.07	7.40	43660
4.	BA	50.81	4.05	5.93	33952
5.	SS	48.82	4.03	6.27	37874
6.	MSCS	38.12	3.78	5.93	33953
7.	MSBA	44.13	4.06	6.47	33956
8.	MSSS	43.67	3.97	6.33	35954
9.	CSBA	33.11	3.34	6.13	31534
10.	CSSS	32.58	3.92	5.93	32259
11.	BASS	34.46	3.89	6.00	33951
12.	MSCSBA	38.15	4.36	6.73	33956
13.	MSCSSS	34.16	3.96	6.27	33950

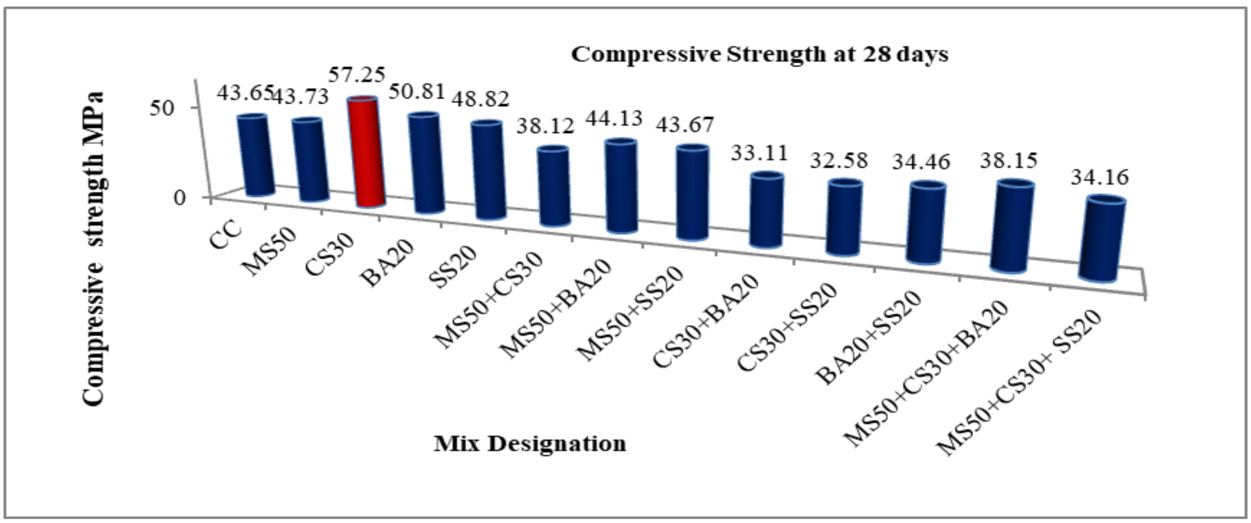

Figure 5: Compressive strength test results

The results showed the compressive strength of concrete with partial or full replacement of fine aggregate in concrete at 28 days of the curing period. The concrete mixes of MS, CS, BA, SS, MSBA, and MSSS strength was increased at 0.18%, 31.16%, 16.40%, 11.84%, 1.10%, and 0.05% compared to the conventional concrete. The concrete mixes of MSCS, CSBA, CSSS, BASS, MSCSBA and MSCSSS strength was decreased at 12.67%, 24.15%, 25.36%, 21.05%, 12.60%, and 21.74% compared to the conventional concrete.

4.2.2 Split tensile strength

The test results on split tensile strength are presented in Table 3 and the graph is shown in figure 6. The results showed the Split tensile strength of concrete with partial replacement of fine aggregate in concrete at 28 days of curing period. The concrete mixes were MS, CS, BA, SS, MSBA, MSSS, CSSS, BASS, MSCSBA and MSCSSS strength was increased at 0.52%, 31.01%, 4.65%, 4.13%, 4.91%, 2.58%, 1.29%, 0.52%, 12.66% and 2.33% compared to the conventional concrete. The concrete mixes of MSCS and CSBA strength were decreased at 2.33% and 13.70% compared to the conventional concrete.

