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Impact of high volume GGBS replacement and steel bar length on flexural behaviour of reinforced concrete beams

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Abstract. The Ordinary Portland Cement (OPC) is one of the major ingredient utilized for the manufacture of concrete. The manufacturing of cement includes the release of huge amounts of CO_2 gas as a main contributor for greenhouse influence and global warming. Several researchers have investigated the characteristics of OPC concrete utilizing cementitious materials like fly ash, silica fume, and Ground Granulated Blast furnace Slag (GGBS) as replacement materials. The article aims to investigate experimentally the flexural behavior of concrete beams with GGBS. The experimental work was divided into three stages, the first one consists of six reinforced concrete beam specimens with (0%, 40% and 60%) of GGBS. During this stage, the used steel bars were 8 mm diameter and 500 mm in length. In the second stage, the length of the steel bars was reduced to 400 mm with the best mixture of (GGBS+OPC) that obtained from stage 1. In the third stage, the best length of steel bars was used with the best (GGBS+OPC) ratio to be tested at 7, 14 and 28 days from the date of casting. Consequences of this exploration suggests that replacement of OPC with 40 percent GGBS with 500 mm steel bar length can be used in reinforced concrete specimens as it shows comparable results relative to control mixtures (0% GGBS).

1. Introduction

Concrete is a necessary material utilized in the Building field [1,2], and as the construction is growing quickly around the globe, the demand for concrete is increasing along with it [3,4]. Concrete constitutes of aggregate and cement mainly. It has been reported that almost 1.35 billion tonnes of Portland cement is consumed [4–6] and in other studies, the consumption was reported to be over 2 billion tonnes annually [3]. Evidently, the energy intensive process of producing Ordinary Portland Cement (OPC) has been increasing in cost [3]. During the recent years, governments and companies in the cement industry has become aware of the negative effects and drawbacks of the usage of the OPC on the environment such as the carbon dioxide (CO_2) emissions [7–11]. The production of 1 tonne of OPC equals to 1 tonne of carbon dioxide emitted to the atmosphere. Worth to note that, approximately 7 % of the emissions of the CO_2 is attributed to the cement industry [12–15]. Therefore, to preserve the environment, CO_2 emissions must be reduced [16]. This led the industry and researchers to investigate suitable replacement to the OPC to decrease this negative influence on the environment [8]. Cementitious waste and/or by-products materials including Meta-kaolin [17], rice husk ash [18], Ground granulated blast furnace slag (GGBS) [19], silica fume [20–25], fly ash [26], waste paper [27], stainless steel powder [28], etc., have been utilized as a replacement to OPC.

The GGBS is a by-product remaining from the steel manufacturing, and utilized as a supplemental cementitious material in the manufacture of concrete. GGBS is extracted from a blast furnace via quenching melted iron slag in water or steam, as result of that, a glassy, granular material would be produced and would require drying and grounding to be turned into a fine powder [3]. The chemical properties of GGBS has shown similarities to the OPC's properties [29], for example, both materials have the formation of CSH gel, however it was stated that; it exists more in GGBS than in OPC and that is a factor in allowing the concrete to gain its strength once GGBS is used as an admixture [30]. The use of GGBS in concrete structure is spreading and chosen often in Europe and recording a grow in utilization in United States of America, Japan and Singapore [31]. Suresh and Nagaraju [31] stated the major benefits of using GGBS in ready mixed concrete such as improving the workability, reducing the risk of thermal cracking, reduce the Alkali Silica Reaction (ASR) and reduce the possibility of reinforcement corrosion.

The OPC replacement with GGBS in the mixing of concrete to be used in reinforced concrete structure members such as beams has been under the study by many authors. Deepa and Anup [3] conducted experimental investigation with the aim of decreasing the cost and environmental impact of normal concrete by using GGBS and recycled coarse aggregate (RCA) in casting reinforced beams. The study found that the combination of 20% of both GGBS and RCA is the optimum mix that would attain the maximum strength for beams with similar flexural behavior, deflection and crack pattern to ordinary reinforced concrete beams. Hawileh et al [7] and Abbas et al [32] argued that there was a lack of research done on high replacement percentage of OPC with GGBS on beams. The study conducted tests on eight beams sample with replacement of 50, 70, and 90%. The samples were compared relatively against beams with 0% GGBS. The investigation reported that the 70% replacement of OPC with GGBS is the optimum combination as it showed similarities in performance to the control mixture (0% GGBS). Concrete is known to be a fragile material that would fail under brittle failure.

