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Research Article

Effect of partial replacement of cement by ground granulated blast furnace slag and sand by iron ore tailings on properties of concrete

Ravikiran Kattoli[1*], Brijbhushan.S[2], Maneeth.P.D[2], Shreenivas Reddy.S[3] and Siddharth.B[2]
PG Student, Department of Construction Technology, VTU CPGS, Karnataka, India[1]
Assistant Professor, Department of Construction Technology, VTU CPGS, Karnataka, India[2]
Professor, Department of Construction Technology, VTU CPGS, Karnataka, India[3]

Abstract
Iron ore tailings (IOT) are the mining waste left after extraction of iron ore. The particles of IOT have grain size of sand and since there is a problem of disposal it can be used as an ingredient in concrete. Ground granulated blast furnace slag (GGBFS) is a waste obtained from blast furnace. Since it has fineness similar to cement, it can be used as an ingredient in concrete. In the present experimental investigation, natural sand is partially replaced by IOT at (10%, 20%, 30% and 40%) different percentages. The cement part was substituted with different percentages of the GGBFS (5%, 10%, 15%, and 20%). Tests on fresh concrete and hardened properties were conducted. Slump cone test and compaction factor test was carried out to find the workability of concrete. Compressive strength test, split tensile strength test, flexural strength test and durability test was conducted to find the strength of concrete. Superplasticizer (SP) was added to have good workability for all replacement levels. The concrete with 20% IOT and 10% GGBFS achieved more split tensile (3.86 N/mm^2), compressive strength (53.47 N/mm^2) and flexural strength (7.33 N/mm^2) than normal concrete. In the durability test of cube specimen, as the substitution % of the concrete mixture increases, the water absorption rate increases. Mix design is carried out for M40 grade concrete.

Keywords
Iron ore tailings, Ground granulated blast furnace slag, Superplasticizer and durability.

1.Introduction
Concrete is widely used building material with cement, fine aggregate (FA), coarse aggregate (CA) and water. It has a wide range of structural applications. The ingredients of the concrete must be rightly proportioned to have good workability, high strength and durability.

In the construction industry, the demand for Iron and Steel is increasing day by day. There are many iron ore mining companies being established due to the presence of ample reserve of iron ore in India. After mining process, the waste generated in the form of IOT is about 10 to 12 million tonnes per annum in India [1]. Another waste produced from iron industry is GGBFS.

IOT are the waste left after extracting valuables from the uneconomic portion of the ore. Tailings contain fine-grained particle sizes ranging from sand grain size to a few microns usually in the form of slurry of a mixture of mineral particles and water.

The disposal of IOT was a major burden to the mining industries. Environmental friendly and sustainable disposal methods have to be chosen by the industries concerned.

At present, the IOT are stored in the tailings dam or stockpiled closer to the mining sites. Some of the mining companies use chosen by the industries concerned for land reclamation and as backfill to previously mined-out areas [2].

GGBFS is a glassy granulated fine powder acquired by quenching slag of molten iron from a blast furnace in water or steam. In blast furnace iron ore, coke and limestone are subjected from the top of the furnace, while hot air is driven from the lower part of the furnace moving by a sequence of pipes so that when the material falls, a chemical reaction takes place down the entire furnace. The by-products obtained were slag phases and molten iron with slag floating above the molten iron. The molten iron is tapped off and the molten slag is subjected to quenching. Fragments obtained were ground to have fineness similar to cement [3].

*Author for correspondence

1.1Scope of the work

In order to conserve the natural sand and reduce the cost needed for FA in concrete production, IOT waste generated after ore extraction process is used as a substitute to FA. In many parts of the country, as Steel production plant increases in number, the waste generation is likely to increase. So instead of disposing and causing problem to environment, we can effectively use as a replacement to sand. The IOT material has fine particles of the size of a grain of sand to a few micrometres.

In order to reduce the environmental problem as there is emission of carbon dioxide to atmosphere in the cement production process, GGBFS which is a waste produced from blast furnace is used as an alternative to cement. GGBFS has inherent cementing properties.

1.2Objectives

The objectives of the study are:

1. Replacement of FA by IOT and cement by GGBFS.
2. To determine the properties of IOT and ground GGBFS.
3. To find the workability of concrete for different percentage replacement of IOT and GGBFS.
4. To determine the workability of concrete with the addition of SP for different percentage replacement of IOT and GGBFS.
5. To determine the strength properties of concrete for different percentage replacement of IOT and GGBFS with the addition of superplasticizer.

2.Literature review

The resistance to attack in aggressive environments is due to presence of mineral composition of GGBFS. Cement can't be replaced completely. Even if it is replaced partially it gives good results and sustainable construction [3].

