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Effect of Partial Replacement of Sand by Iron Ore Tailing (IOT) and Cement by Ground Granulated Blast Furnace Slag (GGBFS) on the Compressive Strength of Concrete

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***Abstract*— Iron ore tailing (IOT) is a waste generated from iron ore industry. Ground granulated blast furnace slag (GGBFS) is obtained by quenching molten iron slag (a by-product of iron and steel making) from a blast furnace in water or steam to produce a glassy, granular product that is then dried and ground into a fine powder. Millions of tonnes of IOT are produced every year in India and disposal of the same is a huge problem as it leads to environmental pollution. Furthermore, sand is today fast depleting. In this experimental work the effect of replacing sand partially by IOT and cement partially by GGBFS on the cube compressive strength of concrete is studied. It is found that there is no sacrifice on the compressive strength of concrete for all percentages of sand replacement from 0 to 60 by IOT at 10 % replacement of cement by GGBFS and maximum compressive strength is obtained when the replacement percentage of sand by IOT is 50.**

Keywords*— *Concrete; Compressive strength; Iron ore tailing; Ground granulated blast furnace slag.

I. INTRODUCTION

The increasing demand for heavy construction material like steel and iron and ample reserve of iron ore in India has resulted in the establishment of many iron ore mining companies. The residue left after extraction of concentrated iron from iron ore is in the form of slurry. This constitutes the iron ore tailing (IOT) (vide Figure 1) and the same is disposed of in the vicinity of plant as waste material over several hectares of valuable land leading to water as well as land pollution. The production of IOT waste is about 18 million tonnes per annum in India. The safe disposal of large quantities of iron ore tailing is certainly a difficult task and a matter of national and social concern.

Figure 1: Iron ore tailings (IOT)

Ground granulated blast furnace slag (GGBFS) is a by-product from the blast furnaces used in iron production (vide Figure 2). The blast furnaces operate at a temperature of about 1,500 degrees centigrade and are fed with a carefully controlled mixture of iron ore, coke and limestone. The iron ore is reduced to iron and the remaining materials form a slag that floats on top of the iron. This slag is periodically tapped off as a molten liquid and if it is to be used for the manufacture of GGBFS it has to be rapidly quenched in large volumes of water. The quenching optimizes the cementitious properties and produces granules similar to the coarse sand. This granulated slag is then dried and ground to a fine powder.

Figure 2: Ground granulated blast furnace slag (GGBFS)

Many studies have been made in India and abroad on the influence of IOT and GGBFS on the properties of concrete. A few are mentioned here. K Ganesh Babu and V Sree Rama Kumar [1] have studied the efficiency of GGBFS in concrete. An Cheng et al. [2] have studied the influence of GGBFS on durability and corrosion behavior of reinforced concrete. Jun-Wu Xia et al [3] have made studies on strength and bond characteristics of GGBFS Concrete. A. Oner and S. Akyuz [4] have carried out an experimental study on optimum usage of GGBFS for the compressive strength of concrete. Kara P., Korjakins A. and Gulbis R. [5] have studied the compressive strength of concrete with GGBFS. Huang et al. [6] have used iron ore tailings in powder form to partially replace cement to enhance the environmental sustainability of ECC (engineered cementitious composites). Mechanical properties and material greenness of ECC containing various proportions of IOTs were investigated. The replacement of cement with IOTs resulted in 10–32% reduction in energy consumption and 29–63% reduction in carbon dioxide emissions in green ECC compared with typical ECC. Rui Ying Bai et al. [7] have assessed the alkali silica reaction (ASR) of iron ore tailings sand using rapid mortar bar method (GB/T 14684-2001). The replacement of cement by 30% fly ash (FA), 50% ground granulated blast-furnace slag (GGBFS), 10% metakaolin (MK) and replacement of sand by 15% ground iron ore tailings (GIOT) led to the ASR-expansion to below 0.10%. Compared with replacement of cement, replacement of sand led to better performance. Furthermore, the fine particles less than 75µm in iron ore tailings sand are beneficial to the reduction of expansion induced by ASR. Sujing Zhao et al. [8] have explored the possibility of using iron ore tailings to replace natural aggregate to prepare UHPC under two different curing regimes. It was found that 100% replacement of natural aggregate by the tailings significantly decreased the workability and compressive strength of the material. However, when the replacement level was no more than 40%, for 90 days standard cured specimens, the mechanical behavior of the tailings mixes was comparable to that of the control mix, and for specimens that were steam cured for 2days, the compressive strengths of the tailings mixes decreased by less than 11% while the flexural strengths increased by up to 8% compared to the control mix. K.G. Hiraskar and Chetan Patil [9] have utilized the blast furnace slag from local industries to find its suitability as a coarse aggregate in concrete making. The experimental results showed that replacing some percentage of natural aggregates by slag aggregates causes negligible degradation in strength. The compressive strength of blast furnace slag aggregate concrete was found to be higher than that of conventional concrete at the age of 90 days. It also reduced water absorption and porosity beyond 28 days in comparison to that of conventional concrete with stone chips used as coarse aggregate.