Limited studies explored the combined impact of substituting OPC by GGBS and length of steel bars on the flexural performance of reinforced concrete beams. Therefore, this research was conducted with the aim of investigating both the impact of substituting the OPC by high volume (40% and 60%) GGBS and the utilization of steel bars with different lengths (400 mm and 500 mm) on the flexural strength of reinforced concrete beams.

2. Materials and Methodology

2.1. Materials

2.1.1. Binder Materials

The binders that utilized in this article were GGBS and OPC. The kind of cement was CEM-II/A/LL 32.5-N. The binder materials (GGBS and OPC) were supplied by Hanson Heidelberg Cement and CEMEX, United Kingdom, respectively. The GGBS and OPC chemical compositions was investigated by an Energy Dispersive X-ray Florescence Spectrometer (EDXRF) brand Shimadzu EDX-720. Table 1 demonstrated the GGBS and OPC chemical analysis.

Table 1. Chemical Analysis of GGBS and OPC.

Composition	OPC	GGBS
CaO	65.21	42.51
SiO_2	24.56	41.06
Al_2O_3	1.7	5.12
Fe_2O_3	1.64	-
MgO	01.3	4.25
Na_2O	01.34	3.09
K_2O	0.82	0.69
SO_3	2.62	1.27
TiO_2	-	0.98
LOI	0.28	0.37
pH	12.73	11.02

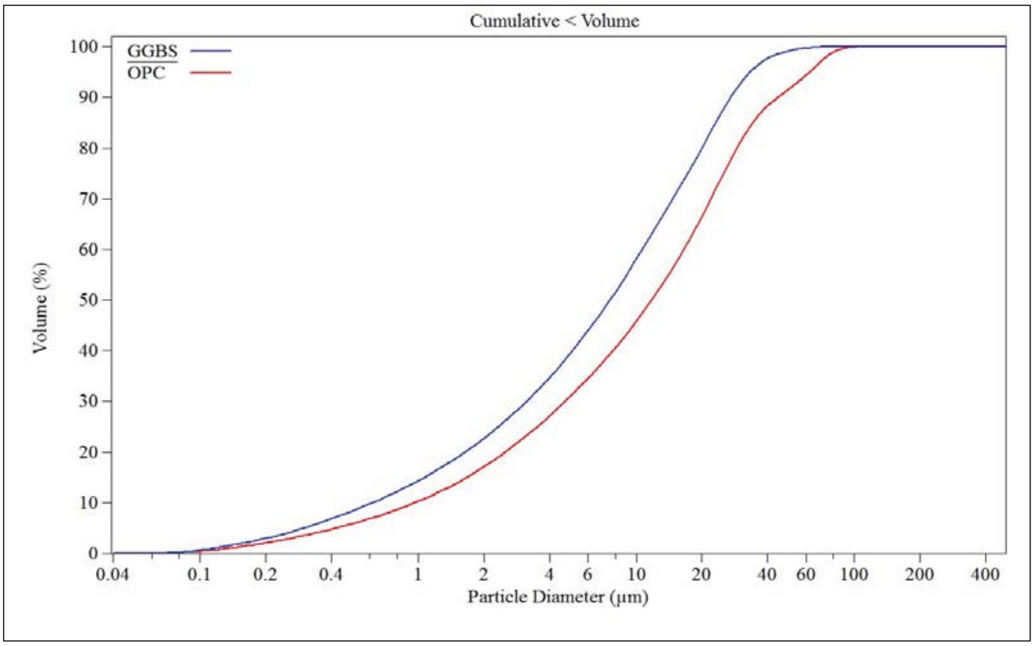

Figure 1. GGBS and OPC particle distribution curve.