FA is substituted partially at 10%, 20%, 30%, 40% and 50% by IOT. It was seen that as the replacement % increases, workability of mix reduces. Replacement at 40%IOT gave max compression strength than Conventional concrete (C.C) and all other %replacement. The flexural strength was more for reference mix than the IOT substituted mixes [4]. Studied on split tensile and compression strength due to use of IOT as a replacement to FA on road pavements. The split tensile and compression strength was maximum at 40% IOT replacement. The strength starts reducing after 50% IOT replacement [1].

Experimental study was carried for M_{20} grade concrete replacing sand by IOT at 10%, 20%, 30%, 40%, 60%, 80%, and 100%. The max increase in compressive strength occurs for 40% sand replacement. Flexural strength of the reinforced concrete beam is found to be maximum for 40% sand replacement [5].

Cement was substituted by GGBFS at 10%, 20%, 30% and 40%. Fosroc conplast SP was used which had a dosage range of 0.5 to 2 liters per 100 kg cement. The dosage was constant for all mixes that is 1.8% by weight of cement. The concrete mixture having 30% GGBFS achieved the highest compression split tensile and flexural strength with all variations in comparison to conventional concrete mixture [6].

The superplasticizers used in concrete were AUROMIX 400, AUROMIX200, BASF and BUILDPLAST. Using all the superplasticizers caused a remarkable reduction in the requirement of cement content from 425 kg/m^3 (concrete without admixture) to 360 kg/m3 in concretes with admixtures. There was an improvement in workability. There was 10 to 15% increase in Compressive strength. There was 20 to 25% increase in flexure strength. The water absorption and permeability are reduced by about 50% [7].

Studied the properties of M25grade concrete when cement was replaced by GGBFS and natural sand by marble slurry waste. At 40% marble slurry and 20% GGBFS in concrete mix the slump increased and it was also found that the compression, split tensile and flexure strength was more than target strength of M25 grade concrete [8].

Concrete mix with cement replacement by GGBFS will be economical and environmentally sustainable option as it can reduce the emission of carbon dioxide. When cement was replaced partially by GGBFS at 30% there was 13.13% increase in compressive strength and 6.97% increase in flexural strength [9].

Studied on concrete properties, when cement was replaced partially at 30%, 40% and 50% by GGBFS. The dosage of SP was 0.7% by weight of cement for all mix. Based on strength properties the most optimized mix was at 30% GGBFS. Beyond 40% replacement the strength decreases [10].

3.Experimental investigation

3.1Materials

3.1.1Cement

The cement used is ordinary Portland cement 53 grade confirming to IS 12269-1987. It was procured from a single source. Various tests are conducted on cement to check the properties of cement [11]. The properties of cement are listed in *Table 1*.

3.1.2Ground granulated blast furnace slag

It was obtained from JSW cement limited, Vijayanagar works, Bellary. *Figure 1* shows the ground granulated blast furnace slag. *Table 1* shows the physical properties of cement tested in the laboratory. *Table 2* shows the physical properties of ground granulated blast furnace slag.

Figure 1 Ground granulated blast furnace slag

Table 1 Physical properties of cement tested in the laboratory

S. No	Property	Result
1	Specific gravity	3.10
2	Standard consistency	32%
3	Initial setting time	50min
4	Final setting time	270
5	Fineness	5%
6	Soundness	2mm

Table 2 Physical properties of ground granulated blast furnace slag

S. No	Characteristics	Result
1	Colour	off white
2	Fineness (M^2/kg)	382
3	Specific gravity	2.88
4	45 Micron (Residue) (%)	7.4

3.1.3Fine aggregate

Natural river sand (from Shahapur) is used. Various Tests are carried on Sand to find the properties as per IS: 2386 (part-2). The sand used was dry and free from vegetation [12]. Refer *Table 3* for results.

Table 3 Results on fine aggregate

S. No	Properties	Results
1	Specific gravity	2.71
2	Fineness modulus	2.94
3	Water absorption	1.93%
4	Silt content	Nil
5	Bulk density (loose condition)	1.8 g/cc
6	Bulk density (dry condition)	1.97 g/cc
7	Moisture content	Nil

3.1.4Iron ore tailings

It was obtained from Kej minerals, Toranagal village in Sandur Taluk of Bellary district (*Figure 2*). *Table 4* shows the physical properties of iron ore tailings.

Figure 2 Iron ore tailings

Table 4 Physical properties of iron ore tailings

S. No	Characteristic	Value
1	Specific gravity	2.66
2	Colour	reddish brown
3	Water absorption	15.87%
4	Fineness modulus	3.78
5	Optimum moisture content	8.84%
6	Maximum dry density	2.508 g/cc

3.1.5Coarse aggregate

The gravel obtained from local quarries is used as CA. The maximum size of CA is 20 mm. The performance of CA is found by testing according to IS 2386 (Part 3) [13]. 40:60 proportion of 20mm and10mm fraction by mass of CA is finalized for casting. *Table 5* shows the physical properties of coarse aggregate.

