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BOND STRENGTH BEHAVIOUR OF GEOPOLYMER CONCRETE

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Abstract: Bond in concrete plays a crucial role in the performance of reinforced concrete structures which are influenced by several factors such as concrete compressive strength, diameter, type and embedment length of bar, confinement of concrete etc. This paper discusses experimental investigation on bond strength behaviour of geo polymer concrete (GPC). The influence of compressive strength and embedment length of reinforcing bar on the bond strength of GPC has been reported. A total of 27 GPC prisms were tested by conducting pull out tests. Three grades of GPC (G20, G35 and G50) and three embedment lengths (75mm, 100mm and 125mm) were used in this study. The results indicated that the bond strength has increased with increase in compressive strength. The bond strength of reinforcing bars in geopolymer concrete decreases with increasing the embedment length.

Keywords: *Geopolymer concrete, bond strength, slip*

1.0 Introduction

The behaviour of reinforced concrete (RC) structures depends on the type of bond developed between the steel reinforcement and the surrounding concrete. Bond stress is the tangential shear or friction developed between the reinforcement and the surrounding concrete that transfers the force onto the reinforcement. To ensure the integrity of various constituent or composite action of concrete and steel reinforcement, sufficient bond should be developed by the surrounding concrete with the reinforcement. Proper bond between the steel reinforcement and the surrounding concrete is also crucial for the overall strength and serviceability of RC members. The failure of RC structures may be primarily due to the deterioration of the bond.

The most commonly used construction material in the world is concrete which traditionally uses ordinary Portland cement (OPC) as the binding agent. Also concrete consumption increases worldwide as infrastructure need in countries like India and China increases. Environmental pollution is one of the major problems today. The production of one ton of OPC by burning of fuel and decomposition of limestone emits around one ton of CO_2, thus leading to global warming. Fly ash is produced as a residue by the combustion of coal and ground granulated blast furnace slag (GGBS) is obtained as a byproduct from blast furnace. Due to its availability worldwide, disposal remains a challenge. Sustainable construction practice aims at utilizing these waste materials as construction material. To save the environment from global warming and to prevent further depletion of natural resources, Geopolymer concrete (GPC) is an alternative as it totally replaces cement with waste materials such as fly ash and GGBS.

Non-reactive Silicate and alumina present in the binder are made to react using alkaline liquids such as NaOH and Na_2SiO_3 or KOH and K_2SiO_3 to form geopolymer which act as the binding agent. The geopolymer binder on mixing with aggregates undergoes polymerization process to form GPC. The polymerization process involves dissolution of Si and Al atoms from source material, orientation into monomers and then polycondensation. GPC shows higher compressive strength, lower creep, lower shrinkage and better resistance to acid attack. To avoid limitations such as need for heat curing and setting time delay, GGBS is added which also gives more strength due to the calcium present in it. Also superplasticizer can be added to improve workability.

Researches [1-7] prove effective use of GPC as construction material. As the constituents of GPC vary from ordinary concrete, there is a need to evaluate the strength of bonding between GPC and reinforced steel so that to apply it for reinforced concrete structures. The bond behavior determines load carrying capacity of reinforced concrete structures. Experimental data available on bond strength of various types of concrete and reinforcement are more [8-13].But bond studies in GPC are very little [13-14]. This paper describes pull out test results which was carried out to determine bond strength behavior of GPC

2.0 Bond Strength

Bond stress is the shear stress that acts at the interface of bar and concrete and helps in transfer of load from concrete to steel due to adhesion, frictional resistance and mechanical resistance. Bond strength is determined by factors like surface condition of bar, concrete strength and development length. Flexural bond and anchorage bond are the two types of bond. Steel and concrete act together by flexural bond which acts along bar length. The bond at bar cut off point that causes slippage between steel and concrete is anchorage bond. The length of the extended bar in concrete to transmit force effectively from bar to concrete is known as development length (L_d). As per IS 456,

$$L_d = \Phi \times f_{st}/4\, \tau_{bd} \qquad (1)$$

where Φ = nominal diameter of the bar, f_{st}= allowable tensile stress in the steel bar and

τ_{bd} = Design bond stress.

The expression for bond stress is given by

$$\tau_{bd} = P/(\pi\ \Phi\ L_d) \quad (2)$$

where
P = Applied load
Φ = nominal diameter of the bar
L_d = development length.

