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Partial Replacement of Cement by Ground Granulated Blast furnace Slag In Concrete

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Abstract

The increased quest for sustainable and eco-friendly materials in the construction industry has led to research on partial replacement of the conventional constituents of concrete by two selected waste materials. The broad aim of this work was to investigate the effects of partially replaced Ordinary Portland Cement (OPC) by ground granulated blast furnace slag (GGBS) on the properties of concrete including compressive strength, tensile splitting strength, flexure, modulus of elasticity, drying shrinkage and initial surface absorption. Results showed that the compressive and tensile splitting strengths, flexure and modulus of elastic increased as the GGBS content increased. The percentage drying shrinkage showed a slight increment with the partial replacement of OPC with GGBS. However, concrete containing GGBS failed the initial surface absorption test confirming that GGBS decreases the permeability of concrete. The optimum mix was the one with 50% GGBS replacement. Thus, GGBS can potentially be used as a cement replacement material for structural concrete applications in line with the sustainability targets of Mauritius.

Keywords: OPC, aggregates, GGBS workability, compressive and tensile splitting strengths

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INTRODUCTION

The manufacture of concrete, primarily its ingredients; cement and aggregates; presents various sustainability issues that need to be dealt. The production of concrete has always lead to massive exploitation of natural resources. Manufacturing 1 tonne of Portland cement requires quarrying 1.5 tonnes of limestone and clay (Civil and Marine, 2007). Moreover, continuous extraction of natural aggregate; sand and gravel; from river beds, lake and other water bodies over the years have led to erosion which eventually leads to flooding and landslides. Further, there is less filtration of rainwater due to reduced amount of natural sand, causing contamination of water needed for human consumption. 1.4 tonnes of Ordinary Portland cement being produced yearly around the globe contributes to 5 percent of greenhouse gas, carbon dioxide, emissions worldwide (Civil and Marine, 2007). Not only burning fuel to heat the kiln emits carbon dioxide, but also decomposition of limestone emits even more gas. These identified problems clearly, contribute significantly to climate change. The ideal target to partly solve the above phenomenon is to develop a sustainable system loop which can turn resources which are landfilled as waste materials into useful products in the construction industry, thus preserving the natural resources.

GGBS, a by-product of iron manufacture, is a glassy, non-metallic granular material which exhibits cementitious properties on its own while others do so in the presence of Portland cement and calcium sulphate which are activators. Thus, GGBS acts as pozzolans and is therefore combined with Portland cement; resulting in a hardened cement of GGBS combined with Portland cement, which has more of smaller gel pores and fewer larger capillary pores than that of normal Portland cement which consequently results in lower permeability and hence greater durability. Moreover, it contains less free lime, which in its presence forms ettringite or efflorescence, and makes the resulting hardened cement more chemically stable. In addition, GGBS has a lower content of C_3A than normal cement, thus decreasing the reactivity with sulphate (Neville & Brooks, 2008). A.Oner and S.Akyuz (2007) presented a laboratory investigation on optimum level of GGBS on the compressive strength of concrete by replacing cement at different percentages by GGBS; 0%, 15%, 30%, 50%, 70%, 90% and 110% by weight; and the concrete mixes were tested at day 7, 14, 28, 63, 119, 180 and 365.

It was found that compressive strength of concrete increased as amount of GGBS increased and after an optimum percentage of 55% of GGBS, there was a decrease in compressive strength upon further addition of the slag. The shrinkage of GGBS and that of normal concrete was found to be similar (Cervantes & Roesler, 2007).

This paper presents experimental work carried out to determine the effect of partial replacement of OPC with GGBS. The compressive strength, drying shrinkage, initial surface absorption, static modulus of elasticity, initial surface absorption, tensile splitting strength and flexural strength are investigated. The optimum GGBS content is also determined. However, this research is limited to unprocessed GGBS obtained from a local supplier in Mauritius.

MATERIALS AND METHODS

Selection of Materials

Ordinaly Portland Cement (OPC) conforming to ASTM C-150 / European Standard EN 197-1, CEM 1 42.5 N was used. The natural aggregates used were natural crushed basaltic rock obtained locally. The coarse aggregates used were angular crushed aggregates having a maximum size of 20mm. The fine aggregates used were washed crushed rocksand with a size range 0-4mm. Tap water was used for mixing the raw materials. The GGBS used in this study was unprocessed and obtained from a local supplier.

Concrete Mixes

Three concrete mixes were prepared. The control mix (CM) A consisted of 100% OPC. In mixes B and C, the cement was partially substituted with 30% and 50% of GGBS by weight respectively. The fine aggregate content was kept constant for all mixes. The British method also known as the 'DoE method' was used for the mix design process. This method of design comprises of tables and charts available at the Building Research Establishment (BRE). The target strength of all mixes was 50 N/mm^2 and the target slump was 135-155 mm. The proportions of materials for each concrete mix are shown in Table 1.