Table 5 Physical properties of coarse aggregate

S. no	Properties	Values
1	Specific gravity	2.81
2	Fineness modulus	7.01
3	Water absorption	1.10
4	Shape of coarse aggregate	Angular
5	Bulk density (loose condition)	1.40 g/cc
6	Bulk density (dry condition)	1.59 g/cc
7	Moisture content	16.10%
8	Crushing test	17.40%

3.1.6Water

According to IS: 456-2000, for all works on concrete, potable water without excess salt is used [14].

3.1.7Superplasticizer (Conplast SP430)

SP used in the present investigation is Fosroc conplastSP430.The dosage of SP for different replacement percentages of IOT and GGBFS in concrete is found by conducting trials on slump test.

3.2Mix proportion

Mix proportion for M-40 grade concrete per metre cube after correction for water absorption [15] (*Table 6*).

Table 6 Mix proportion

Cement	FA	CA	Water
1	1.487	2.648	0.508
437.7Kg	650.97Kg	1159.07Kg	222.7Kg

3.3Mixing and casting

First sand, CA and cement (for replacement material IOT and GGBFS are added at different percentages) are mixed in dry condition for one minute, and then water is added (SP is added for replacement materials along with water) and thoroughly mixed to get a uniform mix. The mixing should be done within 3 to 5 minutes. For cubes, concrete is cast in cubical moulds of size 15cm×15cm×15cm. For a cylinder, moulds with 15 cm diameter and 30cm height are used. For prism, a mould of size 50cm length, 10cm width and 10 cm depth is used.

3.4Curing

For curing specimen were immersed in water. It was demolded after 24hrs. The specimens are cured for a specified time.

3.5Experimental tests

3.5.1Tests on fresh concrete

The tests on fresh concrete are performed to measure the concrete workability. Slump and compaction factor test are carried out in our experiment for C.C, MX1 (10%IOT, 5%GGBFS), MX2 (20%IOT, 10%GGBFS), MX3 (30% IOT, 15% GGBFS) and MX4 (40% IOT, 20% GGBFS).

$$\text{slump} = \text{Height after removal of slump cone} - \text{Height before removal of slump cone}$$

$$\text{compaction factor} = \frac{\text{weight of partially compacted concrete}}{\text{weight of fully compacted concrete}}$$

3.5.2Tests on hardened concrete

Compression split tensile, flexure and durability test were performed. % IOT and GGBFS replacement are given as M1A (10%IOT, 5%GGBFS + .15%S.P), M2B (20%IOT, 10%GGBFS+0.5%S.P), M3C (30%IOT, 15%GGBFS+1%S.P), M4D (40%IOT, 20%GGBFS+1.5%S.P) and normal concrete mix (C.C) [16].

3.5.2.1Compressive strength test

Compressive strength of concrete depends on w/c ratio, quality of materials used, strength of cement and quality control (*Figure 3*). Test is carried on compression testing machine (CTM). Loading is controlled through central valve at $14\text{N/mm}^2/\text{ min}$

$$\text{Compressive strength} = \frac{\text{load at failure}}{\text{area of specimen}}$$

Figure 3 Cube subjected to compression test under CTM

3.5.2.2Split tensile strength
It is tested under CTM with two steel plates placed at the top and bottom of specimen (*Figure 4*). Load is applied at the rate of 1.4 to 2.1$N/mm^2/min$.

$$\text{Split tensile strength, Tsp} = \frac{2 \times P}{\pi \times d \times l}$$

P→Applied load, d→diameter
l→length of specimen

Figure 4 Tensile strength test of cylinder

3.5.2.3Flexural strength test
Test can be conducted either by three point loading method or single point loading method. In our project the test is carried on three point loading method. *Figure 5* shows the prism subjected to third point loading method load is applied continuously till the point of failure.

$$\text{Flexural strength, fbt} = \frac{P \times l}{b \times d^2}$$

P→Load at failure, l→support span, b→width, d→depth

Figure 5 Prism subjected to third point loading method

3.5.2.4 Durability test
Water absorption test is carried out to find durability of concrete. If there are more voids then there will be more absorption of water decreasing the durability. Oven and weighing balance are required to carry out the experiment. This test is carried after 56 days curing of cube specimen.

$$\text{water absorption}(\%) = \frac{(W2 - W1)}{W1} \times 100$$

W1→Oven dried weight of specimen
W2→specimen wet weight after immersion in water

4.Results and discussion
4.1Results on fresh properties
Initially the slump test was carried without using any superplasticizer to check the workability of concrete. Based on the test conducted the values of slump cone test and compaction factor test are indicated the table. *Table 7* shows the slump value obtained without superplasticizer. The dosage of superplasticizer and slump value for all replacement level (*Table 8*).

