RESEARCH ARTICLE OPEN ACCESS

Comparative Study On Bond Strengths Of Reinforcing Bars Embedded In Conventional And Geopolymer Concretes

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Abstract:

Conventional concrete and Geopolymer concrete has been investigated thoroughly in recent times with respect to mechanical strength properties throughout the world. However, that is related to structural behavior of these concretes which needs to be taken up urgently in order to make them acceptable in field applications by practicing engineers. In this regard, studies to bond strength of reinforcing bars with concrete are of greater significance. The attainment of satisfactory performance in bond, when efficiently developed enables the concrete and steel to form composite structure which is the most important aim of reinforcement in RCC structural members. Bond stress in RC members arises due to anchorage of bars in Tension or Compression; anchorage bond problem is merely of determining of the length of embedment required to resist the withdrawal of reinforcing bars. Earlier investigations in conventional concretes and GPCs for straight bars proved that GPCs has better performance than conventional concretes in case of bond. Hence, in the present study it deals about the experimental and numerical work relating to the finite element modeling using ANSYS version 15.0 to correlate the bond strength of straight bars and L-bends/ 90° bends in geopolymer concrete with that in conventional concrete cubes using Pull out test as per Indian codal provision IS 2770:1967.Standard test specimens with respect to compressive strengths were casted and tensile strength of the rod has been found out for using the data to model in ANSYS version 15.0 and the model developed is validated with experimental data of straight bars and L-bends on geopolymer concrete and conventional concrete.

Keywords: *Conventional concrete, Geopolymer concrete, bond strength, Straight bars and L-bend/90° Bend, ANSYS, Pull out Test*.

I. INTRODUCTION

In any RC construction, steel member and surrounding concrete transfers the load because of bond stresses which are being developed at the interface of two materials i.e., steel-concrete composite interaction behaviour contributing towards ductility aspect of structural behaviour. At the serviceability limit state, the bond enables the steel-concrete to act together without slip which helps to control the crack width and deflection. At and nature of bond stress is highly complex due to shear lag and effects of cracking and ribs on the bar surface, the codes of practice gives importance to development length required for the transfer of load from steel to concrete based upon a uniform nominal bond stress through the length of embedment of the rebar. The bond stress in a RC member is developed from the anchorage of bars and change in bar force through its length or due to varying bending moment. The mobilisation of bond must be assured under loading situations such as tension, compression and flexure. Many studies on conventional concretes (CCs) are available, but, not many investigations on the bond strengths of geopolymer concrete (GPC).

Previously, many of the investigators had a focus on studying reaction mechanisms, mix design, physical and mechanical properties, durability aspects etc., of GPCs **[4-6].** But, studies are also needed on bond between concrete and reinforcement, which is a chief requirement in the reinforced concrete for transfer of force from the concrete to rebar **[7,8]**. The initial bond strength comes from the weak chemical bond between steel and hardened concrete, but this resistance is broken at low stress. After the slip occurrence, friction is contributed to bond **[9]**. In case of ribbed bars, bond is largely contributed due to the mechanical interaction between the ribs on the surface of the bar and the surrounding **[9-11].**The bond mechanics is complex and this action is not because only of adhesion of steel with concrete, but also with mechanical locking which is because of projections on the bar. The mechanism of anchorage reinforcement with High Yield Strength Deformed bars is because of Adhesion of concrete and steel, Shear strength of concrete and interlocking of ribs with concrete.

The present study on bond strengths of CCs and GPC specimens with straight bars and L bends was taken up as per IS: 2770**[2]** and numerical simulation done using ANSYS version 15.0**[12]**.The characteristic yield strength of HYSD bars **[3]** is 415 MPa. When the test data compared with provisions of IS: 456-2000**[1]** would create confidence in engineers to adopt GPCs for design and construction of RCC structural components.

II. RESEARCH METHODOLOGY

In this project,100% cement for conventional concrete and 80 % fly ash and 20 % GGBS for geopolymer concrete is taken as the preparation of base material and the mix proportion used was 1(binder):1.5(fine aggregate):2.5(coarse aggregate). Standard cubes was cast to find the compressive strength and Finite Element software ANSYS version 15.0 is used to model the Pull out specimens of Straight bars and L-bends in Conventional concrete and Geopolymer Concrete. Numerical stress results acquired are validated with experimental stress results.

