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Strength Tests on Geopolymer Concrete Made With Black Rice Husk Ash and Ground Granulated Blast Furnace Slag

S. POORNIMA

Amara Institute of Engineering & Technology, Narasaraopet, Guntur, Andhra Pradesh, India

Abstract: **The principal ingredient of concrete, Ordinary Portland Cement (OPC) is unfortunately found to be associated with some adverse effects. Employing such by-products as alternates for cement has multiple benefits including conservation of environment, sustainability of resources and solving the disposal problem of by-products. One of the alternative is 'Geopolymer Concrete' (GPC) .The source materials of geopolymer could be of geological origin like metakaolin or by-product materials like fly ash, Ground Granulated Blast furnace Slag (GGBS), silica fume, rice-husk ash, etc. Black Rice Husk Ash (BRHA) is an agro-industrial waste obt ained by incinerating the rice husk and has a high content of unburnt carbon. Consequently, the use of BRHA as a construction material is very limited, even though it has high silica content about 90%. The objective of the present study was to develop geopolymer concrete mixtures using GGBS and BRHA. The investigation utilized GGBS as the base material for making the control geopolymer concrete. Then BRHA was used to replace GGBS in the mix in three different proportions, from 10-30%, for the rest of the mixes used in the study Basic strength parameters like tensile strength, flexural strength and modulus of elasticity of GPC were studied. Besides Addition of BRHA beyond 10% in GPC retarded its strength development. However, the strengths were well above the target strength up to 20% replacement levels of BRHA in GPC At the same time, addition of BRHA significantly improved the durability. Addition of BRHA beyond 20% is not beneficial.**

Keywords: **geopolymer, concrete, Ground Granulated Blast furnace Slag, Agro waste, Black Rice Husk Ash, Modulus of elasticity, tensile strength.**

I. INTRODUCTION

The production of OPC is highly energy intensive and emits high amount of CO_2 into the atmosphere which contributes significantly to the 'Green House' effect. Bhanumathidas & Mehta (2001) stated that the production of one tonne of cement consumes nearly about 1.5 tonnes of earth minerals and also one tonne of CO_2 is released into the atmosphere. The raw materials required for cement production are non-renewable and are depleting at a rapid rate. But at the same time, a number of industrial and agro wastes with inherent cementitious properties are produced abundantly. But they are mostly disposed into landfills. Employing such by-products as alternates for cement has various benefits including conservation of environment, sustainability of resources and solving the disposal problem of by-products. Particularly in India, with the ever growing demand for cement to cater the rapidly developing constructions and infrastructure projects, the impact created by OPC on the environment is massive. Hence, there is an immediate necessity to control the usage of OPC by developing potential alternates for it. One such alternative is 'geopolymer concrete' (GPC) which completely eliminates OPC in its. In 1978, Joseph Davidovits (1999) proposed that it is possible to produce binders resulting from the polymerization reaction between alkaline liquids and source materials that are rich in silica and aluminium. He coined the term 'geo-polymer' to describe this family of mineral binders that possess a chemical composition similar to zeolites but exhibiting an amorphous microstructure. Paloma et al (1999) suggested that pozzolanic materials like blast furnace slag can be activated with the help of alkaline liquids to produce binders which could completely replace OPC in concrete production. [1] Black Rice Husk Ash (BRHA) is an agro-industrial waste generated from rice milling industry [2]. It is obtained by incinerating the rice husk. The resultant ash from this combustion process has a high content of unburnt carbon. Consequently, the use of BRHA as a construction material is very limited, even though it has high silica content about 90%. Although, several researchers including (Chatweera & Lertwattanaruk 2011; Piyaphanuwat & Asavapisit 2009) have reported that the addition of BRHA in concrete has improved its durability property. The results of this investigation may provide useful data on the strength and durability of geopolymer concrete that has been developed from GGBS and BRHA, which are essentially industrial by-products. Such tested scientific information on geopolymer concrete will help in changing the perception of conventional concrete and also a broader recognition of this material in practical applications. In this investigation, GGBS was utilized as the base material for making the control geopolymer concrete. Then BRHA was used to replace GGBS in the mix in three different proportions, for the rest of the mixes used in the study. Basic strength parameters including tensile and flexural strengths of geopolymer concrete were studied[4].

II. METHODOLOGY

A. Properties of Ground Granulated Blast Furnace Slag (GGBS):

GGBS conforming to the specifications of IS 12089-1987 was used as the primary binder to produce GPC in which BRHA was replaced from 0% to 30%. GGBS was obtained from JSW cements limited, Bellari, India. The chemical composition and physical properties of GGBS were tested are given in Table 1. [6].

