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AN EXPERIMENTAL INVESTIGATION OF THE STRESS-STRAIN BEHAVIOUR OF GEOPOLYMER CONCRETE

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Abstract

This paper focuses on the mechanical properties and modulus The test results not- ed the good mechanical properties and of elasticity of fly ash and GGBS based geopolymer concrete. measured stress-strain relations of fly ash and GGBS based In this study an 8 molarity concentration of NaOH and alkaline geopolymer concrete under ambient curing conditions. The elastic liquid ratio in a ratio of 2.5 was used. This study includes the modulus was significantly varied with increases in the grade of the stress- strain behaviour along with the flexural strength, concrete. An equation was proposed to determine the modulus of compressive strength and split tensile strengths for the elasticity based on the compressive strength of the geopolymer GPC20, GPC40 and GPC60 grades. Tests were carried out on concrete. 150 mm x 150 mm x 150 mm cubes and 100 x 100 x 500 mm prisms and 150 x 300 mm cylindrical geopolymer concrete specimens.

Key words

Geopolymer concrete, Modulus of elasticity

Alkaline solution, Stress-strain behavior

1. INTRODUCTION

One of the major problems with the cement industry is the pro- duction of ordinary Portland cement (OPC) as it liberates a huge amount of CO_2 into the atmosphere. Attempts have been made to pro- duce alternatives to cement such as cement-free concrete. In which are the core components of cement-free concrete. Geopolymers are commonly reported to be much more sustainable than OPC in terms of the reduced production of energy, and lower CO_2 is released in comparison with OPC concrete (Turner, 2013). But the use of OPC to produce concrete releases an enormous amount of CO_2, which re-

sesses pozzolanic properties that make it suitable material for geopolymer concrete (GPC). The silica, alumina and calcium react with an alkaline activator solution to form the aluminosilicate hydrate gel and calcium silicate hydrate (C-S-H) gel responsible for binding. Thus the binder (fly ash and GGBS), alkali liquids, and aggregates sults in pollution of the environment. Also, the production of OPC leads to the depletion of raw materials. To reduce these problems caused by OPC concrete, geo-polymer cement is replaced with Ground Granulated Blast Furnace Slag (GGBS) and fly ash which are by-products obtained from the iron and coal industries. Generally, cement-free concrete is made from waste materials such as fly ash and GGBS with an alkaline solution; it is basically a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), which is a polymerization process that differs from OPC concrete. Fly ash is rich in alumina and silica, whereas GGBS contains calcium in addition to silica and alumina and pos-

concrete (GPC) has been introduced; it completely eliminates cement with by-products from thermal power plants and the steel industry. Therefore, the complete replacement of OPC with GGBFS or fly ash or a combination of both would significantly reduce CO_2 emissions. Fly ash and GGBS can be used as binders and are suitable materials for the polymerization pro- cess. An alkaline activator solution is used as a liquid medium in ge- opolymer concrete similar to the water in Portland cement concrete. The physical, mechanical and durability properties of GPC depend on the proportion of fly ash and GGBS and the curing process (Duxson, 2007). GPC specimens are either ambient cured or oven. Oven curing at high temperatures of around 60^0C-90^0C enhances the polymerization process and results in better gel formation, thus leading to improved strength and durability properties (Hardjito,2004), but it is practically difficult to do under in-situ conditions. To dispense with curing, fly ash is partially replaced with GGBS, which results in high early strength and improved mechanical and durability prop- erties (Davidovits, 2005). It has been reported by various authors that GPC has comparable mechanical properties to those of OPC concrete. It has also been reported that the stress strain behaviour of fly ash and GGBFS-based geopolymer concrete under compression is similar to that of OPC concrete, and it has further been stated that the Poisson's ratio for GPC falls between 0.2 - 0.24 (Khadiraniakar et al. 2014; Venu and Rao, 2017). Giasuddin proposed a model for the stress–strain behaviour of geopolymer concrete under a tri-axial state of stress and concluded that the proposed GPC model has many similarities to OPC concrete and that there is an increased stiffness of GPC versus that of OPC concrete (Giasuddin et al. 2014).

The modulus elasticity of fly ash and GGBS-based geopolymer concrete was found to be 25% to 30% less than that of OPC concrete (Nath et al., 2017). An equation was proposed to find the modulus of elasticity of fly ash and GGBS-based polymer concrete: $E = 11400+4712\sqrt{f}$, (f is the average compressive strength

$E_{GPC} = E_{cm} E_{cm}$

at 28 days) which was used to compare GPC and OPC concrete to conclude that GPC had a lower modulus of elasticity than OPC con- crete (Noushini et al., 2016). The empirical formulae to determine the modulus elasticity of GPC was given based on ACI 318 and concluded that even with an increase in the compressive strength of GPC, there is no significant increase in the modulus of elasticity (R.J.
Thomas et al., 2015).