The distribution of particle size (PSD) is a major physical examination that gives details on the binder materials scale. The (GGBS and OPC) particle size distribution collected from the analyser laser particle size as demonstrated in Figure 1. The compressive strength of concrete and mortar is greatly influenced by the PSD of the binder components (GGBS and OPC). In concrete and mortar manufacturing, the fine particles of the substance utilized as partial substitute for cement, in order to gain the better compressive strength [33]. In Figure 1, it could be shown from the distribution line graph of particle size that GGBS is finer particles compared to OPC. This implies that the performance of concrete beams will be increased by applying GGBS.

2.1.2. Fine and Coarse Aggregate. For the preparation of the mortar specimens, building sand moving from sieve size 3.35 mm has been utilized. The British standard BS EN 196-1 defines this form of sand. The distribution of the particle size of the sand is given in Figure 2. Additionally, limestone coarse aggregate was used with 20 mm maximum size in preparing all the concrete mixtures.

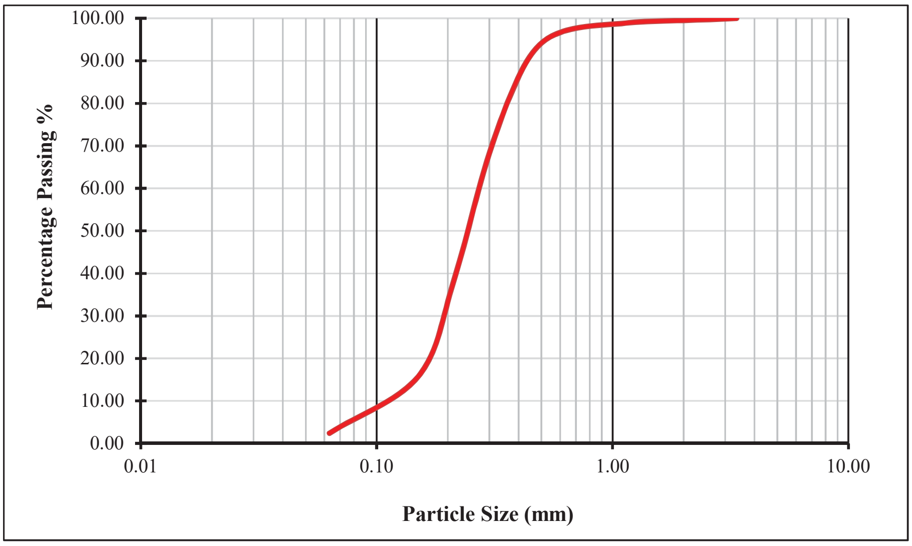

Figure 2. Sand particle distribution curve

2.1.3. Steel bar. Steel bars with 8 mm diameter with different length 400 mm and 500 mm was used as a reinforcement for concrete beam.

2.2. Methodology

2.2.1. Step one. Three sets of samples (six beams) have been cast and checked by Phase One. 2 beams have been evaluated as follows to every set.

All the selected beams were checked for flexural strength and the findings were contrasted with the control beam of 100 percent Portland cement (First Set). The optimum performed beam has been sent to the second stage for 400 mm steel bar length testing. The approach of using one steel bar reinforcement is suggested by the authors.

Table 2. Mixing proportions for step one.

	OPC	GGBS	Age of test	The length of steel bars
First Set	100%	0%	Seven days	500 mm
Second Set	40%	60%	Seven days	500 mm
Third Set	60%	40%	Seven days	500 mm

2.2.2. Step two. At the step two, either the 60 percent or 40 percent concrete based GGBS will be tested at 7 days based on their performance at the first step but with 400 mm steel bar this time. The main aim of decreasing the length of the steel bar is to reduce the cost of the used materials and this approach is suggested by the authors. The increasing in the GGBS% which may resist the flexural strength, is the more eco-friendly concrete (With less OPC).

At the same Step, two beams were tested and the results were compared with the specimens of the similar percent but various steel bar length.

2.2.3. Step three. Depending on the results gained from the Step 2, the optimum specimen with best performance (either 60 percent or 40 percent GGBS with steel bar length of 400 mm or 500 mm) will be chosen for the third stage.