TABLE 1: PROPERTIES OF GGBS

S. No	Property	Value
1.	Silicon-di-Oxide (SiO_2)	31.25 %
2.	Aluminium tri oxide (Al_2O_3)	14.06 %
3.	Ferric Oxide (Fe_2O_3)	2.80 %
4.	Calcium Oxide (CaO)	33.75 %
5.	Magnesium Oxide (MgO)	7.03 %
6.	Loss on Ignition	1.52%
7.	Specific gravity	2.61
8.	Blaine fineness	4550 cm^2/g

B. Properties of Black Rice Husk Ash (BRHA):

BRHA was obtained from a rice mill near Karaikudi. It was finely ground in a ball-mill for 30 minutes and passed through 75 sieve (Rashid et al, 2010) before using in GPC production. The chemical composition and physical properties of BRHA were tested given in Table 2.

TABLE 2: PROPERTIES OF BRHA

S. No	Property	Value
1.	Silicon-di-Oxide (SiO_2)	93.96 %
2.	Aluminium tri oxide (Al_2O_3)	0.56 %
3.	Ferric Oxide (Fe_2O_3)	0.43 %
4.	Calcium Oxide (CaO)	0.55 %
5.	Magnesium Oxide (MgO)	0.40 %
6.	Loss on Ignition	9.79%
7.	Specific gravity	2.14
8.	Blaine fineness	5673 $^2/g$

C. Mix Proportions:

Since there are no standard codal provisions available for the mix design of geopolymer concrete, the density of geopolymer concrete was assumed as 2400 kg/m^3 and other calculations were made based on the density of concrete as per the mix design given by Lloyd & Rangan (2010). The combined total volume occupied by the coarse and fine aggregates was assumed to be 77%. The alkaline liquid to binder ratio was taken as 0.40. As there are no standard mix design procedures available to estimate the target strength of GPC and besides this being a relatively new type of concrete that is still in developmental stage, minimum target strength was taken as 30 MPa, considering it as a regular strength concrete. GGBS was kept as the base material for making the control GPC specimens (GP). Then BRHA was used to replace GGBS in the mix in three different proportions, 10% (GPR1), 20% (GPR2) and 30% (GPR3), for the rest of the mixes used in the investigation [5]. The mix proportions of GPC are given Table 3.

TABLE 3: MIX PROPORTIONS OF GPC

S. No	**Quantities**		**Proportions (kg/m^3)**		
		GP	**GPR1**	**GPR2**	**GPR3**
1.	GGBS	394	355	315	276
2.	BRHA	0	39	79	118
3.	Coarse aggregate	1201	1201	1201	1201
4.	Fine aggregate	647	647	647	647
5.	Sodium hydroxide	45	45	45	45
6.	Sodium silicate	113	113	113	113
7.	Super-plasticizer	8	8	8	8
8.	Water	59	59	59	59

D. Preparation Of Test Specimens [3]:

The materials for the mixes were weighed and first mixed in dry condition for 3-4 minutes. Then the alkaline liquid which is a combination of sodium hydroxide and sodium silicate solutions along with super-plasticizer were added to the dry mix. Then some extra water about 15% by weight of the binder was added to improve the workability. The mixing was continued for about 6-8 minutes. After the mixing, the concrete was placed in steel moulds by giving proper compaction. Precautions were taken to ensure uniform mixing of the ingredients. Two types of curing were used for the specimens to be tested for the study on the influence of curing temperature on the compressive strength. One set of cubes was oven cured and the other set was cured under ambient condition. For oven curing, initially the cubes were placed along with their moulds the oven immediately after casting at two different temperatures, 60°C and 90°C respectively for 24 hours. Then the cubes were de-moulded and kept as such in the oven at the same respective temperatures for another 24 hours. Then they were taken out and allowed to cure in the room temperature till the required day of testing. For the ambient curing, the cubes were kept under room temperature after casting and de-moulded after 1 day and further cured in the room temperature till the day of testing. For all other tests, the specimens were prepared by adopting the oven curing procedure at 60°C [7].

E. Tests Conducted **[8]:**

i. Split Tensile Strength Test:

The split tensile strength test was carried out as per IS 5816:1999. The apparatus test precision was the same as IS 516:1959. Cylindrical concrete specimens of size 150 mm diameter and 300 mm height were cast and tested for their splitting tensile strength using a CTM at the ages of 3, 7 and 28 days. Figure 1 shows the test setup.

Figure 1: Test setup of split tensile strength

Figure 2: Test setup of flexural strength

ii. Flexural Strength Test:

The flexural strength of GPC was carried out as per IS 516:1959. The permissible error was not to be greater than ± 0.5% of the applied load. Beams of size 700 mm × 150 mm × 150mm were cast and then tested using Universal Testing Machine (UTM) at the ages of 3, 7 and 28 days. The flexural strength test setup is shown in Figure 2.

