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A Study on Properties of Concrete Made with Processed Granulated Blast Furnace Slag as Fine Aggregate

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Abstract. This study focusses on understanding the influence of processed granulated blast furnace (PGBS) slag on fresh and hardened state properties of concrete. Nowadays, metallurgical slags are being explored as alternative materials to natural virgin aggregates in concrete. Before using any such material in concrete, it is important to understand its influence on properties of concrete. In this study an attempt has been made to use granulated blast furnace slag from a local steel plant as a substitute to natural sand in normal concrete. The study mainly focusses on understanding the influence of different replacement ratios and suitability of slag replacement ratios higher than 50% in normal concrete. The blast furnace slag used in the present study was processed using a vertical shaft impactor to modify the particle shape and enhance its aggregate properties. The replacement was done at 50%, 75% and 100% by mass of natural sand in the concrete mix. The concrete properties such as slump, compressive strength, splitting tensile strength and flexural strength, were studied at all the replacement ratios.

1. Introduction

The acute shortage of natural sand has made the Indian construction industry to look for all possible alternative materials. In the recent past there are many studies reported on using materials such as waste foundry sand, coal bottom ash, copper slag, steel slag, fly ash, recycled concrete aggregates and mined mineral tailings [1–3], as a replacement to natural sand in concrete. Among all the possible alternative materials explored, metallurgical slags have drawn the attention of researchers and are being examined for their suitability as fine aggregate in concrete. The lack of appropriate engineering data about such materials makes it hard for the designers to use them optimally in construction. In India, a major share of granulated blast furnace slag (GBS) is consumed by the cement industries. Whenever the cement production slows down, the continuously operating blast furnaces make a huge pile of slag and the stocks of this excess slag are mostly dumped on the ground covering fertile land spaces. Researchers are exploring ways to utilise GBS as a replacement to fine aggregates in mortars and concretes. Several investigations are conducted so far to characterize GBS and its influence on properties of concrete [1,4,5]. Yuksel and Genc [6], studied non ground blast furnace slag to make concrete and have reported that compressive strength and flexural strength decreased at higher replacement ratios. Most of the investigations [1,4–6] recommend a GBS replacement ratio in the range of 30%-60%, stating that at higher replacement levels the workability, compressive and tensile strengths of concrete were negatively affected. Nevertheless, attempt to process GBS to improve its material properties and to study the suitability of processed GBS as fine aggregate in concrete have been less explored.

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2. GBS and the processed granulated blast furnace slag

In the present study, at first, unprocessed GBS sample sourced from a local steel plant was investigated (Jindal Steel works, Vijayanagar, India). During the preliminary investigations it was observed that unprocessed GBS had less bulk density, sharp edges and rough surface texture, giving rise to serious workability issues. The material had large number of sharp glassy particles making it extremely difficult to handle during the making of concrete. Further, the GBS was processed at steel plant using a vertical shaft impactor to modify the shape and texture of GBS. The processing method adopted improved appearance, shape and texture of particles. The breakage of particles during processing resulted in increase in the percentage of finer fraction improving the bulk density of aggregate. The typical shape and morphology of GBS and processed GBS (PGBS) observed under scanning electron microscope is shown in figure 1. The properties of GBS, PGBS and natural sand are provided in table 1.

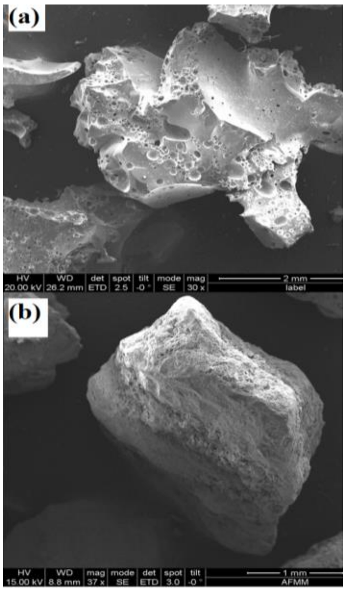

Figure 1. SEM images of (a) GBS and (b) PGBS particle.