II. PRESENT EXPERIMENTAL WORK

In this work, IOT is used as a partial replacement of sand and GGBFS as a partial replacement of cement in concrete. The IOT which was brought from Kuduremukh Iron Ore Company Limited (KIOCL), Kuduremukh for the present work has the properties given in Tables 1 and 2. The properties of GGBFS used in the present work are given in Table 3.

TABLE 1: PHYSICAL PROPERTIES OF IOT

Particle shape	Spherical
Color	Dark tan (brown)
Density	14.5 kN/ m³
Specific gravity	3.425
Optimum dry density (ODD)	1.72gm/cc
Optimum moisture content (OMC)	21 %

TABLE 2: CHEMICAL CONSTITUENTS OF IOT

Item	Percentage
Fe (Iron)	19 %
SiO_2(Silicon dioxide)	69 %
Al_2O_3 (Aluminium Trioxide)	3.0
MnO (Manganese Oxide)	0.2
P (Phosphorus)	0.04
S (Sulphur)	0.08
TiO_2 (Titanic Dioxide)	0.10
CaO (Calcium Oxide)	0.10
MgO (Magnesium Oxide)	0.16
Na_2O (Sodium Oxide)	0.06
K_2O (Potassium Oxide)	0.04
Cu (Copper)	0.003
Ni (Nickel)	0.002

TABLE 3: PROPERTIES OF GGBFS

Fineness	500 m^2/kg
Bulk density	1050 kg/m^3
Relative density (Specific gravity)	3.04
Colour	Off white

The specific gravity of ordinary Portland cement used is 3.04. The initial and final setting times of cement are 90 minutes and 8 hours. The values of the specific gravities of fine aggregate, coarse aggregate, IOT and GGBFS used in the experimental work are 2.367, 2.61, 3.425 and 3.04 respectively. The fineness moduli of fine aggregate, coarse aggregate and IOT are 3.082, 8.365 and 2.134 respectively. Mix proportions were designed by Bureau of Indian Standards Method [10, 11 and 12] and the design stipulations were (i) characteristic compressive strength at 28 days = 20 N/mm², (ii) maximum size of coarse aggregate = 20 mm, (iii) type of aggregate : crushed rock (granite), (iv) workability: 100mm (slump), (v) degree of quality control: good and (vi) type of exposure: mild. The designed mix proportions were 1: 2.4:2.9. Potable water was used for making concrete. The experimental value of slump observed was 105 mm. Concrete cubes of size 100 mm x 100 mm x 100 mm were cast by replacing sand by IOT and cement by GGBFS. The sand replacement and cement replacement percentages used in this work were 0%, 10%, 20%, 30%, 40%, 50% and 60%. The cubes were cured for 28 days and then tested for compressive strength in a compression testing machine in accordance with the specifications of Bureau of Indian Standards [13].

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III. RESULTS AND DISCUSSION

The results of the compression test conducted on concrete cubes with varying percentages of replacement of sand and cement by IOT and GGBFS respectively are given in Tables 4 through 10 and presented in Figures 3 through 9.

TABLE 4: COMPRESSIVE STRENGTH FOR ZERO PERCENT REPLACEMENT OF SAND BY IOT & VARYING REPLACEMENT PERCENTAGES OF CEMENT BY GGBFS

Percentage of replacement of sand by IOT	**Percentage of replacement of cement by GGBFS**	**Compressive strength (N/mm^2)**
0	0	33.0
0	**10**	**34.0**
0	20	29.0
0	30	27.5
0	40	25.4
0	50	24.0
0	60	22.4