F. Modulus of Elasticity Test:

The modulus of elasticity test was carried out as per IS 516:1959. The instrument accuracy was ± 0.5%. Cylindrical concrete specimens of size 150 mm diameter and 300 mm height were cast and tested for their Young's modulus at the age of 28 days. The specimens were tested using a using a CTM with the load being applied continuously at a rate of 140 kg/cm^2/min until an average stress of (C+5) kg/cm^2 was reached, where C is one-third of the average compressive strength of the cubes. The deformations were measured by a compressometer attached to the specimen. The test setup is shown in Figure 3.

Figure 3: Test setup of modulus of elasticity

From the deformation values, the strain values were calculated and the stress-strain curves were plotted for the GPC mixes. The experimental values of elastic modulus (E) were obtained from the slopes of the stress-strain curves. These experimental values were then compared with the theoretical elastic modulus values calculated as per IS 456-200 using the equation,

$$E = 5000\ f_{ck} \quad (1)$$

Where, f_{ck} is the characteristic compressive strength of concrete at 28 days.

III. RESULTS AND DISCUSSION

Tests were conducted on GPC with three different levels of BRHA replacement 10%, 20% and 30%. The results show the flexural strength, splitting tensile strength and elastic modulus of the GPC specimens tested. The test results are discussed below.

A. *Splitting Tensile and Flexural Strength Tests:*

The results of splitting tensile and flexural strengths of the geopolymer concrete at 3, 7 and 28 days are given in Table 4 and the variation of the split tensile strength and flexural strength for the various mixes are shown in Figures 4 and 5 respectively.

TABLE 4: SPLITTING TENSILE AND FLEXURAL STRENGTHS OF GPC

S. No	Mix	Split tensile strength (MPa)			Flexural strength (MPa)		
		3 days	7 days	28 days	3 days	7 days	28 days
1.	GP	6.2	6.4	6.7	5.1	5.7	6.1
2.	GPR1	6.5	6.7	6.9	5.7	6.3	7.1
3.	GPR2	3.7	3.9	4.3	3.2	3.6	4.1
4.	GPR3	0.8	0.9	1.1	0.9	1.0	1.3

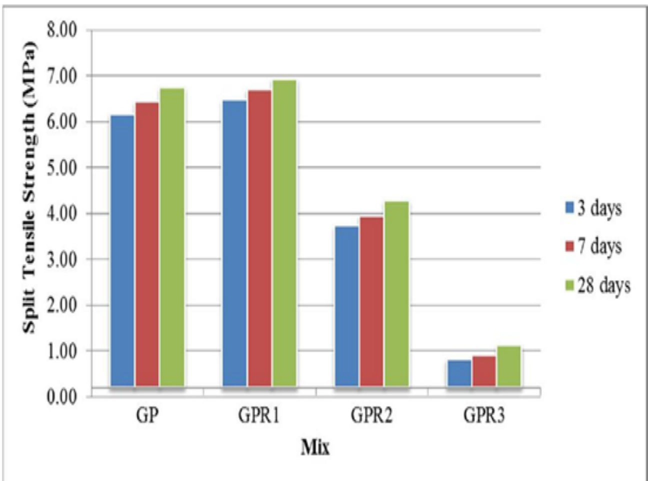

Figure 4 Splitting tensile strength of GPC

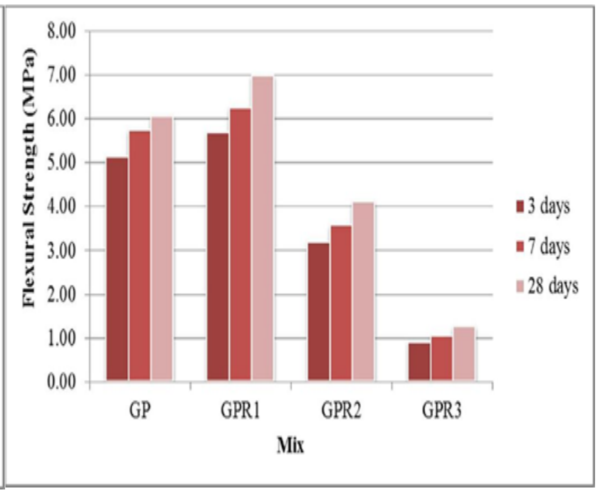

Figure 5: Flexural strength of GPC

When comparing the 10% BRHA replaced mix GPR1 with control mix GP, there was a slight improvement in both split tensile and flexural strengths. The heat curing of the specimens along with a suitably increased SiO_2/Al_2O_3 ratio and higher fineness of BRHA particles might have assisted the dissolution of ions and polycondensation mechanism of the geopolymer framework. But with further increase in BRHA content, the split tensile and flexural strength seemed to get decreased. The reason for the reduction in the mechanical strengths beyond 10% BRHA replacement could be due to the fact that the BRHA particles possess a different silicate structure.

