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A Study on Bond Strength of Geopolymer Concrete

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***Abstract*—This paper presents the experimental investigation on the bond behavior of geo polymer concrete. The bond behavior of geo polymer concrete cubes of grade M35 reinforced with 16 mm TMT rod is analyzed. The results indicate that the bond performance of reinforced geo polymer concrete is good and thus proves its application for construction.

***Keywords*—Geo polymer, Concrete, Bond Strength, Behaviour.

I. Introduction

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 Ordinary Portland Cement (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, Geo polymer 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 geo polymer which act as the binding agent. The geo polymer 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 super plasticizer can be added to improve workability.

Researches [1]-[6] 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 [7]-[12]. But bond studies in GPC are very little. This paper describes pull out test results which was carried out to determine bond strength of GPC.

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II. 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,

$$L_d = \Phi \text{ x } fst/4\ \tau_{bd}$$

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

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

where P = Applied load; Φ = nominal diameter of the bar

III. Present Investigation

The aim is to find the bond strength of GPC. 5 GPC cubes of 150x150x150 mm size each were casted of grade M35. Out of these five cubes, three cubes were casted to find the strength of GPC. Two cubes GP35-75 and GP35-100 were casted to find the bond strength with 16 mm diameter rod embedded in it where development length was 75 mm in one cube and 100 mm in another cube. After seven days, investigation for bond strength was carried out. Then the relation between slip and bond stress was plotted. And also ultimate bond strength was found.

IV. Materials Used

The mix design of geo polymer concrete is similar to ordinary concrete but cement is replaced by binder and water with alkaline solution. The mix proportion used was 1:1.69:2.16 and the ratio of alkaline to binder were 0.45. Sodium hydroxide solution and sodium silicate solution was used as alkaline activators. GPC was made by total replacement of cement with sixty percent fly ash and forty percent 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 are given in Table I.

TABLE I
THE DETAILS OF MIX PROPORTION

Flyash (kg/m^3)	GGBS (kg/m^3)	Fine aggregates (kg/m^3)	Coarse aggregates (kg/m^3)	Alkaline liquid (l/m^3)
272.10	181.40	767.13	979.20	204.06

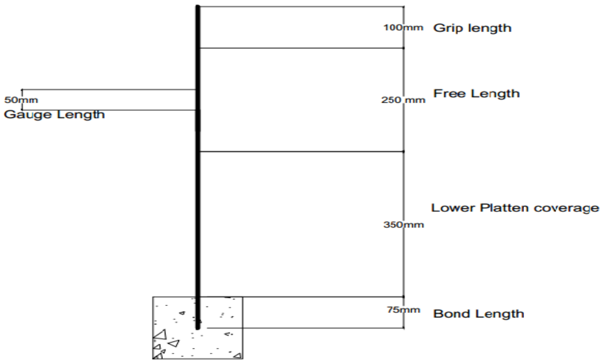
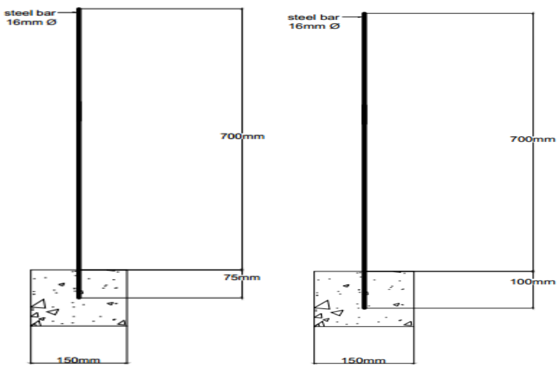


Fig. 1 Bar length details



(a) GP35-75 (b) GP35-100

Fig. 2 Bar length details of casted cubes

CONPLAST SP430 was used as Super plasticizers 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.