3.0 Present Investigation

The aim is to find the bond strength of GPC by conducting pull-out test. A total of 27 GPC prisms of 100x100x200 mm size each were cast with 16 mm diameter TMT rod embedded in it for the purpose of pull-out test. Three different grades of GPC viz. G20, G35 and G50 were used in the investigation. In each grade there were 9 prisms. Three different embedment lengths of 16mm diameter TMT rod in to the GPC prisms viz. 75mm, 100mm and 125 mm, was considered in the investigation. After twenty eight days, test for bond strength was carried out by conducting pull out tests. Also cubes of size 150 x 150 x 150 mm each and cylinders of size 150 x300 mm each were cast and tested to find compressive strength and split tensile strength for each of the three grades.

4.0 Materials Used

The mix design of geopolymer concrete is similar to ordinary concrete but cement is replaced by binder and water with alkaline solution. Sodium hydroxide solution and sodium silicate solution was used as alkaline activators. GPC was made by total replacement of cement with fly ash and GGBS. The ratio of sodium silicate solution (Na_2SiO_3) to sodium hydroxide (NaOH) was 2.5 by mass. 320 grams of sodium hydroxide pellets were dissolved in water to make one liter of NaOH solution with concentration of 8 molarities. Preparation of alkaline solution is an exothermic reaction and hence it was prepared one day before mixing with aggregates. The mix proportion details for three different grades of GPC are given in the Table 1.

Table 1: The details of mix proportion of Geo polymer concrete

Concrete Grade	*Fly ash (kg/m^3)*	*GGBS (kg/m^3)*	*Fine agg. (kg/m^3)*	*Coarse agg. (kg/m^3)*	*Alkaline liquid (l/m^3)*
G20	248.6	106.5	763.6	1076.3	213.1
G35	272.8	181.8	768.4	982.1	204.7
G50	225.2	225.2	761.5	973.1	225.2

The Compressive strength (fc) and Split tensile strength (ft) of geopolymer concrete and that of normal concrete used in the present investigation are given in Table.2.
The combination of fly ash and GGBS used for the development of GPC has yielded satisfactory levels of compressive strength without the need for any heat curing. In the present study three grades of concrete of GPC viz. G20, G35 and G50 were developed based on trial and error method. All the three grades were satisfying the compressive strength results

Table 2: The Compressive strength (fc) and Split tensile strength (ft) of Geopolymer concrete

GPC Grade	*fc (MPa)*	*ft (MPa)*
G20	25.8	1.9
G35	39.2	2.3
G50	56.4	2.6

CONPLAST SP430 was used as Superplasticizer to improve workability. Low calcium Class F fly ash was used. The fine aggregate conforming to Zone-2 according to IS: 383 were used. Coarse aggregates sieved through sieve sizes of 20 mm, 16 mm, 12.5mm, 10 mm and 4.75 mm were used. Rust free and straight TMT (Thermo Mechanically Treated) 16 mm steel bars having yield stress of 550 N/mm^2 were used.

4.1 Casting and Curing of Specimen

Mould were fitted without any gap between plates and then oiled. To mix concrete, rotating drum type 100 kg capacity pan mixer was used. All dry materials like aggregates and binder were mixed in pan. And then alkaline liquid and superplasticizer were added and mixing continued for 5 to 7 minutes. Bars with suitable length were put in prisms and embedded length was controlled carefully. An embedment length of 75mm, 100 mm and 125 mm has been adopted. Excluding embedded length a grip length of 100 mm for fixing and 350 mm for lower platen coverage was considered. The specimens were allowed for 28 days ambient curing at room temperature. A cast specimen ready for testing is presented in Figure 1.

Figure 1: Test specimen

4.2 Testing of Specimens

The bond strength test was carried out according to IS 2770-1997 [15]. A 16 mm diameter deformed steel reinforcing bar was embedded into the concrete prism at centre. All specimens were tested up to failure of bar matrix interfacial bond. The peak load at failure of bond and maximum slip was observed. The pattern of load transfer for prisms is shown in Figure 2. All specimens failed with vertical crack along the embedded length of bar with cracking sound. After 28 days, Pull out test was carried out in all GPC specimens using 100 ton capacity Universal tensile testing machine and the test setup is shown in Figure 3. Tension test on 16 mm diameter TMT rod was conducted separately which gives elongation of rod (Δe) by fixing an extensometer at middle of rod with gauge length of 200 mm and precision of 0.002 mm .Total movement (Δa) of the frame was measured by dial gauge with precision of 0.01 mm by fixing it at the top of main arm. For every 0.4 ton increment of load, dial gauge readings was noted. Load in the form of static mechanical energy will be transferred through bar to specimen which will cause elongation of bar as it absorbs same amount of energy.