B. *Modulus of Elasticity Test :*

The modulus of elasticity was determined at 28 days from the date of casting of the specimens and the stress-strain curves of GPC are shown in Figure 6. The experimental modulus of elasticity (E) values of the respective GPC mixes were obtained from the slopes of the corresponding stress-strain curves. The elastic modulus values of GPC are shown in Figure 7

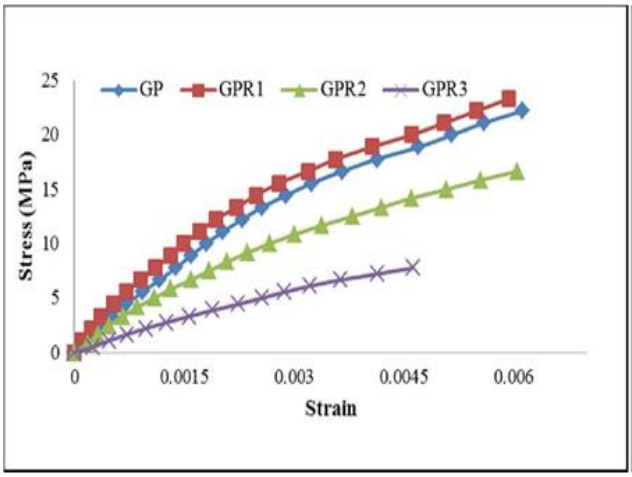

Figure 6. Stress-strain curves of GPC

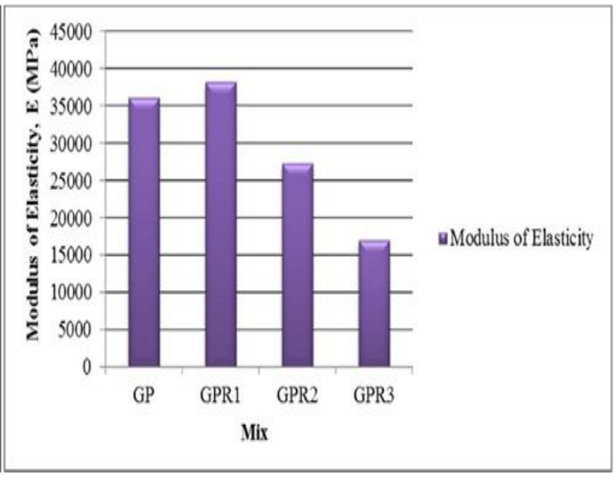

Figure 7. Elastic modulus of GPC

TABLE 5. THEORETICAL AND EXPERIMENTAL E VALUES OF GPC

S. No	Mix	Theoretical E (MPa)	Experimental E (MPa)
1.	GP	41773	36155
2.	GPR1	42231	38183
3.	GPR2	35418	27252
4.	GPR3	23937	17007

The 10% BRHA replaced mix GPR1 has a higher elastic modulus than the control mix GP. The increase in E value was about 5.7% for GPR1. Both the mixes GP and GPR1 showed E values as high as 36155 MPa and 38183 MPa respectively. The possible reason for such high values of elastic modulus could be the co-existence of the secondary C-S-H phase along with the primary geopolymer phase. The other two mixes GPR1 and GPR2 show reduced elastic modulus in comparison with the control mix. The possible reason for the decrease in elastic modulus could be attributed to the reduction in strength due to inappropriate silica-alumina ratio from excessive addition of BRHA. Comparing the theoretical and measured E values obtained from the stress-strain curves of GPC, the actual experimental values were less than that of the predicted values. The additional strains caused from the experimental setup and loading mechanism might have been the reason for such variation between the theoretical and experimental values.

IV. CONCLUSIONS

The experimental results show that it is possible to produce geopolymer concrete possessing substantial strength using GGBS and BRHA. The strength increase ranged between 10 to 18% Addition of BRHA beyond 20% is not beneficial in geopolymer concrete. The 30% BRHA replaced specimens neither achieved significant strength nor proved to be durable. The strength results show that the optimum proportion of BRHA that can be used in GPC is 10% to 20% considering target strength of M30. The results from this study are very important in the development of such innovative concretes which completely omit OPC in their production. It promotes the utilization of alternate materials like GGBS and BRHA to produce binders. Since these materials are essentially industrial by-products, it also means a solution to their disposal problem. The performance of GPC over conventional concrete has already been comprehensively proved. At the same time, certain issues with GPC must also be addressed. At present, the heat cured GPC can be viable mainly for precast structures. Besides, this is a newly developed concrete whose production has a stark difference against conventional concrete. Proper training and knowledge must be imparted to the workers regarding the production of GPC and the safety measures to be taken during the production as it involves the usage of chemicals. With awareness and appropriate training to the personnel involved in concrete production, definitely the production of geopolymer can also be cost effective over conventional concrete in long run.

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