Moulds 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 super plasticizers were added and mixing continued for 5 to 7 minutes. Bars with suitable length were put in two cubes and embedded length was controlled carefully. An embedment length of 100 mm and 75 mm has been adopted. Three cubes were casted to find strength without any bar. Excluding embedded length a grip length of 100 mm for fixing, 350 mm for lower platen coverage and free length of 250 mm was considered. The specimens were allowed for 7 days ambient curing at room temperature. The details of bar length are shown in Fig. 1. The bar length details of casted cubes are shown in Fig. 2.

V. TESTING OF SPECIMENS

The bond strength test was carried out according to IS 2770-1997 [13]. A 16 mm diameter deformed steel reinforcing bar was embedded into the concrete cube at centre. All specimens are tested up to failure of bar matrix interfacial bond. The peak load at failure of bond and maximum slip is observed. All specimens failed with vertical crack along the embedded length of bar with cracking sound. Three cubes were tested for its 7 day compressive strength using 100 ton capacity Universal Tensile testing machine. After seven days, Pull out test was also carried in specimens GP35-75 and GP35-100 to determine bond strength and the test setup is shown in Fig. 3. Elongation of rod (Δe) was measured by fixing an extensometer at middle of rod with gauge length of 50 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 extensometer and dial gauge readings were 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

$$\Delta s = \Delta a - \Delta e$$

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

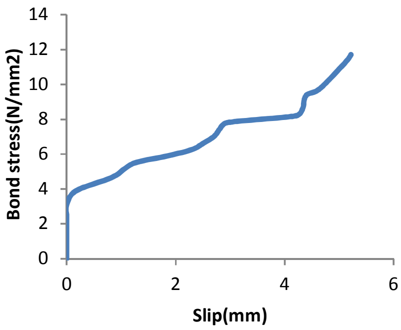
Fig. 3 Pull out Test

VI. Discussion of Test Results

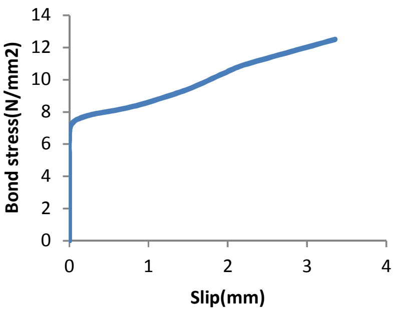
The seven day average Compressive Strength (fck) of Geopolymer Concrete (GPC) obtained under ambient conditions (i.e. at Room temperature) was found to be 37.96 MPa. The high compressive strength obtained for GPC is due to the addition of GGBS to the fly ash (sixty percent fly ash and forty percent GGBS). The results of pull out test of the cubes are presented in Table II.

TABLE II
Pull Out Test Results

Specimen	Ld (mm)	Failure Load in Bond (Tons)	τbd (N/mm^2)	Slip (mm)	τbd /fck
GP35-75	75	4.8	12.50	3.4	0.329
GP35-100	100	6.0	11.72	5.2	0.308



(a) GP35-100



(b) GP35-75

Fig. 4 Bond Strength vs Slip

The Bond strength of Standard concrete (as per IS 456-2000) having the compressive strength of 37.96, considering the deformed bars is about 2.8MPa. However, the Geopolymer concrete has shown very high bond strength and the bond strengths obtained are in agreement with the published literature. The Bond strength of GPC obtained is about one third of the corresponding compressive strength. Also the bond strength of GPC is about four times higher than the corresponding standard concrete made using conventional materials. This may be attributed to the high bonding between the aggregates and alkaline solution. However more such tests are required to confirm the above observations. The plot between slip and bond stress of GP35-75 and GP35-100 is shown in Fig. 4. The failure pattern of the specimens is shown in Fig. 5. The failure occured at the concrete region where steel bar was bonded.

(a) GP35-100

(b) GP35-75

Fig. 5 Failure Pattern of Specimens tested for Bond Strength

VII. Conclusions

From the experimental investigation, the following conclusions are drawn.

1. The Geopolymer concrete exhibited high bond strength.
2. The Bond strength of GPC is in the order of about one third of the corresponding compressive strength.
3. The bond strength of GPC is about four times higher than the corresponding standard concrete

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