Hence dial gauge reading will give both slip in specimen and free bar elongation. Thus slip (Δs) is given by

$$\Delta s = \Delta a - \Delta e \qquad (3)$$

Where Δe = Total bar elongation, Δa = Total frame movement.

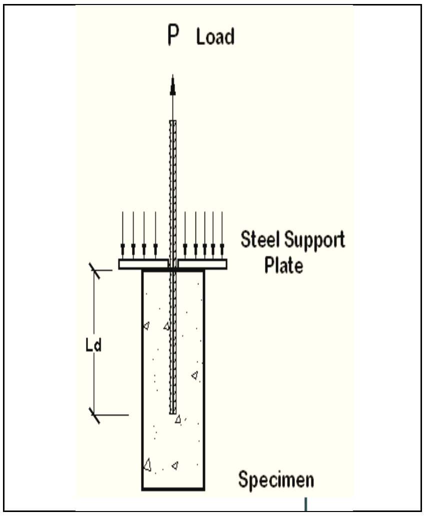

Figure 2 Pattern of load transfer

Figure 3: Pull out test setup

5.0 Discussion of Test Results

5.1 Effect of Compressive Strength

The bond strength (σ_b) of GPC obtained in the pull-out test, for different concrete compressive strengths is presented in Table 3. It is seen from the results presented in Table 3 that the bond strength of GPC increases with increase in compressive strength of GPC. This behavior is similar for all the embedment lengths. However the increase is not proportional to the increase in compressive strength.

5.2 Effect of Embedment Length

The bond strength (σ_b) of Geopolymer concrete (GPC) obtained in the pull-out test, for different embedment length are presented in Table 3. It is seen from the results presented in Table 3 that the bond strength of GPC decreases with increase in embedment length of reinforcing bar. This behavior is similar for all the compressive strengths. The fact is that as the surface area of embedment increases, the maximum bond stress decreases. Similar conclusions have been drawn by the earlier researchers that the bond strength decreases as the embedment length increases [12].Relatively brittle failures have been observed in members with large embedment length

For the purpose of comparison the bond strength values were normalized by specifying the 'Bond Coefficient (K)'. The bond coefficient is obtained by dividing the bond strength with the square root of respective concrete compressive strengths. Hence the bond coefficient (K) of GPC is calculated for different embedment lengths and for different concrete compressive strength. Table 3 presents the bond coefficients of GPC.

The variation of bond strength with compressive strength of GPC, for different embedment lengths is shown in Figure 4. The variation of average bond coefficient (K) with compressive strength of GPC is shown in Figure 5. It is seen from the Figure 5 that the bond coefficient is decreasing with increase in compressive strength of GPC. This indicates that the bond strength may approach a maximum value and it may not increase further even if the compressive strength of GPC increases.

Table 3: Bond Strengths and Average Bond Coefficient of GPC

GPC Grade	*fc (MPa)*	*Bond Strengths for different embedment length (Ld) in MPa*			*Average*	
		75mm	*100 mm*	*125mm*	*σb*	*K*
G20	25.8	8.2	7.4	5.9	7.1	1.4
G35	39.2	8.4	7.6	6.3	7.4	1.1
G50	56.4	8.9	8.1	7.2	8.0	1.0

Bond Coefficient ($K=\sigma b/(fc)^{0..5}$)

