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Stress–strain behaviour of confined Geopolymer concrete

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HIGHLIGHTS

- Studied the behaviour of PCC and GPC specimens.
- Stress–strain behaviour in uniaxial compression was studied.
- Effect of confinement on the stress–strain behaviour of GPC and PCC were studied.
- Proposed an analytical model for the stress–strain behaviour of confined GPC.

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ABSTRACT

Fly ash based Geopolymer concrete (GPC) is an environment friendly alternative to conventional concrete made from alkali activated aluminosilicate and aggregate. This study intends to examine the effects of confinement on the behaviour of GPC and conventional Portland Cement Concrete (PCC). Out of the 36 cylinders tested under monotonic loading 24 cylinders were made with GPC and the remaining with PCC. The variable considered in this study is the volumetric ratio of confinement. An analytical model is proposed for the stress–strain behaviour of confined GPC. The results showed that confinement reinforcement greatly improved the strength and ductility of GPC than PCC.

1. Introduction

An important ingredient in conventional Portland Cement Concrete (PCC) is Ordinary Portland Cement (OPC). The production of cement is increasing by about 3% annually. The process of cement production is highly energy intensive and releases large volume of greenhouse gases like CO_2 [1]. Thus the cement industry is responsible for some of the greenhouse gas emissions into the atmosphere. In this respect, geopolymer technology introduced by Davidovits provides an alternative low emission binding agent to PCC [2]. Geopolymers are inorganic aluminosilicates produced by alkali activation of materials of geological origin such as kaolin or bentonite or byproduct materials such as fly ash or rice husk ash. Thus Geopolymer concrete (GPC) is obtained by alkali activation of industrial waste materials such as fly ash in the presence of sodium hydroxide and sodium silicate solution, which is a polymerization process that differs widely from Portland cement hydration [3]. Thus the source material (fly ash), alkaline solution and aggregates constitute the main components of Geopolymer concrete (GPC). The properties of GPC include high early strength, low shrinkage, excellent freeze–thaw resistance, sulphate resistance and corrosion resistance [2,4]. Confinement is an important factor which affects the behaviour of concrete. Since sectional strength and ductility depend on the stress–strain characteristics of concrete they are also influenced by the confinement of the members. The properties of confined concrete have been extensively studied in the past [5,6]. Confinement increases the compressive strength and the capacity of concrete to sustain large deformations without substantial loss of strength. From the literature review, it is found that the stress–strain behaviour varies considerably depending on the type of concrete and the confinement. Although information on the confinement of normal concrete is available in literature, the effect of confinement on GPC has been only scantly investigated. This study has attempted to obtain experimentally the stress–strain curve of confined GPC and develop analytical models for the same.

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2. Experimental investigation

2.1. Materials and mix proportions

Fly ash (ASTM Class F) was used as the main source material for synthesizing the geopolymer binder. Coarse aggregate of 20 mm nominal size was used for making GPC and PCC. Locally available river sand conforming to zone II as per IS: 383-1970 was used as fine aggregate. A combination of sodium silicate solution and sodium hydroxide (NaOH) solution was chosen as the alkaline liquid to activate the source material. Commercially available sodium silicate solution with SiO_2-to-Na_2O ratio by mass of 2 (Na_2O = 14.7%, SiO_2 = 29.4%) and water = 55.9% by mass were used for the study. A naphthalene based superplasticiser was also used to improve the workability of GPC. Ordinary Portland cement of 53 grade was used for preparing PCC. HYSD bars of 6 mm diameter and 360 N/mm^2 yield strength were used for making spiral reinforcement cages of 90 mm diameter. The pitch of the spirals used were 75 mm, 50 mm and 25 mm (volumetric ratios 1.36%, 2.05% and 4.1%). The GPC and PCC specimens were designated as GPCP1, GPCP2, GPCP3 and PCCP1, PCCP2, PCCP3 corresponding to pitches of 75 mm, 50 mm, 25 mm respectively. GPCP0 and PCCP0 represents unconfined GPC and PCC specimens.

Since there are no codal recommendations available for the mix design of GPC, different trial mixtures of GPC were prepared as per the guidelines given in the literature [7]. For the trial mixes, the alkaline activator to fly ash ratio, amount of extra water, superplasticiser content, fine aggregate to total aggregate ratio, molarity of NaOH, mixing time and curing temperature were considered as variables. The final mix proportion for M30 grade GPC was selected based on the 28th day compressive strength and a workability giving compacting factor of 0.9. PCC mix of the same grade was also prepared as per IS: 10262 [8] and the details are given in Table 1.