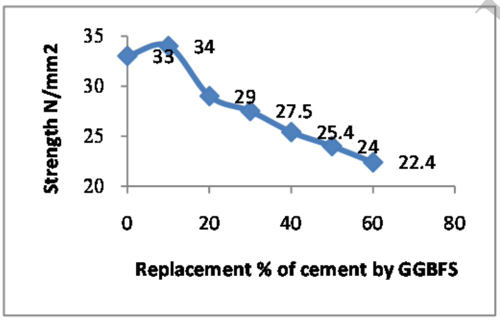

Figure 3: Compressive strength versus replacement % of cement by GGBFS (0%replacement of sand by IOT)

It is observed from Table 4 and Figure 3 that the maximum compressive strength of concrete occurs at about 10% replacement of cement by GGBFS and is about 34 MPa. As the replacement percentage of cement by GGBFS increases beyond 10, the compressive strength reduces.

TABLE 5: COMPRESSIVE STRENGTH FOR 10 PERCENT REPLACEMENT OF SAND BY IOT & VARYING REPLACEMENT PERCENTAGES OF CEMENT BY GGBFS

Percentage of replacement of sand by IOT	**Percentage of replacement of cement by GGBFS**	**Compressive strength (N/mm^2)**
10	0	35
10	**10**	**35.4**
10	20	29.8
10	30	28.4
10	40	26.4
10	50	24.4
10	60	23.0

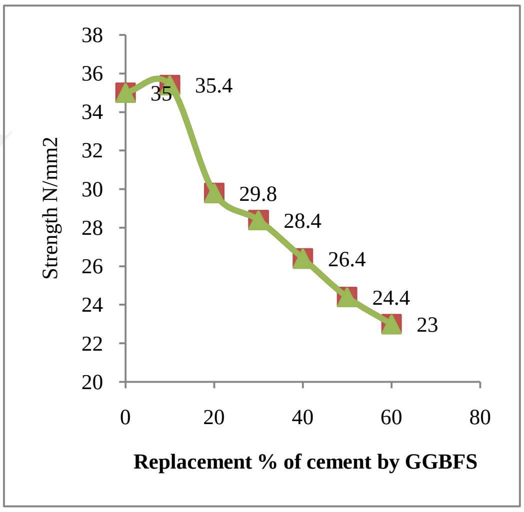

Figure 4: Compressive strength versus replacement % of cement by GGBFS (10% replacement of sand by IOT)

It is observed from Table 5 and Figure 4 that the maximum compressive strength of concrete is about 35.4 N/mm^2 at about 10% replacement of cement by GGBFS. As the replacement percentage of cement by GGBFS increases beyond 10, the compressive strength reduces.

TABLE 6: COMPRESSIVE STRENGTH FOR 20 PERCENT REPLACEMENT OF SAND BY IOT & VARYING REPLACEMENT PERCENTAGES OF CEMENT BY GGBFS

Percentage of replacement of sand by IOT	**Percentage of replacement of cement by GGBFS**	**Compressive strength (N/mm^2)**
20	0	36.2
20	**10**	**37.0**
20	20	31.8
20	30	30.8
20	40	29.2
20	50	28.4
20	60	25.4

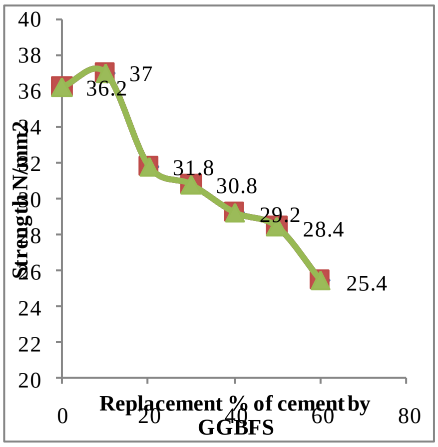

Figure 5: Compressive strength versus replacement % of cement by GGBFS (20% replacement of sand by IOT)

It is observed from Table 6 and Figure 5 that the maximum compressive strength of concrete is about 37.0 N/mm^2 at about 10% replacement of cement by GGBFS. As the replacement percentage of cement by GGBFS increases beyond 10, the compressive strength reduces.