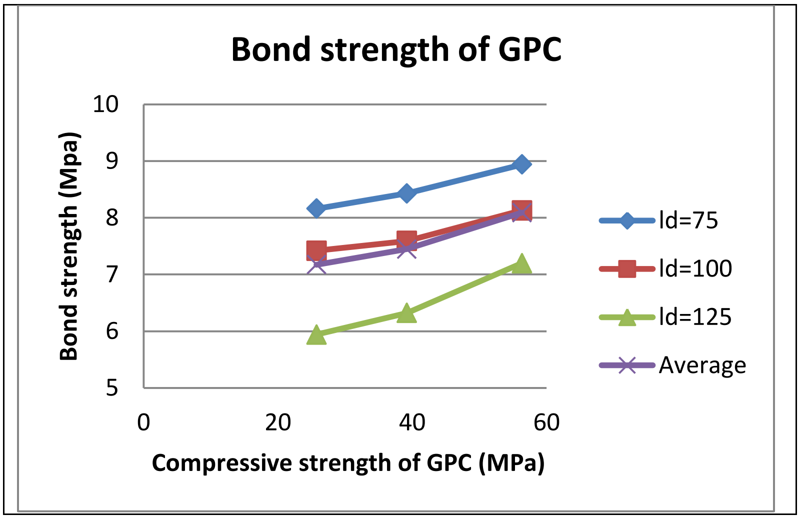

Figure 4: The bond strength (σb) of Geopolymer concrete (GPC)

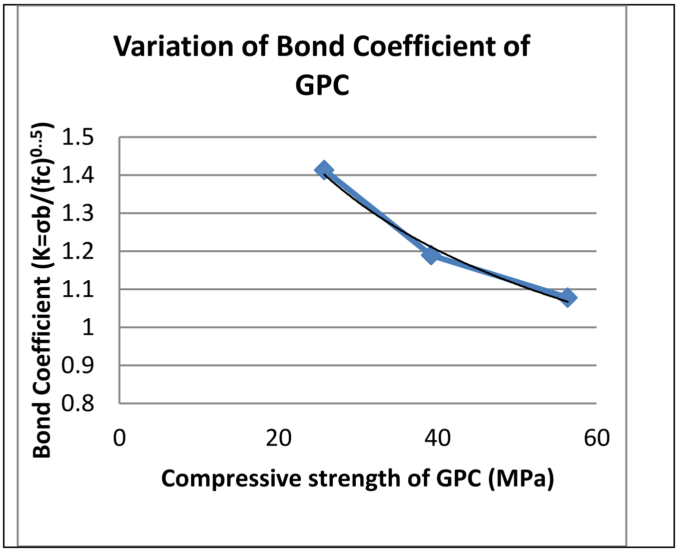

Figure 5: The bond Coefficient (K) of Geopolymer concrete

Figure 6: Failure pattern of specimens

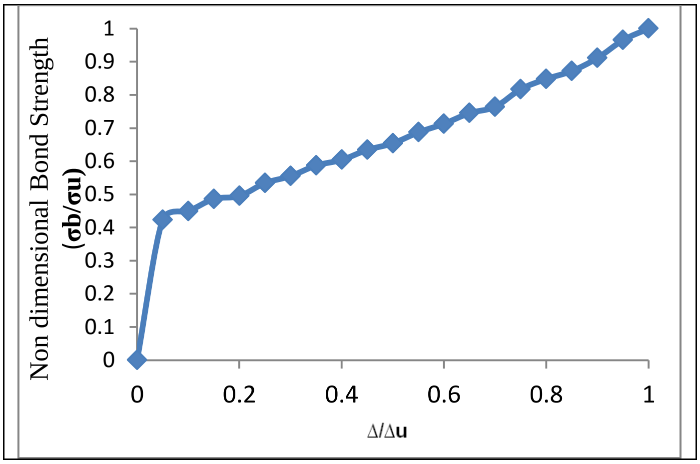

Figure 7: Non dimensional Bond Strength vs slip.

The failure pattern of specimens is shown in Figure 6. The failure occurred at the concrete region where steel bar was bonded. The plot between normalized bond strength and ultimate slip of GPC is shown in Figure 7.This bond slip behavior shown in Figure 7 indicate that bond slip behavior can be idealized as a bilinear behavior. Also the bond slip curve indicates that rate of increase in slip slow up to about 45% of ultimate bond strength level. The slip increases rapidly once the bond stress goes above 45% of ultimate bond strength.

6.0 Conclusions

Based on the experimental investigation, the following conclusions are drawn.

1. The combination of fly ash and GGBS used for the development of GPC has yielded satisfactory levels of compressive strength without the need for any heat curing.
2. The bond strength of GPC increased with increase in compressive strength of concrete. However the increase is not proportional to the increase in compressive strength of concrete.
3. The bond coefficient of GPC is decreasing with increase in compressive strength of GPC.
4. The bond slip response of GPC can be idealized as a bilinear behavior.
5. The rate of increase in slip is slow up to about 45% of ultimate bond strength level. The slip increases rapidly once the bond stress goes above 45% of ultimate bond strength.

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