At the same Step, three beams were tested at age (7, 14 and 28 days to determine the performance at various testing ages

The performance of different reinforced concrete beams with dimensions of 500 x 100 x 100 mm (Figure 3) was evaluated by flexural strength test that was conducted through four points loading (Figure 4). Table 3 provided details about the concrete mix design used in this investigation.

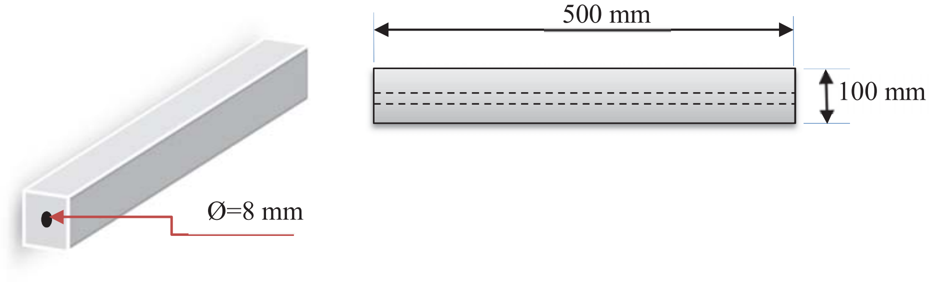

Figure 3. Beam cross-section and details.

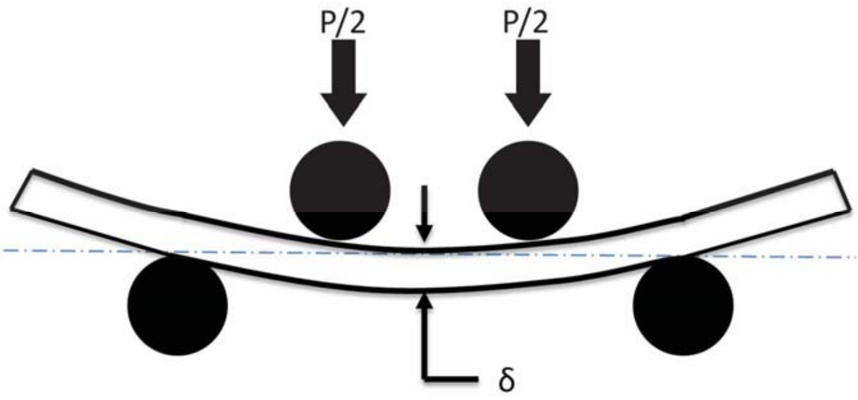

Figure 4. Loading condition for all tested beams.

Table 3. The mixing design of the Concrete

Amounts	**Cement**	**Water**	**Fine aggregate**	**Coarse aggregate**
Per m^3	456	205	528	1231
0.005 m^3(for every beam)	2.28	1.025	2.64	6.155

*All materials was measured in kg

3. Results and Discussion

3.1. Effect of GGBS

The using of GGBS in concrete works as an alternative material that showed similar behavior as normal concrete with OPC only due to the similar chemical composition OPC and GGBS as shown in Table 1. Table 4 and Figure 5 show that with increasing GGBS replacing ratio the average flexural Strength decreased. Using of 40% and 60% GGBS lead to decrease the average flexural Strength from 1.625 MPa for control sample with 0% GGBS to 1.19 MPa and 0.905 MPa, respectively. As the mixture with 40% GGBS (Second Set) showed better performance than the mixture with 60% GGBS (Third Set), therefore, Second Set mixtures was used in Step 2.

Table 4. Step 1 flexural strength results (MPa) at the age of 7 days.

Step 1					
OPC	**GGBS**	**The length of bars**	**Specimen 1**	**Specimen 2**	**Average flexural Strength (MPa)**
100%	0%	500 mm	1.63	1.62	1.625
60%	40%	500 mm	1.18	1.2	1.19
40%	60%	500 mm	0.89	0.92	0.905