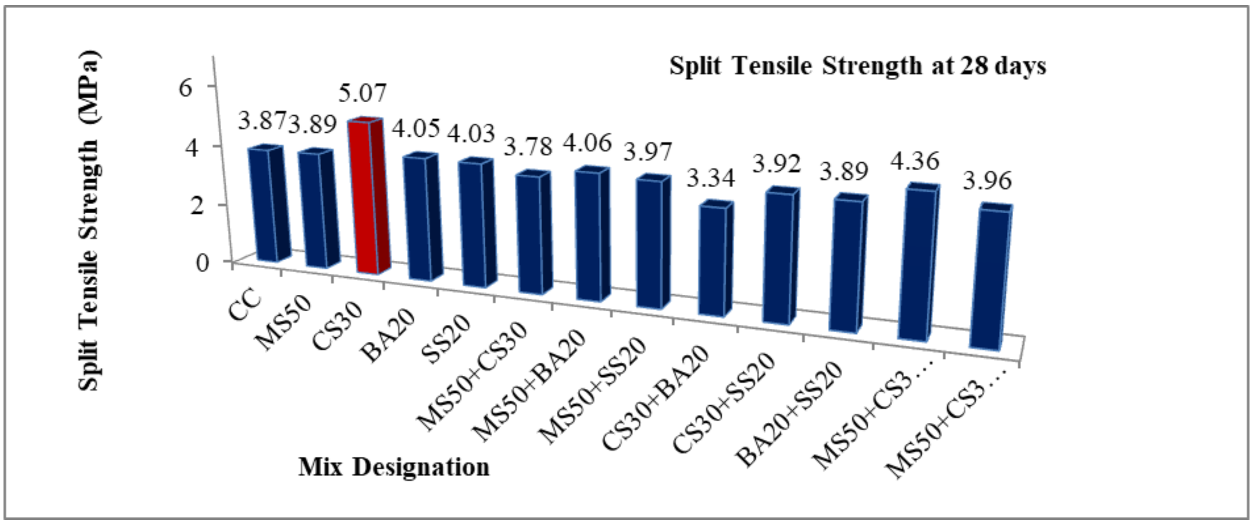

Figure 6: Split tensile strength test results

4.2.3 Flexural strength

The test results on flexural strength are presented in Table 3 and the graph shown is in figure 7. The results showed the flexural strength of concrete with partial replacement of fine aggregate in concrete at 28 days of the curing period. The results are shown in the form of a graph in figure 7. The concrete mixes were MS, CS, BA, SS, MSCS, MSBA, MSSS, CSSS, CSBA, BASS, MSCSBA and MSCSSS strength was increased at 2.41%, 37.04%, 9.81%, 16.11%, 9.81%, 19.81%, 17.22%, 13.52%, 9.81%, 11.11%, 24.63% and 16.11% compared to the conventional concrete.

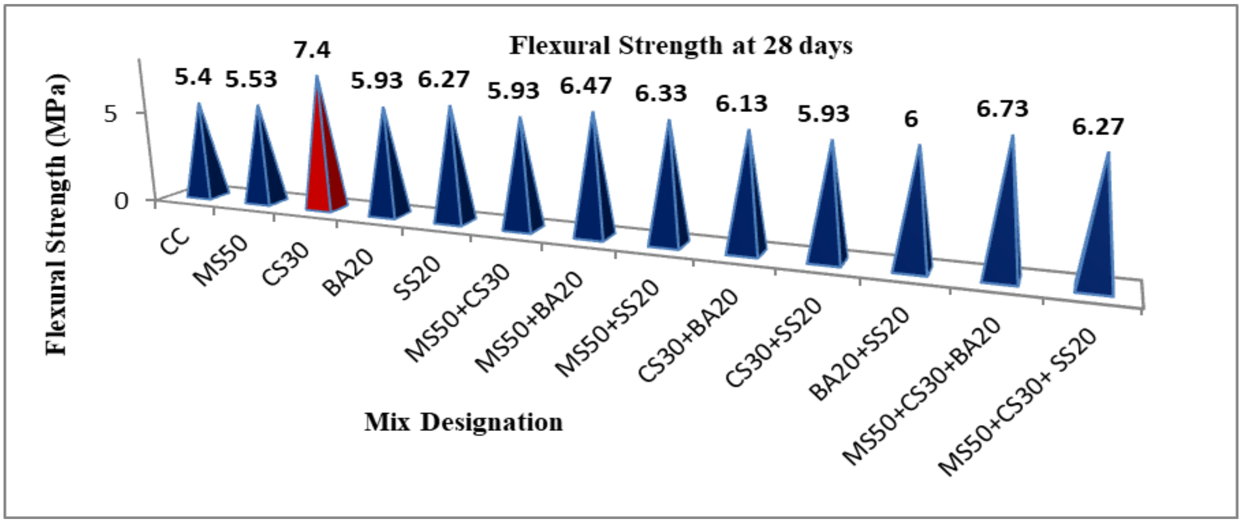

Figure 7: Flexural strength test results

4.2.4 Modulus of elasticity

The test results on the modulus of elasticity are presented in Table 3 and the graph is shown in figure 8. The results showed the modulus of elasticity of concrete with partial replacement of fine aggregate in concrete at 28 days of the curing period. The concrete mixes of strength CS, SS, and MSSS were increased by 28.60%, 11.56%, and 5.90%, and MS, BA, MSCS, MSBA, BASS, MSCSBA, and MSCSSS concrete mixes were approximately the same as compared to the conventional concrete. The concrete mixes of CSBA and CSSS strength were decreased at 7.12% and 4.98% compared to the conventional concrete.