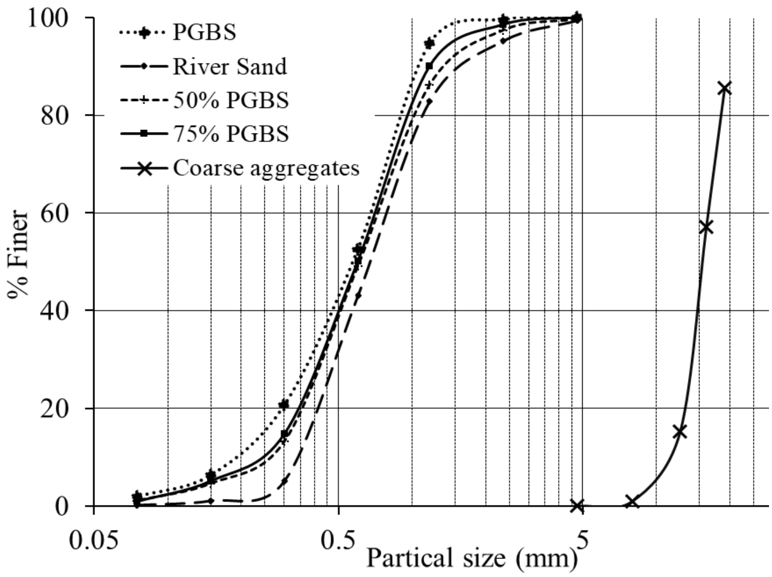

Figure 2. Particle size distribution of aggregates.

Table 1. Properties of GBS, PGBS and natural sand.

Material properties	GBS	PGBS	Natural sand
Bulk density, kg/m^3	1190	1340	1450
Specific gravity	2.65	2.71	2.66
Water absorption, (%) by mass	4.81	5.84	1.07
Fineness modulus	2.89	2.40	2.71

3. Scope of work and experimental program

The present study aimed at characterising the physical and chemical properties of PGBS aggregates. Further, concrete mixes with three levels of PGBS replacement were examined. The mix having 100 % natural sand as fine aggregate was considered as control concrete. Other concrete mixes were prepared by replacing natural sand at 50 %, 75 % and 100 % by PGBS in the control mix. The details of concrete mix and the mix designations are provided in table 2. The investigation aimed at studying the influence of natural sand to PGBS replacement ratios on the properties of concrete such as workability, compressive strength, splitting tensile strength and modulus of rupture. The study focussed on examining compressive strength of concrete mixes at 7, 28 and 90 days and tensile strengths of concrete mixes at 7 and 28 days. The results obtained for concrete mixes with different PGBS content were compared with control concrete mixes of similar age.

4. Materials and mix proportions

Ordinary portland cement (OPC) conforming to Indian Standard specification IS:12269 [7] with a consistency of 32 % and a specific gravity of 3.15 was used. The cement showed an initial setting time and final setting of 165 and 291 minutes respectively and 28-day compressive strength of 56.2 MPa. The physical properties of natural sand and PGBS are presented in table 1. Along with PGBS aggregate the natural sand conforming to IS:383 [8] was used in this study. The particle size distribution of fine aggregates used in the study is shown in figure 2. The PGBS had 33.6% SiO_2, and 22.3% Al_2O_3 along with 26.3% CaO. The MgO in PGBS was about 5% with minor quantities of other oxides. The PGBS showed a lime reactivity of 0.24 MPa. The crushed stone aggregate of size 20 mm and down was used as coarse aggregate. It had a specific gravity of 2.71, bulk density of 1580 kg/m3, and a water absorption 0.35%. Potable water was used to prepare the concrete mixes. A Chloride free, sulphonated naphthalene polymer based super plasticizer from Fosroc brand complying with ASTM C494 standard [9] was used. The concrete mix was designed following the guidelines of IS:456 [10] and IS:10262 [11]. The design was aimed at yielding a concrete slump in the range of 50 to 100 mm. It also aimed at a concrete characteristic compressive strength (f_{ck}) of 20 MPa and a corresponding target cube compressive strength of at least 26.5 MPa at 28 days as per IS:516 [12]. Several trial mixes were studied to understand the relationship of w/c to slump before finalizing the concrete mix proportions. The super plasticizer dosage was adjusted such that the concrete with 100% PGBS yielded a minimum slump of 50 mm. The fine aggregate and coarse aggregate were in air-dried condition at the time of mixing. The moisture content of each batch of aggregates were measured before weigh batching and the total water was adjusted accordingly before adding water to the concrete mix. The details of the concrete mix proportions are summarised in table 2.

5. Specimen preparation and testing

The concrete was mixed, placed, compacted and finished as per the guidelines of IS:516 [12]. A motorized pan mixer was used to mix the concrete ingredients. The consistency of fresh concrete was determined immediately after mixing, by measuring slump as per IS:1199 [13]. All the specimen moulds were compacted using a needle vibrator as specified in IS:516 [12]. The compressive strength was determined by crushing concrete cubes of 150 mm. The concrete cylinders having 150 mm diameter and 300 mm height were prepared for split tensile strength determination. Unreinforced concrete prisms of dimension 100 mm x100 mm x500 mm were cast for flexural strength determination. All the test specimens were cured by soaking in clean water until the date of testing or up to 28 days from the time of casting.

Table 2. Details of concrete mixes.