Table 1 - Mix Proportions of Mixes

Materials (kg/m^3)	% GGBS		
	A: 0%	B: 30%	C: 50%
Cement	388	272	194
GGBS	0	116	194
Coarse aggregate 14/20	670	670	670
Coarse aggregate 6/10	335	335	335
Fine aggregate 0/4	857	857	857
Water	225	225	225

Casting and Curing

For each mix, six 100mm×100mm×100mm cube, 75mm×75mm×300mm prisms and 150 mm diameter x 300 mm long cylindrical test specimens were cast. After 24 hours, the specimens were de-moulded and cured in water at room temperature until they were tested.

TESTING

Compressive Strength

The compressive strengths of three 100mm x 100mm x100mm test cubes were determined in accordance with BS EN 12390-3:2009: Testing hardened concrete: Compressive strength of test specimens. The specimens were tested for 7 and 28 day strengths.

Drying Shrinkage

The drying shrinkage of three 75mm×75mm cross, 300mm prisms was determined as per the requirements of BS ISO 1920-8:2009: Testing of concrete. Determination of the drying shrinkage of concrete for samples prepared in the field or in the laboratory. The drying shrinkage was calculated as the difference in length between the wet and dry measurement (oven dried for 14 days at a temperature of 50 to 65^{o}C), expressed as a percentage of the length of the specimen.

Static Modulus of Elasticity

The modulus elasticity in compression of concrete were determined for three 150mm diameter, 300mm long cylinders according to BS 1881 Part 5: 1983 - Method for determination of static modulus of elasticity in compression. This was carried out to determine the stiffness of the concrete samples after 28 days of curing.

Initial Surface Absorption Test (ISAT)

The initial water absorption of three 100 mm x 100 mm x 100 mm test cubes was determined in accordance with BS 1881: Part 208: 1996 – Recommendations for the determination of the initial surface absorption of concrete after 28 days of curing. This was carried out in order to determine the permeability of the concrete.

Tensile Splitting Strength Test

The tensile splitting strength of the three 150mm diameter, 300mm long cylinders was determined according to BS EN 12390-6:2009: Testing hardened concrete: Tensile splitting strength of test specimens after 28 days of curing.

Flexural Strength

The flexural strength of three 75mm×75mm cross, 300mm concrete prisms was determined according to BS EN 12390-5:2009: Testing hardened concrete: Flexural strength of test specimens after 45 days of curing. A load was applied on the specimens with an increasing rate until failure of the specimen occurred

RESULTS AND DISCUSSION

Compressive strength

The compressive mean strengths of the test specimens for Mixes A, B and C at 7 days and 28 days are summarised in Figure 1.

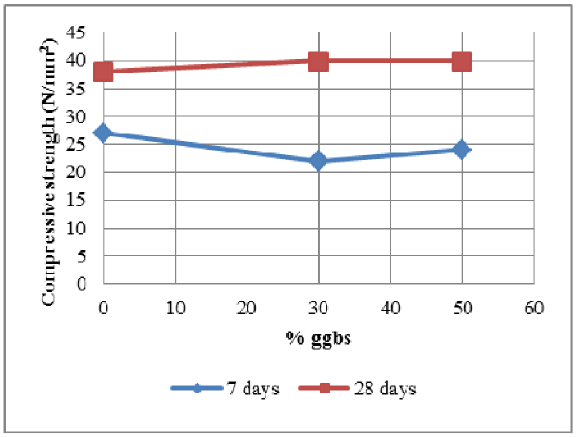

Figure 1 – Variation of compressive strength with GGBS content

It can be observed that there is a general increase in the compressive strength of all test specimens from Day 7 to Day 28. This is due to the development of C_2S in the concrete resulting in strength gain.

At 7 days, it is also observed that the compressive strength reduces by 19 % and 11% when OPC is partially replaced with 30% and 50% of GGBS respectively. On the other hand, the compressive strengths of the samples with 30% and 50% GGBS are both 5% greater than that with 100% OPC. The results confirm that the presence of GGBS in concrete leads to lower early strength gain but higher later strength.

Drying Shrinkage

The results for the drying shrinkage tests for all mixes are shown in Figure 2. It is observed that as the OPC is replaced by 30% and 50 % of GGBS, the drying shrinkage increases by 3% and 4% respectively. This confirms that the as the GGBS content increases, the drying shrinkage also increases.

Static Modulus of Elasticity

The modulus of elasticity for all mixes is shown in Figure 4. It is observed that as the GGBS content increase to 30% and 50%, the modulus of elasticity of the test specimens increases by 5% and 13% respectively in comparison with the 100% OPC mix. This confirms that the addition of GGBS results in the formation of a denser cement matrix which lowers the porosity of the concrete thereby increasing the modulus of elasticity.

Initial Surface Absorption Test (ISAT)

Table 2 summarises the initial surface absorption at 10, 30 and 60 minutes. The initial surface absorption of the samples at 10 minutes for all mixes is shown in Figure 3.