GPC40 and GPC60 with a combination of fly ash and GGBS as

1 SIGNIFICANCE OF RESEARCH

Fly ash and GGBS-based geopolymer concrete has attracted at- tention due to its use of an oven curing technique. Not much litera- ture is available on ambient curing techniques for fly ash and GGBS- based GPC. It has been concluded from the literature that GPC has comparable mechanical properties to that of OPC concrete, but not much literature is available on the modulus of elasticity of GPC under ambient curing. This study examines the performance of geopolymer concrete and aims to determine the modulus of elasticity of GPC20,

2. Aggregate

River sand was used as a fine aggregate (FA) and corresponds to Zone-II of IS 383:1978. Crushed rock was used as a coarse aggregate (CA). The fine aggregate and coarse aggregate have a specific gravity of 2.58 and 2.7 with fineness moduli of 2.7 and 6.36 respectively.

3. Alkaline Activator Solution

A combination of sodium silicate and sodium hydroxide in a mass ratio of 2.5 was used as an alkaline activator solution. NaOH in a pellet form and Na_2SiO_3 in a liquid form was obtained from Finar Chemicals, India. An NaOH solution with a concentration of 8M was used. The sodium silicate solution with a chemical composition of Na_2O = 8.5%, SiO_2=26.5%, H_2O=65% by mass was used. The al- kaline activator solution has a Na_2O/SiO_2 (molar ratio) of 0.6. For proper mixing of the solutions, it has been suggested to prepare the alkaline activator solution one day prior to the casting.

4. Superplasticizer (SP)

A sulphonated naphthalene-based high range water reducer, i.e., CONPLAST SP 430, which was obtained from Fosroc Chemicals, India, was used as a superplasticizer (SP) to improve the workability of the mix. The dosage of superplasticizer (SP) mentioned in Table 2 is with respect to the weight of the binder (fly ash and GGBS).

2 EXPERIMENTAL PROGRAM

The experimental program consisted of determining the fresh and hardened properties of fly ash and GGBS-based geopolymer concrete cured under ambient conditions. The mechanical properties and modulus of elasticity were determined for GPC20, GPC40 andGPC60. The modulus of elasticity was determined on cylinder specimens 150 mm

150 mm diameter x 300 mm height, and 3 prisms sized 100 mm x diameter cylinder specimens with a 300 mm height. For each mix 3 cubes sized 150 mm x 150 mm x 150 mm, 6 cylinders sized

a binder under ambient curing. A comprehensive assessment of their mechanical properties has been evaluated for making geopolymer concrete.

Materials

1. Binder used

Fly ash obtained from the NTPC Ramagundam Thermal Power Station, India, and GGBS obtained from Toshali Cements, Vizag, In- dia, were used in this research; their chemical composition is shown in Table 1. Fly ash and GGBS have a specific gravity of 2.17 and 2.9 respectively.

Tab. 1 *Chemical composition of Fly ash and GGBS.*

Composition	SiO_2	Al_2O_3	Fe_2O_3	SO_3	CaO	MgO	Na_2O	LOI
Fly ash	60.11	26.53	4.25	0.35	4.00	1.25	0.22	0.88
GGBS	34.06	20	0.8	0.9	32.6	7.89	NIL	NIL

100 mm x 500 mm were cast to determine their modulus of elasticity and their corresponding mechanical properties. The mix proportions for the GPC20, GPC40 and GPC60 are shown in Table 2. The fol- lowing mix proportions are adopted from the literature (Rao GM and Rao TDG, 2016).

Tab. 2 *Mix Proportions of the Geopolymer Concrete.*

Mix	Fly ash	GGBS	Fine Agg.	Coarse Agg.	Alkaline Soln	Na SiO_2	$_3$NaOH	SP (%)
GPC20	252	108	774	1090.8	198	141.42	56.57	3
GPC40	270	180	760	972	248	177.15	70.85	4
GPC60	260	260	717.6	915.2	286	204.28	81.72	5

All units are in kg/m^3

The modulus of elasticity of the GPC was measured from the stress-strain curve as a ratio of the stress to the strain up to the elastic limit (the secant modulus). The tests were performed according to IS: 516-1959. All the prepared cylinder specimens were connected to an extensometer for recording any deformations at the corresponding loads. The tests were performed using a Tinius–Olsen testing machine with a 2000 kN capacity. The test set up is shown in Figure 2. The modulus of elasticity for the geopolymer cylindrical specimen

Preparation of the GPC specimens

The concrete ingredients were weight batched according to the mix proportions given in Table 2. Initially, the coarse and fine ag- gregates were dry mixed in a Hobart mixer for 3 minutes. Then the **Fig. 1** *Casting and curing of GPC specimens.*

binder (fly ash and GGBS) was added to the aggregates and mixed for about 3 minutes; the prepared alkaline solution was added along with the super plasticizer, if any. The mixing continued for about 4 minutes until a homogeneous mixture was obtained. Before casting the spec- imens, the workability of the GPC in terms of slump was measured. These 3 cubes, 6 cylinders, and 3 prisms were cast simultaneously. The specimens were demoulded after one day and cured under direct sunlight until the testing day (28 days). The casting and curing of the specimens is shown in Figure 1. The mix proportions and slump values are given in Table 3.

