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Tie-confinement aspects of fly ash-GGBS based geopolymer concrete short columns

M. Venu, T.D. Gunneswara Rao *

Department of Civil Engineering, National Institute of Technology Warangal, India

HIGHLIGHTS

- Inclusion of GGBS to accelerate the ambient curing of fly ash based geopolymer concrete.
- Study on the effect of tie-confinement on the stress-strain behaviour of fly ash & GGBS based geopolymer concrete.
- A single non dimensional stress-strain equation is proposed to predict the stress-strain behaviour of tie-confined GPC.

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ABSTRACT

This paper presents the influence of tie-confinement in Fly ash and GGBS based geopolymer concrete (GPC) activated alkaline solution for three different grades i.e., GPC20, GPC40 and GPC60. The grade of concrete, tie configuration and spacing of ties are the parameters varied in this study. Specimens of size 200 × 100 × 100 mm were cast and cured under outdoor conditions (temperature 35 ± 2 °C; humidity 75%) to determine the stress-strain behaviour of confined GPC under uniaxial compression. The obtained results concluded that increase in area of reinforcement the ultimate strength, strain at ultimate strength, post-peak strain response, toughness and ductility were found to be increased. For the better assessment of the stress-strain behaviour of geopolymer concrete a single non dimensional stress-strain model was developed.

1. Introduction

Sustainable development for concrete industry needs research towards "no cement concrete". As cement production involves large amount carbon dioxide is emitted into the atmosphere. The alternative sustainable cementitious materials (viz. metakolin, fly ash, GGBS) with alkali activated solution (combination of NaOH and Na_2SiO_3) could produce Geopolymer concrete (GPC). GPC was introduced by Davidoviots in 1978 with an aim to produce green sustainable concrete. [1]. In this context most of the research work have been experimented on fly ash based GPC with oven curing to enhance the polymerisation process. Many authors reported the importance of mass ratio of Na_2SiO_3 to NaOH and concluded that 2.5 is optimum in achieving maximum compressive strength [2]. Recent studies focussed on the effect of molar ratio's (viz. SiO_2/Na_2O, CaO/Na_2O, SiO_2/Al_2O_3), sodium hydroxide concentration, curing temperature, etc. Most of the studies have been focused on strength and durability aspects of GPC, rather than stress-strain, ductility, shrinkage and creep.

It is observed from the literature that the deformation capacity or stiffness of geopolymer concrete is quite low compared to conventional concrete. The stiffness and deformability can be improved by various methods like wrapping laminates, fibre reinforcement, confinement, etc. Of all these methods, confinement is the most effective way to improve the ductility of concrete and also it improves the compressive strength of the member. Studies on laminate wrapping and confined concrete evaluating the strength and deformation capacities have been receiving much attention recently. The fibre reinforced polymer fabrics significantly improved the ductility and flexural capacity of both short and long eccentrically loaded columns [3]. The polymer fabrics are difficult to install and are costly. A lot of research has been reported on confined stress-strain behaviour of conventional concrete but literature on confined GPC is scantly available. It is reported that GPC exhibited almost similar structural properties to that of OPC concrete [4]. Therefore, similar tests can be conducted on GPC to evaluate the strength and deformability characteristic similar to OPC concrete. Tests on confined concrete has

* Corresponding author at: Department of Civil Engineering, National Institute of Technology Warangal, Telangana State 506004, India.

E-mail address: tdgtdg@gmail.com (T.D. Gunneswara Rao).

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Notations

b, d	breadth and depth of prism
$\mathbf{f_y}$	yield stress of lateral steel
$\mathbf{A_s}$	longitudinal steel area
f_u/f'	stress ratio
$\boldsymbol{\varepsilon_u/\varepsilon'}$	strain ratio
f'	peak stress of unconfined concrete
$\mathbf{f_u}$	peak stress of confined concrete
$\boldsymbol{\varepsilon'}$	peak strain of unconfined concrete
$\boldsymbol{\varepsilon_u}$	peak strain confined concrete
f_u/f'	=($1.6294x^{0.124}$) = tie confined concrete strength of stress ratios
$\boldsymbol{\varepsilon_u/\varepsilon'}$	=($1.5041x^{0.128}$)= tie confined concrete ultimate strain at ultimate stress
$\mathbf{C_i}$	Confinement index $=(P_b - P_{bb})\left(\frac{f_v}{f_c}\right)\left(\sqrt{\frac{b}{s}}\right)$ ratio of volume of transverse
$\mathbf{P_b}$	reinforcement to the volume of concrete
$\mathbf{P_{bb}}$	ratio of the volume of transverse reinforcement to the volume of concrete which corresponds to a limiting pitch (=1.5b)
$\mathbf{f_v}$	yield stress in lateral ties
S	spacing between lateral ties
GA	GPC mix 20 MPa
GB	GPC mix 40 MPa
GC	GPC mix 60 MPa
GA0	unconfined GPC 20 MPa
GB0	unconfined GPC 40 MPa
GC0	unconfined GPC 60 MPa
6#	lateral reinforcement diameter
8#	lateral reinforcement diameter

proved that suitable arrangements of transverse reinforcement had a significant improvement in both strength and ductility. Also, the strength improvement from confinement and descending portion slope of stress-strain curve had a significant influence on flexural strength and ductility of reinforced concrete members.