TABLE 7: COMPRESSIVE STRENGTH FOR 30 PERCENT REPLACEMENT OF SAND BY IOT & VARYING REPLACEMENT PERCENTAGES OF CEMENT BY GGBFS

Percentage of replacement of sand by IOT	**Percentage of replacement of cement by GGBFS**	**Compressive strength (N/mm^2)**
30	0	37.4
30	**10**	**38.8**
30	20	33.0
30	30	32.2
30	40	30.8
30	50	30.0
30	60	27.6

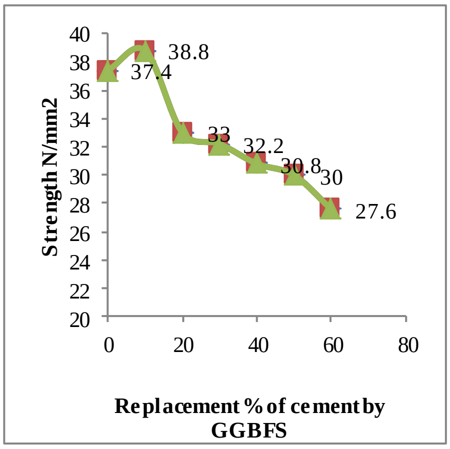

Figure 6: Compressive strength versus replacement % of cement by GGBFS (30% replacement of sand by IOT)

It is observed from Table 7 and Figure 6 that the maximum compressive strength of concrete is about 38.8 N/mm^2 at about 10% replacement of cement by GGBFS. As the replacement percentage of cement by GGBFS increases beyond 10, the compressive strength reduces.

TABLE 8: COMPRESSIVE STRENGTH FOR 40 PERCENT REPLACEMENT OF SAND BY IOT & VARYING REPLACEMENT PERCENTAGES OF CEMENT BY GGBFS

Percentage of replacement of sand by IOT	**Percentage of replacement of cement by GGBFS**	**Compressive strength (N/mm^2)**
40	0	38.4
40	**10**	**39.8**
40	20	34.4
40	30	34.0
40	40	32.4
40	50	31.0
40	60	30.0

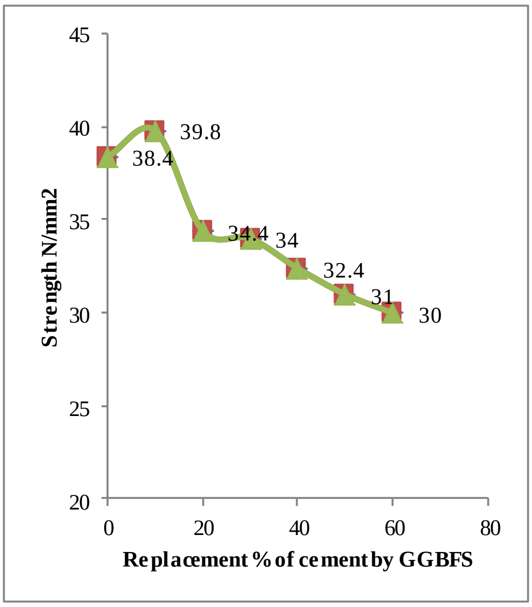

Figure 7: Compressive strength versus replacement % of cement by GGBFS

It is observed from Table 8 and Figure 7 that the maximum compressive strength of concrete is about 39.8 N/mm^2 at about 10% replacement of cement by GGBFS. As the replacement percentage of cement by GGBFS increases beyond 10, the compressive strength reduces.

TABLE 9: COMPRESSIVE STRENGTH FOR 50 PERCENT REPLACEMENT OF SAND BY IOT & VARYING REPLACEMENT PERCENTAGES OF CEMENT BY GGBFS

Percentage of replacement of sand by IOT	Percentage of replacement of cement by GGBFS	Compressive strength (N/mm^2)
50	0	39.2
50	**10**	**42.8**
50	20	37.4
50	30	33.4
50	40	31.8
50	50	30.4
50	60	29.4

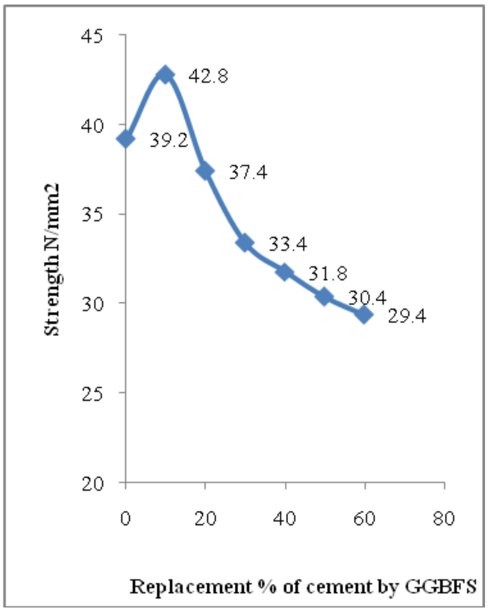

Figure 8: Compressive strength versus replacement % of cement by GGBFS (50%replacement of sand by IOT)

It is observed from Table 9 and Figure 8 that the maximum compressive strength of concrete is about 42.8 N/mm^2 at about 10% replacement of cement by GGBFS. As the replacement percentage of cement by GGBFS increases beyond 10, the compressive strength reduces.