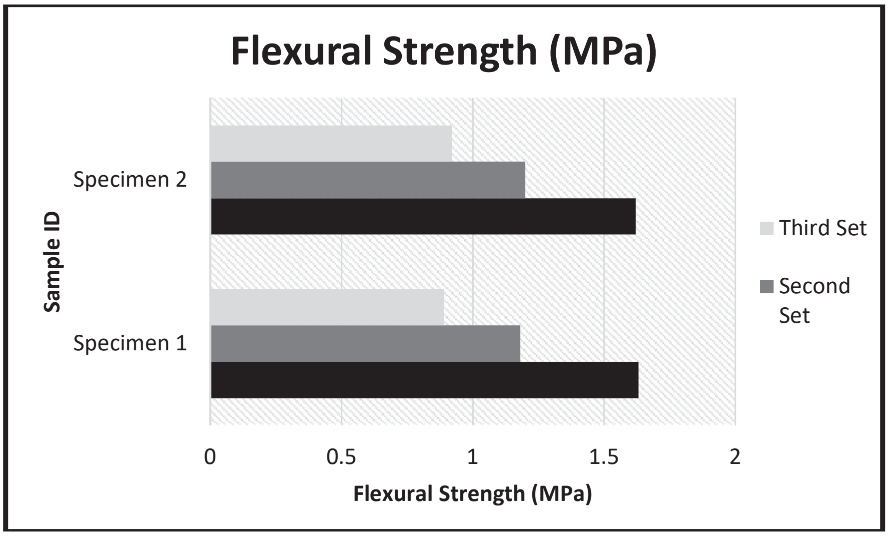

Figure 5. Flexural Strength Results using 500 mm steel bars.

3.2. Effect of steel bar length

The changing in the steel bar length cause an effect on the Average flexural Strength. Table 5 shows that the decreasing the steel bar length affected negatively on the Average flexural Strength (MPa) at 7 curing age. In comparison with second set in the first step, it has been shown decreasing steel bar length from 500 mm to 400 mm lead to decrease the average flexural Strength from 1.19 MPa to 0.885 MPa. Therefore, 500 mm steel bar length was considered as the optimum bar length that utilised in Step 3.

Table 5. Step 2 flexural strength (MPa) at the age of 7 days

Step 2					
OPC	GGBS	The length of bars	Specimen 1	Specimen 2	Average flexural Strength (MPa)
60%	40%	400 mm	0.89	0.88	0.885

3.3. Effect of curing age

As well known the curing age has significant effect on the strength of the concrete samples with Pozzalanic materials due to the hydration of cement and creating of cement gel increase with extend the curing age from 7 to 28 days. Table 6 shows that with 500 mm steel bar length, the average flexural strength was increases from 1.19 MPa at 7 days to 1.72, 1995 MPa after 14 and 28 days of curing, respectively. This improvement in the flexural strength with increasing the age of curing is mainly attributed to the glassy phase of GGBS, which takes longer time to react with water [34–38].

Table 6. Step 3 flexural strength (MPa) at age 7, 14 and 28 days

Step 3					
OPC	**GGBS**	**bar length (mm)**	**Ave flexural (MPa)Strength at 7 days**	**Ave flexural (MPa)Strength at 14 days**	**Ave flexural (MPa)Strength at 28 days**
60	40	500	1.19	1.72	1.995

4. Conclusion

The aim of this research was to investigate the impact of high volume GGBS replacement and steel bar length on flexural behaviour of reinforce concrete beams. Based on the obtained results, it can conclude that:

1. The use of slag in concrete resulted in decreasing the average flexural strength and the ratio of decreasing increased with increase the GGBS content
2. The reduction in the length of steel bar lead to decrease the average flexural strength for the same replacement ratio.
3. There is a significant improvement in the flexural strength of concrete beams incorporated GGBS with extending the age of curing from 7 to 28 days by about 68%.

5. Recommendations for future studies

It is worth mentioning that the drawn conclusions are within the study limitations and conditions. Therefore, changing any of the conditions could significantly affect the results. For future investigations, authors recommended the utilization of different waste and/or by products in the production of RC beams to improve the sustainability and reduce the cost of such wastes and/ or by product materials. For example, industrial wastes [39–45], agricultural waste [46,47], municipal solid wastes [48] and waste from water and wastewater planes [19,49]. Moreover, due to the role of openings in reducing time and cost for bending pipes under the beams [50], the application of the replacement method used in this study to reinforced concrete beams with openings is a worthy issue

[51]. Additionally, modeling the RC beams using artificial intelligence model [52] is also recommended.

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