Stress-strain behaviour of confined concrete is very essential to obtain moment-curvature relationship to evaluate the ductility and deformability of reinforced concrete members. The parameters affecting the stress-strain behaviour of confined concrete are longitudinal reinforcement (its diameter, position and amount), spacing of bars, active reinforcement (circular, square ties), pseudo-active reinforcement (ferro mesh), passive reinforcement (viz. steel, glass fibres), diameter and yield strength of confining reinforcement, strength of concrete, confining reinforcement/concrete core (volumetric ratio), size and shape of tested specimen.

K.T. Iyengar et al. (1970) developed an analytical model to study the stress-strain behaviour of confined concrete for members with either rectangular or circular sections subjected to axial compression and reported that circular ties are most effective in improving the ductility, ultimate strength and ultimate strain [5]. Confinement index considered by Iyengar et al. is similar to the one proposed by S.R. Reddy confinement index**.** Mander et al. (1988) developed a single equation to represent both the ascending and descending portions of the stress-strain curve. This model can be used for dynamic loading by modifying the quasi-static concrete parameters by dynamic factors which are to be used in stress-strain model [6]**.**

Later, another analytical model proposed by El-Dash et al. (1994) to predict the stress-strain behaviour for low and high strength square and rectangular short confined columns with a variety of cross-sectional shape, active reinforcement configuration and passive reinforcement configuration [7]**.** The stress in the transverse reinforcement for a confined concrete can be computed from the model proposed by Daniel Cusson et al. (1995) and was observed that in adequately confined columns, strength and toughness can be improved with an increase of the tie yield strength and at low confinement level, increase in tie yield strength doesn't improve strength and ductility [8]**.**

Presence of passive reinforcement (steel fibres) to the confined concrete has improved the stress-strain behaviour and material properties. A non-dimensional characteristic equation was developed by Ramesh et al. (2003) to predict the behaviour of confined fibre reinforced concrete in axial compression. Addition of Steel fibres (passive reinforcement) to the tie confined (active reinforcement) specimens provides an indirect additional confinement of concrete [9]**.** Generally high strength concrete shows brittle failure, in order to overcome this more confinement is required to achieve desired post-peak deformability in columns. Legeron & Paultre (2003) model was more appropriate than the other existing models for high strength concrete [10]**.** Visintin et al. (2017) investigated the shear properties of GPC with low levels of confinement and proposed an equation to predict the concrete contribution to the shear capacity of beams without stirrups [11]**.** Confinement of GPC has grabbed attention in recent times. A stress-strain model for confined GPC was proposed by P K Sarkar et al. (2009) after minor modifications to an existing stress-strain model proposed by Popovics for OPC. This model was validated by comparing results with experimental data obtained from their study [12]**.** Thereafter a stress-strain behaviour of confined GPC (fly ash based) was compared with that of conventional concrete, and an analytical model was proposed. Volumetric ratio of confinement was the main parameter varied. It was obvious from the results obtained that confinement has enhanced the strength and ductility of GPC. However, this study is shown appropriate behaviour to present experimentation [13]**.** A new stress-strain model for steel confined and FRP confined concrete was developed by Yu-Fei Wu et al. (2014) modifying the existing Popovics model. The proposed model has shown a good co-relation with obtained experimental results as well as existing analytical models [14]. Subsequently, mechanical properties and stress block parameters of GPC was determined, it was found that GPC possesses enhanced mechanical properties compared to that of conventional concrete. However the stress block parameters derived for GPC were found to be closely matching with those given in IS 456:2000 for conventional concrete [15]. The modulus elasticity of fly ash & GGBS based geopolymer concrete was found to be 25% to 30% less than that of OPC concrete [16]**.** Noushini et al. (2016) proposed an equation to find the modulus of elasticity of fly ash & GGBS based geopolymer concrete $\mathbf{E_{GPC} = -11{,}400 + 4712\sqrt{f_{cm}}}$ and OPC concrete $Eo_{PC} = 4293 + 3775\sqrt{f_{cm}}$ (f_{cm} is average compressive strength at 28 days) and found that the modulus of elasticity of GPC is lower than OPC concrete [17]**.** Empirical formulae to determine the modulus elasticity of GPC have been given based on **ACI 318** and concluded that the modulus of elasticity of GGBFS based GPC is around 30 GPa and does not vary with its compressive strength [18]. S.R. Reddy [19] developed an equation for calculating confinement index of concrete and is shown in Eq. (1).

$$\mathbf{C_i} = (P_b - P_{bb})\left(\frac{f_v}{f_c}\right)\left(\sqrt{\frac{b}{s}}\right) \tag{1}$$