Testing of the GPC Specimens

was determined according to the procedure specified in ASTM stand- ard C469-02. The following equation was used to estimate the elastic modulus of the geopolymer cylindrical specimen (Giasuddin, 2014).

$$E = 1450_c (f_c{}^1)^{1/2} \qquad f_c{}^1 = \text{Peak axial stress in MPa}$$

For each mix, i.e., the GPC20, GPC40 and GPC60, three (3) cylinders were tested for the elastic modulus; then, the corresponding compressive, split tensile and flexural strengths were found (IS: 516). The setup for the flexural strength, compressive and split tensile tests are shown in Figures 3, 4, and 5.

3 RESULTS AND DISCUSSION

Fig. 2 *Test setup for Elastic Modulus.*

Fig. 3 *Compressive Strength of Cube.*

Fig. 4 *Test Setup for Split Tensile test.*

Tab. 3 *Workability of GPC.*

GPC Mix	Mix Proportion (Binder: FA: CA: Alkaline soln.)	Slump (mm)
GPC20	1: 2.15: 3.05: 0.55	122
GPC40	1: 1.69: 2.16: 0.5	110
GPC60	1: 1.38: 1.76: 0.5	78

Workability of GPC

The workability of the geopolymer concrete for the different mixes is shown in Table 3.

According to Table 3, we can conclude that the GGBS content is indirectly proportional to its workability. This might be due to faster polymerization at a higher GGBS content, which results in decreased workability.

Mechanical properties of GPC

The compressive, flexural and split tensile strengths were determined after 28 days of curing, and the results obtained are shown in Table 4. The values in Table 4 are the averages of the three speci-

Fig. 5 *Test Setup for Flexural Strength.*

formation of additional C-A-S-H gel along with N-A-S-H gel, there by leading to an enhancement in strength.

Split tensile and flexural strength tests are normally carried out to evaluate the tensile strength of concrete. The flexural strength of the GPC specimens was determined under two point loading with the longitudinal axes perpendicular to the loads. The split tensile and flexural strengths of the GPC specimens cured under ambient conditions are shown in Table 4. The results concluded that with an increase in the slag content, the split tensile and flexural strength of the GPC increases. The rate of development of the tensile strength increased considerably

mens.

Modulus of Elasticity of the GPC

Tab. 4 *Mechanical Properties of GPC.*

Mix	Binder Content (kg/m^3)	Compressive Strength (MPa)	Split Tensile Strength (MPa)	Flexural Strength (MPa)
GPC20		26.76	2.16	2.2
GPC40		43.44	3.73	3.61
GPC60	520	62.89	5.49	5.36

For the compressive strength of 20 MPa (GPC20), the fly ash and GGBS proportions were selected in a ratio of 70:30. For the GPC40 and GPC60, the fly ash and GGBS proportions were 60:40 and 50:50 respectively. As seen in Table 4, the increase in compressive strength is due to the increase in the binder content and the increase in the GGBS content. With a higher binder content, a greater a mount of alkaline solution is available for polymerization, which results in the increased strength of the concrete. With a higher GGBS content more calcium is available for polymerization, which results in the

360

450

Figure 6 shows that the ultimate stress increased with the increase The stiffness increases with an increase in the elastic modulus in the compressive strength of the concrete. The maximum strain and compressive strength of the concrete. This might be due to an**Nath, P., Sarker, P.K. (2017)** *Flexural strength and elastic modulus of ambient-cured blended low-calcium fly ash geopolymer con- crete*. Construction and Building Materials, Vol. 130, No.3.

Noushini, A., Aslani, F., Castel A., Gilbert R.I, Uy B., Foster S. (2016) *Compressive stress-strain model for low-calcium fly ash-*

with the inclusion of GGBS in the binder. The reaction of the slag is higher compared to that of fly ash, thereby re- sulting in a higher strength (Puertas, 2000).

With the increase in the compressive strength of the GPC, its corresponding split tensile and flexural strength is seen to increase in a similar manner. The results obtained indicated that the GPC mixes with GGBS and fly ash as a binder indicate good mechanical proper- ties under ambient curing conditions without the need for heat curing as in the case of fly ash-based geopolymer concrete. Our findings are in agreement with (Siddique, 2007).

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The stress-strain curve of the GPC specimens tested under com - pression is shown in Figure 6, and the modulus of elasticity results are shown in Table 5.

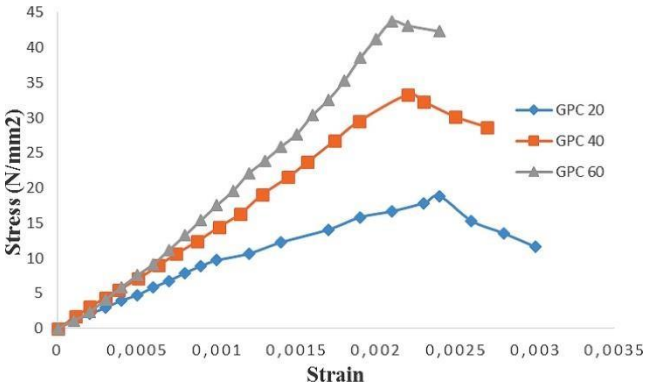

Fig. 6 *Stress-Strain Curve of the GPC.*

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