Table 7 Slump value obtained without superplasticizer

S. no	Mix type	Slump value in mm
1	C.C	105
2	MX1 (10%IOT,5%GGBFS)	95
3	MX2 (20%IOT,10%GGBFS)	26
4	MX3 (30%IOT,15%GGBFS)	0
5	MX4 (40%IOT,20%GGBFS)	0

Table 8 Dosage of superplasticizer and slump value for all replacement level

S. no	Mix type	Dosage of SP (%)	Slump value in mm
1	MX1 (10%IOT,5%GGBFS)	0.15	102
2	MX2 (20%IOT,10%GGBFS)	0.5	65
3	MX3 (30%IOT,15%GGBFS)	1.0	75
4	MX4 (40%IOT,20%GGBFS)	1.5	55

As the values of slump obtained for all replacement levels have good workability. Hence the dosages fixed are now incorporated to all the further tests. *Table 9* shows the results of compaction factor test.

Table 9 Results of compaction factor test

S. no	Mix type	Compaction factor
1	C.C	0.95
2	M1A	0.92
3	M2B	0.9
4	M3C	0.91
5	M4D	0.88

As the replacement level increases the compaction factor value decreases. This indicates the fall in the level of workability.

4.2Results on hardened properties

A total of 45 cubes, 45 cylinders and 45 prisms were casted. For each value 3 moulds were casted and test was performed. The average of the three values was taken for each result.

Table 10 shows that the compressive strength was maximum (53.47 N/mm^2**)** for the mix M2B (20% IOT and 10% GGBFS) than the conventional concrete (51.40 N/mm^2).

Table 11 shows that the split tensile strength was maximum (3.86 N/mm^2**)** for the mix M2B (20% IOT and 10% GGBFS) than the conventional concrete (3.53 N/mm^2).

Table 12 shows that the split tensile strength was maximum (7.33 N/mm^2**)** for the mix M2B (20% IOT and 10% GGBFS) than the conventional concrete (7.16 N/mm^2).

In the durability test, the water absorption rate increases as the replacement level increases in the concrete mixture. The water absorption is maximum for mix M4D (40% IOT and 20% GGBFS) that is 0.86% (*Table 13*).

Table 10 Results of compression test

S. no	Mix type	Compressive strength (N/mm^2)		
		3days	7days	28days
1	C.C	18.81	32.29	51.40
2	M1A	17.32	31.55	49.74
3	M2B	21.0	33.75	53.47
4	M3C	16.73	27.70	41.77
5	M4D	14.36	24.13	31.8

Table 11 Results of split tensile test

S. No	Mix type	Split tensile strength (N/mm^2)	
		7days	28days
1	C.C	2.63	3.53
2	M1A	2.44	3.34
3	M2B	2.68	3.86
4	M3C	1.88	3.02
5	M4D	1.46	2.73

Table 12 Test results of flexural strength

S. no	Mix type	Flexural strength (N/mm^2)	
		7days	28days
1	C.C	5.33	7.16
2	M1A	4.66	6.83
3	M2B	5.66	7.33
4	M3C	4.33	6.83
5	M4D	3.83	6.66

Table 13 Durability test results

S. no	Mix type	dry weight in grams (W1)	wet weight in grams (W2)	% water absorption
1	C.C	8439.84	8466	0.31
2	M1A	8661.75	8699	0.43
3	M2B	8629	8673.5	0.515
4	M3C	8618.6	8679	0.7
5	M4D	8745.8	8821.5	0.86

5.Conclusion

As the % replacement of IOT and GGBFS increase in the concrete mix, workability reduces. This is due to IOT which absorbs more water. When superplasticizer was added at different dosages for all replacement levels, it gave good workability. The mix with 20% IOT and 5% GGBFS gave more compressive, split tensile and flexural strength than the conventional mix. The mix with 10% IOT and 5% GGBFS has achieved target compression strength but was less than the conventional mix. In the durability test, the rate of water absorption increases as the replacement level increase. The optimum replacement to be taken for having good strength properties is at 20% IOT and 10% GGBFS in the concrete mix.

With the addition of different admixtures, changing w/c ratio, mix design, using pre-treatment methods further research can be made. Keeping the replacement of 20% IOT constant, the GGBFS % replacement can be increased further to study properties of concrete. More durability tests can be conducted like chloride penetration tests, carbonation test, and air permeability test.

Acknowledgment

None.

Conflicts of interest

The authors have no conflicts of interest to declare.

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Ravikiran Kattoli was born in 1994. He received his Bachelor Degree in the Department of Civil Engineering, PDA college Gulbarga in 2016. At present, he is pursuing his Master Degree in Construction Technology, VTU CPGS Gulbarga.

Email: ravi.sk132@gmail.com