Mix designations		A	B	C	D
Cement	(kg/m³)	320	320	320	320
Natural sand	(kg/m³)	870.4	435.2	217.6	0
PGBS	(kg/m³)	0	435.2	652.8	870.4
PGBS replacement ratio (% by mass)	(%)	0	50	75	100
Coarse Aggregate	(kg/m³)	1024	1024	1024	1024
W/C ratio	-	0.5	0.5	0.5	0.5
Water content	(kg/m³)	160	160	160	160
Super Plasticizer	(kg/m³)	3.8	3.8	3.8	3.8
Slump	(mm)	112	82	73	58

6. Results and discussions

The results of tests conducted on concrete mixes such as slump measurement, compressive strength, split tensile strength, flexural strength studies are discussed in the following sections.

6.1. Concrete workability

The properties of fine aggregate in concrete have a direct influence on the workability of concrete. The shape and surface texture of the fine aggregate affects the properties of fresh concrete more than the hardened concrete. Compared to smooth and rounded aggregates, rough, angular and elongated particles need higher cement paste to produce desired workability [14]. The slump of fresh concrete was measured within 15 minutes of mixing. Table 2 provides the slump measurements obtained for each concrete mix. The mix with 100% natural sand had the highest slump, i.e., 112 mm. The slump reduced with increasing replacement levels of PGBS. The mix with 100% PGBS gave the least slump compared to all other mixes. The slump loss with 100% PGBS replacement was nearly 50 percent. The PGBS aggregate were more angular, rough and showed higher water absorption compared to natural sand. Therefore, with increase in the PGBS content, the effort required to overcome the intergranular friction also increased, resulting in reduced workability.

6.2. Compressive strength (f_c)

The compressive strength of concrete mixes with respect to PGBS content, at 7 days, 28 days and 90 days has been shown in figure 3. All specimens were cured as mentioned in section 5. The concrete specimens tested at 90 days were cured in water for 28 days and were stored at room temperature until the date of testing. At 7 days, mix B and C showed 7% and 5% higher compressive strength, respectively, than control mix, while mix D with 100% slag showed a reduction in strength of 3%. All concrete mixes achieved the target mean compressive strength at 28 days as per the mix design. At 28 days, the compressive strengths of PGBS based concrete mixes was higher compared to that of control mx. The percentage variation of compressive strength of PGBS based concrete mixes with respect to the control mix is shown in figure 4. Mix 'B' with 50% PGBS replacement ratio performed better under compression compared to mix C and D at all testing ages. The higher compressive strength of mix B could be due to two reasons. One, the inclusion of finer particles of PGBS resulted in better particle distribution and the pozzolanic activity of PGBS aggregate. The PGBS had 17% higher finer fraction compared to natural sand. The combination of 50% of PGBS and natural sand by mass improved the particle distribution in finer zone of aggregate (figure 2). The lime reactivity of PGBS as mentioned in section 3 indicates that, though very weak, PGBS particles may still show some pozzolanic reactions with time. Therefore, there could be some amount of pozzolanic activity shown by finer slag particles contributing to the formation of additional C-S-H. However, quantification of hydration products of concrete mixes and more thorough study of concrete microstructure may help to decisively comment on the compressive strength variation in concrete mixes.

6.3. Splitting tensile strength (fs) and flexural strength (ft) of concrete mixes

The variation of splitting tensile strength and flexural strength of concrete mixes with respect to the PGBS replacement ratios is shown in figure 5 and figure 6 respectively. The variation in the split tensile strength and flexural strength with respect to PGBS content closely followed the trend observed in the case of compressive strength. At 7 days mix 'D' with 100% PGBS achieved lower splitting tensile strength and flexural strength than control mix. At 28 days, the flexural strength of all PGBS based mixes were higher than that of control mix. Mix 'B' with 50% PGBS showed highest split tensile strength and flexural strength compared to all other mixes. According to IS:456 [10], the flexural strength of normal concrete is considered as $0.7\sqrt{f_{ck}}$, where f_{ck} is the characteristic compressive strength of concrete and with that criteria, all the PGBS concrete mixes in the present study achieved the minimum expected flexural strength. For normal concrete, the ratios of splitting tensile strength to compressive strength (fs/fc) and the ratio of flexural strength to compressive strength (ft/fc) ranges between 7-9% and 11-18% respectively [14]. Also, the flexural strength of concrete is almost 1.5 to 2 times that of splitting tensile strength. provides the (fs/fc), (ft/fc) and (ft/fs) values obtained for PGBS concrete mixes. It appears that these values obtained for concrete mixes considered in the present study (table 3) are within the range of values expected for normal concrete. The surface texture and gradation of fine aggregate plays an important role in influencing the crack development of concrete under tension. The rough textured aggregates improves the tensile behaviour of concrete compared to more rounded aggregates during early age of concrete [15]. In this present case, the rough texture of PGBS aggregate particles may have influenced the formation of stronger physical bond between cement paste and aggregate, therefore improving the tensile behaviour of concrete.