III. EXPERIMENTAL PROGRAM

A. Materials

The precursor materials used in this study were class-F fly ash (FA) and ground granulated blast furnace slag (GGBS). Fly ash was provided by Ennore, thermal Power Plant, India. GGBS was provided by Jindal Steel Plant, Bellary, and Karnataka, India. These FA and GGBS are the main aluminium and silicon sources for synthesizing geopolymer binder. The chemical composition of FA and GGBS is being analysed by the X-ray fluorescence spectroscopy are listed in Table I .Mechanical properties of Geopolymer concrete has been represented in Table II and the tensile test results are tabulated in Table III.

TABLE I
CHEMICAL COMPOSITION OF FA & GGBS (EDXRF)

Composition (%)	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**CaO**	**K_2O**	**MgO**	**Na_2O**	**LOI**
FA	47.55	33.45	10.17	2.099	1.65	0.05	0.015	1.1
GGBS	21.58	14.88	1.78	55.25	0.48	2.63	0.015	1.8

Laboratory grade sodium silicate solution (MR SiO_2/Na_2O: 0.86) and NaOH solution (lye contains 50% NaOH concentration) were used to prepare Alkali Activator Solution (AAS) as a combination of sodium silicate solution and lye. Fine aggregate (river sand) with fineness modulus 2.73 and aggregate maximum size of 4.75 mm was used. Similarly coarse aggregate consist of particle sizes consisting of 12.5 mm passing and 10 mm retained were used. The HYSD bars used were generally conforming to IS: 1786[3].

Figure 1: Compressive strength testing by UTM of capacity 40 tonnes

TABLE III
MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE

Mix ID	Liquid/Binder Ratio	Compressive strength (N/mm^2)	Modulus of Elasticity(N/mm^2)
OPCC	0.45	45.3	33655
GPC80	0.55	39.8	31543

- GPC80 indicates the Geopolymer concrete with binder containing 80 % Fly ash and 20 % GGBS.
- OPCC represents the concrete made using ordinary Portland cement.
- Liquid in GPC80 is formulated sodium silicate solution
- Liquid in OPCC is portable Water

The Tensile strength of 12 mm steel bar is tested in servo control UTM to calculate, Tensile strength, Young's Modulus etc., and the graph obtained through UTM in which X – axis represents Cross Head Travel(in mm) and Y – axis represents the Load(in kN) is shown in Figure 2, from which the Table III Properties are determined.

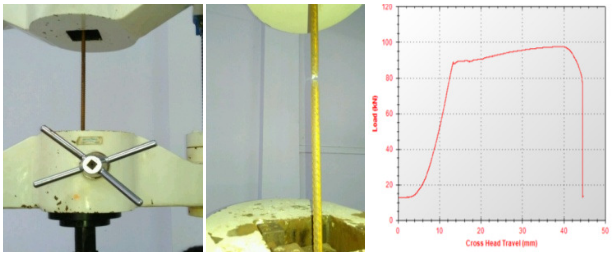


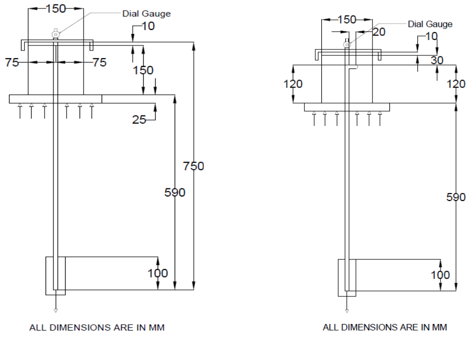
Figure 2: Tensile strength results obtained through UTM of capacity 100 tonnes

TABLE IIII
PROPERTIES OF HYSD BAR USED IN EXPERIMENTAL PROGRAM

Diameter of the bar (mm)	Gauge length (mm)	At Peak point		Extension at Break point (mm)	At Yield point	
		Extension (mm)	Tensile strength (N/mm^2)		Extension (mm)	Yield stress (N/mm^2)
12	450	39.9	861.3	44.82	13.5	775.0

B. Geopolymer Concrete Pull Out Test Specimens

Pull out test specimens of cubes with size 150 mm x 150 mm x 150 mm were cast with a 6mm diameter of plain bars with helical reinforcement and 12 mm diameter bar placed centrally and testing is carried out in UTM (universal testing machine) of capacity 100 tonnes.



(a) (b)

Figure 3: The Schematic Line sketch of test setup for pull out test

Figure 3(a) represents the pull out test setup of straight bar and Figure 3(b) represents the pull out test setup of L – bends.