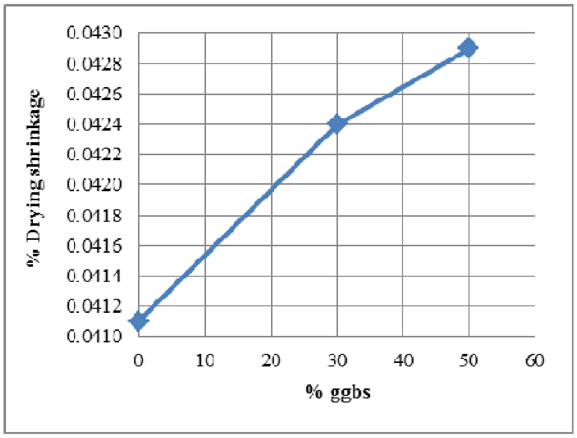

Figure 2 – Variation of drying shrinkage with GGBS content

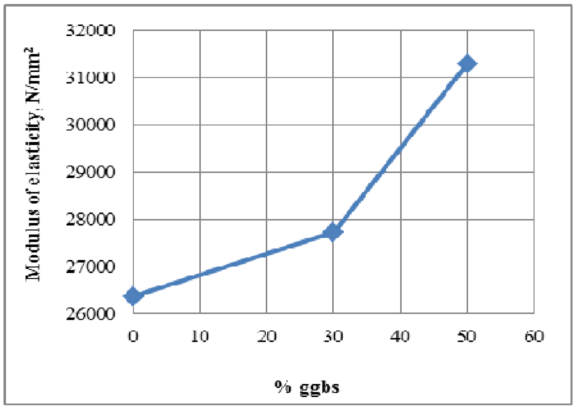

Figure 3 – Variation of modulus of elasticity with GGBS content

Table 2 – ISAT results with varying GGBS content

Mix	Initial Surface Absorption, ml/(m²s)		
	10 min	30 min	60 min
A	0.0500	0.0400	0.0100
B	0.0005	-	-
C	0.0000	-	-

For Mix A (100% OPC), it is observed that the initial surface absorption decreases with time. This is due to the development of the C_2S matrix in the concrete thereby preventing the absorption of water in the concrete surface. Figure 3 shows that as the GGBS content increases, the initial surface absorption decreases significantly. Results also confirm that as the GGBS content increases, the concrete becomes too impermeable to be sensitive for the test to a longer term test (30 and 60 minutes). This can be attributed to the pozzolanic effects of GGBS which results in a much denser matrix than samples consisting of 100% OPC.

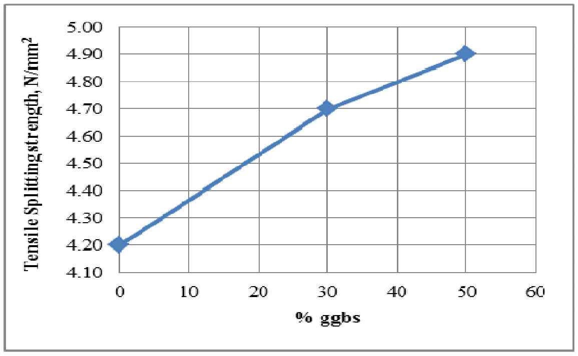

Figure 5 – Variation of tensile splitting with GGBS content

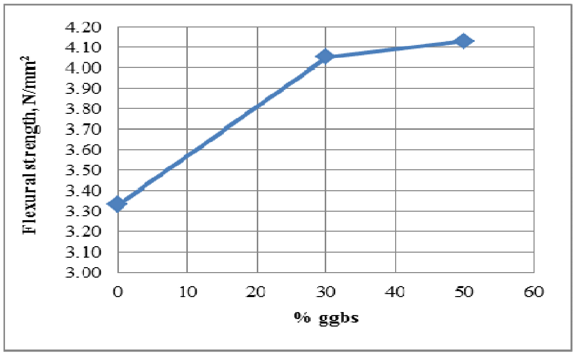

Figure 6 – Variation of flexural strength with GGBS content

Tensile Splitting Strength Test

The tensile splitting strength variation for all mixes is shown in Figure 5. Results indicate that as the GGBS content increases to 30% and 50%, the tensile splitting strength increases by 12% and 17% respectively compared to the 100% OPC mix. When GGBS is added to the concrete, stronger bonds develop between the GGBS cement paste and the aggregate which leads to a rise in the tensile splitting strength of the test specimens.

Flexural Strength

Figure 6 shows the flexural strength results for each mix. It can be seen that as OPC is partially replaced by 30% and 50% of GGBS, the flexural strength increases by 22% and 24% respectively. This is due to the formation of more cement gel upon addition of GGBS, thus resulting in stronger bonds between cement paste and aggregate.

CONCLUSION

The aim of this paper was to determine the effect of partially replacing OPC with 30% and 50% of GGBS on the fresh and hardened properties of concrete. The main conclusions are as follows:

- The partial replacement of OPC with GGBS improves the workability but causes a decrease in the plastic density of the concrete.
- The compressive and tensile splitting strengths, flexure and modulus of elasticity increases with increasing GGBS content.
- The drying shrinkage shows a slight increment with GGBS.
- GGBS fails the initial surface absorption test confirming that the surfaces of their concrete mixes were practically impermeable.
- Based on the results, the optimum mix is the one with 50% OPC/50% GGBS.

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