2.2. Preparation of test specimens

Coarse aggregates and sand in the saturated surface dry condition were first mixed in laboratory mixer with fly ash for about three minutes. Then alkaline solution, super plasticizer and extra water were added to the dry materials and were mixed for four minutes. The GPC resembles PCC in its appearance. Immediately after mixing, the slump and compacting factor of fresh concrete were measured to observe the consistency of the mixture. Cubes of 150 mm, prisms of 100 mm × 100 mm × 500 mm, cylinders of 150 mm diameter and 300 mm height were prepared for determining the compressive strength, modulus of rupture and splitting tensile strength respectively. For finding the stress–strain behaviour cast-iron moulds of 150 mm diameter and 300 mm height were fabricated. Special provision was provided in the mould to insert the plates for fixing the LVDTs so that the core strain could be measured accurately [9]. The test set-up is shown in Fig. 1. The plates were inserted in such a way that the gauge points were symmetrical about the centre of the specimen and the gauge length was 100 mm. After casting, all GPC specimens were kept at room temperature for one day. The GPC specimens were then placed inside the oven along with moulds and cured at 60 °C for 24 h. After curing, the specimens were removed from the chamber and left to air-dry at room temperature for another 24 h before demoulding. The test specimens were then left in the laboratory ambient conditions till the day of testing. PCC specimens were also prepared and kept immersed in water for 28 days after one day of casting. Six GPC and three PCC specimens for each volumetric ratio of confinement were cast.

2.3. Testing

After 28 days of casting, the specimens were tested for cube compressive strength, flexural tensile strength, splitting tensile strength and modulus of elasticity. The stress–strain behaviour was determined by carrying out tests on cylindrical specimens. The 5 mm LVDTs having least count of 0.001 mm were used. The specimens were placed in a compression testing machine of 3000 kN capacity and tested under uni-axial compression. The loading arrangement is shown in Fig. 2. The LVDTs were attached to the plates on opposite sides of the specimen and parallel to the longitudinal axis. The LVDT readings were taken at equal increments of 250 N load.

3. Results and discussions

3.1. Fresh and hardened properties

The fresh and hardened properties of all the mixes are shown in Table 2. From the table it can be seen that the strength development in GPC is faster than in PCC. This may be attributed to the fast polymerization process due to heat curing. In the case of GPC the splitting tensile strength increased by approximately 13%, whilst the flexural strength increased by 12%. This is probably due to the geopolymer paste present in GPC which provides better bonding between the fine and coarse aggregate than that of cement paste in PCC. The studies conducted by Frantisek et al. [10] have shown that the interfacial transition zone which is considered as the weakest part in ordinary concrete is not found between geopolymer and aggregate and the absence of such a layer contributes to the superior mechanical properties of GPC. The modulus of elasticity increased by 50% for GPC compared to PCC.

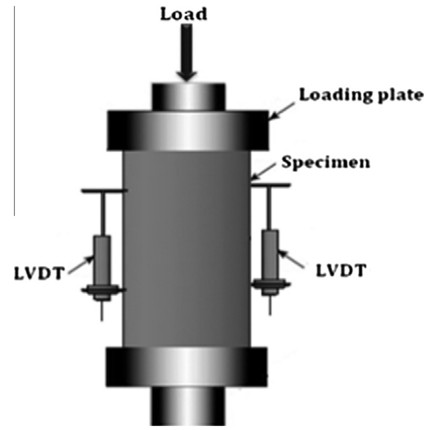

Fig. 1. Test set-up.

3.2. Stress–strain behaviour

The stress–strain curves of GPC and PCC specimens with various percentages of spiral confinement are shown in Fig. 3. From figure, it can be seen that the stress–strain behaviour is almost similar for both GPC and PCC. However GPC mixes have shown improved stress values for the same strain levels compared to that of PCC in the unconfined state. At the initial stage, the deformation of GPC specimens increases at a slower rate than that of PCC.

This trend continued up to about 80% of the peak stress. The increase in deformation was faster in GPC. This may be due to the development of large number of micro cracks in the geopolymer paste near the peak stress point as noted by other researchers [4,10]. Since the plain GPC specimens (GPCP0) had a brittle failure, the descending branch of stress–strain curve could not be determined in any of these specimens. But the behaviour of confined specimens was comparatively ductile than unconfined specimens.

The behaviour of all unconfined specimens in the ascending branch up to the peak stress is similar. This is due to the fact that in the case of confined concrete at low levels of stress the transverse reinforcement is hardly stressed; hence the concrete is unconfined. The concrete becomes confined at stresses approaching the uniaxial strength [11]. The confinement considerably improved the stress–strain characteristics of GPC at higher strain levels. The stress–strain curves were analyzed to obtain the effect of confinement on the strength and ductility of GPC.

Table 1
Mix Proportions.

Mix	Cement (kg/m^3)	Fly ash (kg/m^3)	Sodium silicate solution (kg/m^3)	Sodium hydroxide solution (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	Water (kg/m^3)	SP (kg/m^3)
GPC	–	408	103	41	1294	554	14.5	10.2
PCC	426	–	–	–	1266	598	192	0