(a)

(b)

(c)

(d)


(e) (f)

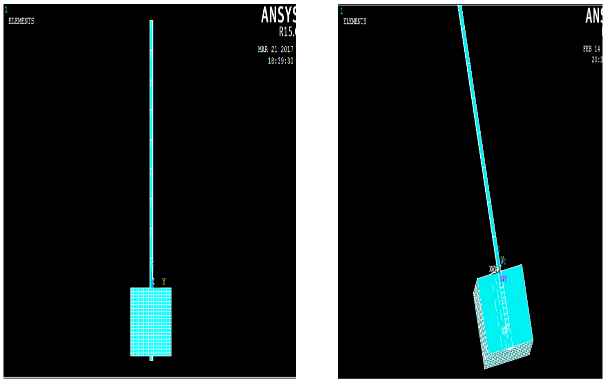
Figure 4: Pull Out Test Specimen Details

Figure 4(a) represents the reinforcing bars of straight bars and L – bends with 4mm diameter spokes attachment to measure the slip obtaining through anchorage. Figure 4(b) represents the 6mm diameter plain bars helical reinforcement. Figure 4(c) represents the typical mould arrangement for pull out specimen. Figure 4(d) denotes the cast specimen. Figure 4(e) represents typical arrangement of experimental setup. Figure 4(f) represents the typical arrangement of dial gauge on the pull out test specimen. The results obtained experimentally and numerically are discussed in results and discussions heading.

IV. ANALYTICALSTUDY

A. Geometry and Modeling

The modeling of finite element analysis of pull out test cube specimen of geopolymer concrete with straight bar is shown in Figure 5(a) and with L - bend is shown in Figure 5(b).



(a) (b)

Figure 5: Numerical model showing Geometry and Meshing of pull out specimens

B. Element Types

Solid 65 of eight noded solid brick element with three degrees of freedom at each node and translations in x, y and z directions have been used to model the geopolymer concrete with a Poisson's ratio of 0.3 and density of 0.00024 gm/mm^3. Link 180 (a 3-D spar has been used to model the steel) with a Poisson's ratio of 0.3 and density of 0.00785 gm/mm^3. Coefficient of friction generally have a range of 0.3 to 0.5 and 0.3 is used to create the contact between steel and concrete's and so that both shares the common nodes at the interface and the details are as shown in table IV.

TABLE IVV

ELEMENT TYPES AND MATERIAL PROPERTIES FOR MODELLING

Element type		**Material properties**		**Density (kN/ m^3)**	
Concrete	**Steel**	**Modulus of elasticity (E) in MPa**	**Coefficient of friction**	**Concrete**	**steel**
Solid 65	Link 180	5000 sqrt (fck)	0.3	24	78.5

C. Meshing, Loads and Boundary Conditions

To obtain satisfactory results from Solid 65 element, a hexagonal mesh was considered and meshing of steel rebar corresponds to meshing of concrete volume is done is shown in fig 6

The boundary conditions for the geometric model are applied at the top surface of the cube for which three directions(x, y and z) are constrained except the nodes adjacent to the steel rebar for which constrained in two directions(x and y) is shown in Figure 6.

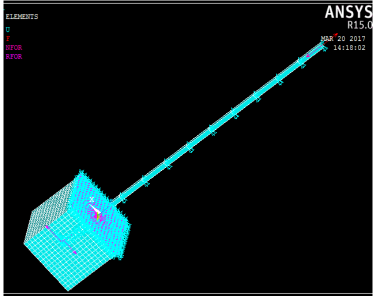


Figure 6: Loads and Boundary conditions for the Pullout Test Specimens

V. ANALYTICALSTUDY

The results of Pull out test cube specimens with straight bars and L – bends of conventional concrete Geopolymer Concrete via both experimentally and numerically are discussed in the following text. The average bond stress along the whole anchorage length of steel bar is considered as uniformly distributed as per IS: 2770[1] and it is computed by $T = P / (\pi * d * l)$

Where, T= Bond stress or bond strength in MPa, P= Load in N, d = diameter of the steel bar in mm, l = embedded length of the steel bar in mm. The mean values of the bond strengths on minimum of three specimens are used. The Experimental and Numerical design bond stresses as per the IS codes [1] [2] is shown in table V and table VI.