TABLE 10: COMPRESSIVE STRENGTH FOR 60 PERCENT REPLACEMENT OF SAND BY IOT & VARYING REPLACEMENT PERCENTAGES OF CEMENT BY GGBFS

Percentage of replacement of sand by IOT	Percentage of replacement of cement by GGBFS	Compressive strength (N/mm^2)
60	0	36.4
60	**10**	**37.8**
60	20	32.4
60	30	28.4
60	40	26.8
60	50	25.4
60	60	24.4

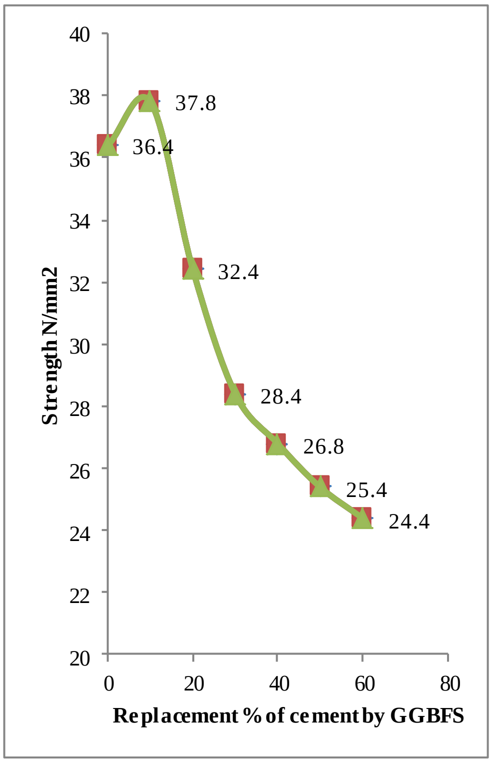

Figure 9: Compressive strength versus replacement % of cement by GGBFS (60% replacement of sand by IOT)

It is observed from Table 10 and Figure 9 that the maximum compressive strength of concrete is about 37.8 N/mm^2 at about 10% replacement of cement by GGBFS. As the replacement percentage of cement by GGBFS increases beyond 10, the compressive strength reduces.

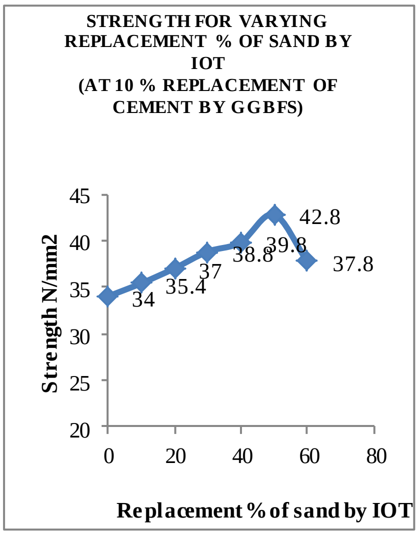

Figure 10: Compressive strength versus replacement % of sand by IOT (At 10% replacement of cement by GGBFS)

From Figure 10, it is observed that the maximum compressive strength of 42.8 MPa occurs at 10 % of replacement of cement by GGBFS and 50 % of replacement of sand by IOT.

IV. CONCLUSIONS

Based on the above study, the following conclusions are drawn:

- The maximum compressive strength occurs at about 10% replacement of cement by GGBFS for all percentages of sand replacement by IOT considered in the present work, namely 0 to 60%. The increase in compressive strength due to addition of GGBFS is not significant. The absolute maximum compressive strength occurs at about 50% replacement of sand by IOT and is equal to 42.8 MPa for the mix considered in the present work.
- There is no sacrifice on the compressive strength of concrete for all percentages of sand replacement from 0 to 60 by IOT at 10 % replacement of cement by GGBFS. Hence, effective use can be made of the IOT, which otherwise would cause environmental pollution when disposed of on land, in situations where concrete is basically subjected to compression without sacrificing the strength of concrete.

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