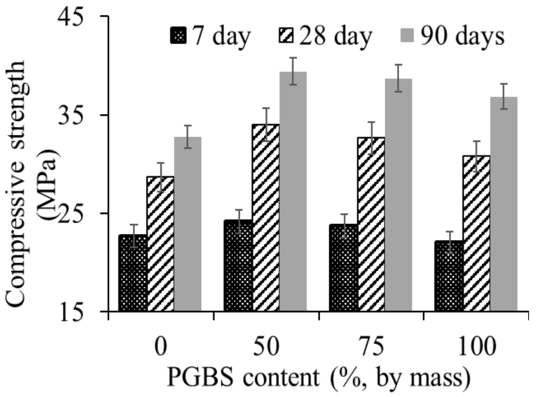

Figure 3. Compressive strength of concrete mixes.

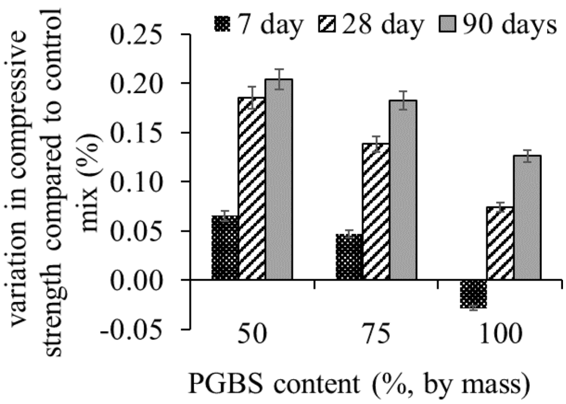

Figure 4. Variation of compressive strengths with respect to control mix.

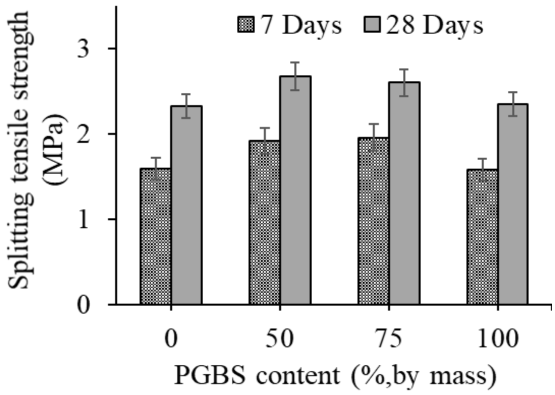

Figure 5. Splitting tensile strength of concrete mixes.

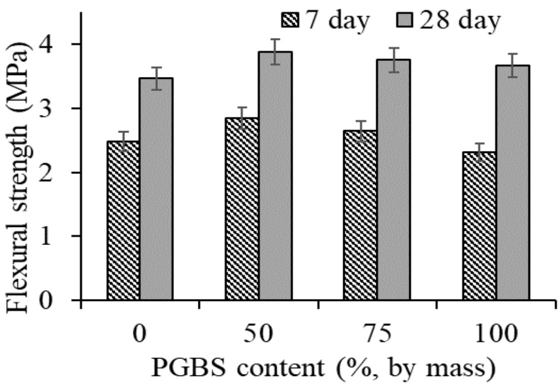

Figure 6. Variation of flexural strength of concrete mixes.

Table 3. The ratios of (f_s / f_c), (f_t / f_c) and (f_t / f_s), of concrete mixes.

PGBS content (%, by mass)	(f_s / f_c) %		(f_t / f_c) %		(f_t / f_s)	
	7 days	28 days	7 days	28 days	7 days	28 days
	7.0	8.0	11	11	1.57	1.50
50	8.0	7.8	12	11	1.49	1.45
75	8.2	8.0	11	12	1.35	1.44
100	7.1	8.1	11	12	1.47	1.58

7. Conclusions

In the present study it was observed that addition of PGBS in place of natural sand positively influenced the properties of concrete except workability and shrinkage. Although, the concrete with 50% replacement levels gave the highest numbers considering strength under compression and tension, it can be concluded that even at 100 % replacement levels, the PGBS concrete showed satisfactory mechanical properties. Therefore, both partial and complete replacement of natural aggregates in concrete is possible with PGBS. Replacement of PGBS in the concrete reduced the workability of concrete significantly. The workability of the concrete decreased with increase in PGBS replacement percentages. However, with incorporation of suitable modern-day superplasticizers, one can achieve desired workability and make the PGBS concrete suitable for the desired application. The PGBS concrete met the strength requirements as per IS 456, both at 7 days and 28 days, at all replacement levels. However, 50% and 75% PGBS replacement showed higher compressive strength, splitting tensile strength and flexural strength when compared to 100% replacement with PGBS.

8. References

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