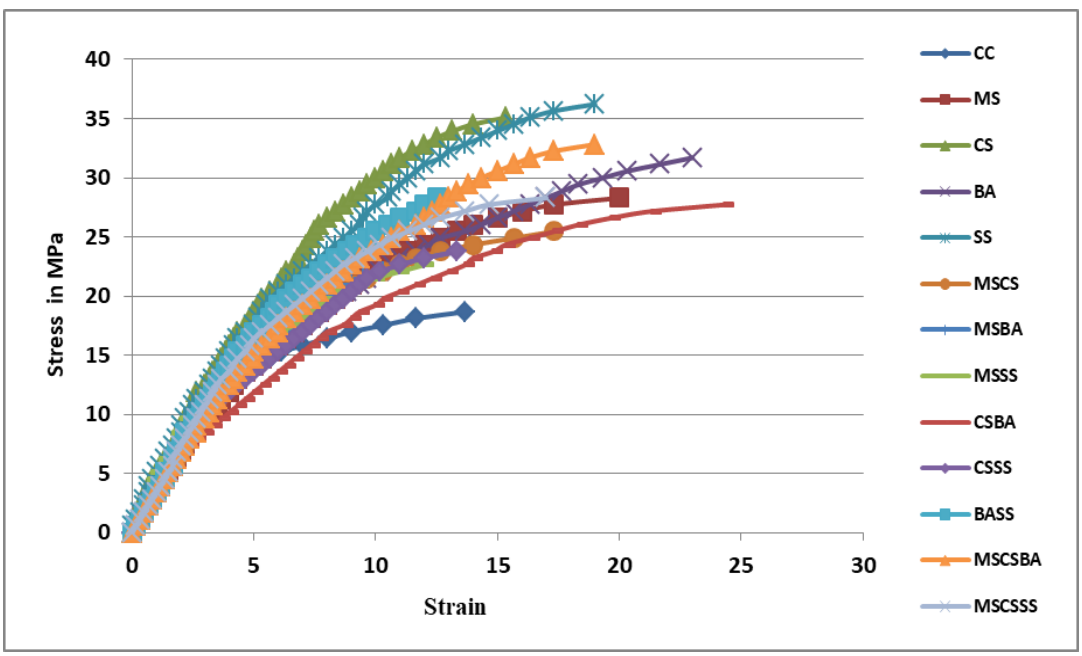

Figure 8: Modulus of elasticity test results

5. Conclusions

Results were analyzed to derive conclusions regarding the fresh property of workability and hardened properties of compressive strength, split tensile strength, flexural strength, and modulus of elasticity of concrete with partial replacement of fine aggregate in different proportions for M30 grades. The following conclusions may be drawn from the study.

- The results of the slump test done on M-sand, Copper slag, and Steel slag concrete with partial replacement of fine aggregate mixes better workability to maintain the slump values 50mm to 75mm.

- The workability of all the Bottom ash combination concrete mixes results indicates that the water demand increased. The amount of superplasticizer was adjusted in each Bottom ash combination mix to maintain a required slump of 50mm to 75mm.

- The 30% Copper slag replacement by natural sand was obtained optimum compressive strength, split tensile strength, flexural strength, and modulus of elasticity of concrete compared to all other combinations of mixes and conventional concrete mix at 28 days curing period.

- The single combination mix of M-sand 50%, Copper slag 30%, Bottom ash 20%, and Steel slag 20% concrete mixes (MS, CS, BA, & SS) compared to the conventional concrete all the mixes obtained higher compressive strength, split tensile strength, flexural strength and modulus of elasticity of concrete at 28 days curing period.

- The Binary combination of mixes of M-sand 50% with Bottom ash 30% (MSBA) and M-sand 50% with Steel slag 20% (MSSS) shows higher compressive strength, split tensile strength, flexural strength, and modulus of elasticity compared to conventional concrete at 28 days curing period.

- Ternary combination mixes 100% fully replacement of fine aggregate by M-sand 50%, Copper slag 30% with Bottom ash 20% (MSCSBA) and M-sand 50%, Copper slag 30% with Steel slag 20% (MSCSSS) shows decreased compressive strength and increased split tensile strength, flexural strength and modulus of elasticity compared to conventional concrete at 28 days curing period.

- Industrial by-products such as M-sand, Copper slag, Bottom ash, and Steel slag are the best alternative for natural sand partial replacement in terms of workability and mechanical properties.

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Conflicts of interest

The authors have no conflicts of interest to declare.

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