TABLE V

EXPERIMENTAL AND NUMERICAL DESIGN BOND STRESSES FOR OPCC OF 45.3 MPA

Mix Id	Experimental		Numerical	
OPCC	Straight bar	L bend	Straight bar	L bend
Peak bond stress, T_{peak} (MPa)	13.4	14.8	13.4	14.9
Bond stress at slip of 0.025, $T_{0.025}$ (MPa)	13.2	14.6	13.2	14.7
Bond stress in IS 456:2000 = $T_{IS\ 456}$ = 0.45sqrt(f_c) (MPa)	3.0	3.0	3.0	3.0
$T_{0.025}/T_{IS456}$	4.4	4.9	4.4	4.9
$T_{peak}/T_{IS\ 456}$	4.5	4.9	4.5	5.0
K= T_{peak}/sqrt(f_c)	2.0	2.2	2.0	2.2

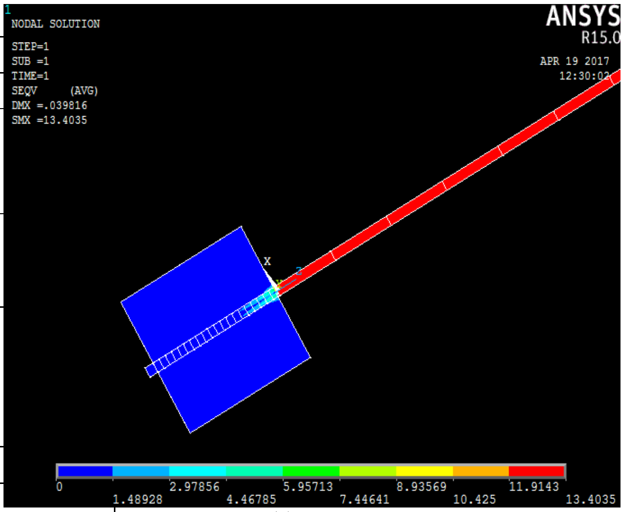
TABLE VI

EXPERIMENTAL AND NUMERICAL DESIGN BOND STRESSES FOR GPC OF 39.8 MPA

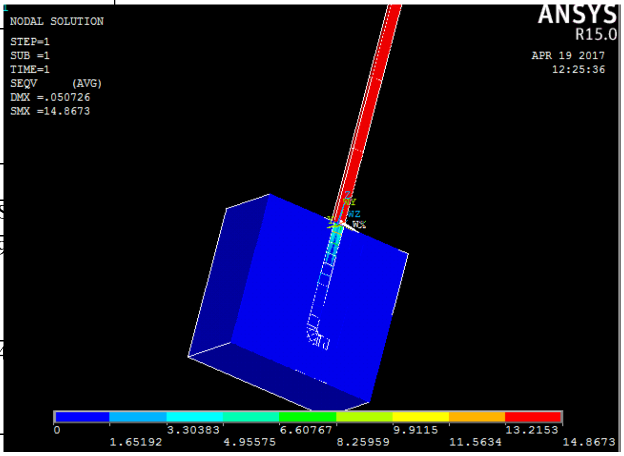
Mix Id	Experimental		Numerical	
OPCC	Straight bar	L bend	Straight bar	L bend
Peak bond stress, T_{peak} (MPa)	9.9	1.2	10.6	12
Bond stress at slip of 0.025, $T_{0.025}$ (MPa)	4.5	4.1	4.8	4.4

Bond stress in IS 456:2000 = $T_{IS\ 456}$ = 0.45sqrt(f_c) (MPa)	2.8	2.8	2.8	2.8	2.8
$T_{0.025}/T_{IS456}$	1.6	1.5	1.7	1.6	1.6
$T_{peak}/T_{IS\ 456}$	3.5	4.0	3.8	4.3	3.5
K= T_{peak}/sqrt(f_c)	1.6	1.8	1.7	1.9	1.6

By using ANSYS 15.0, the Numerical design bond stresses of conventional concrete with straight bars and L bends are shown in figure 7(a) and 7(b) and for geopolymer concrete with straight bars and L bends are shown in fig 7(c) and 7(d) w.r.t experimental design bond stresses as per the IS codes [1] [2].



(a)



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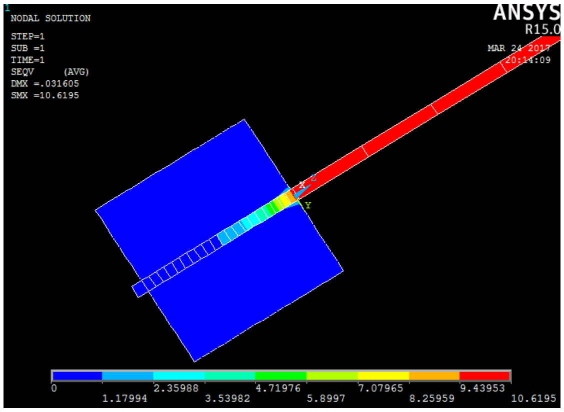

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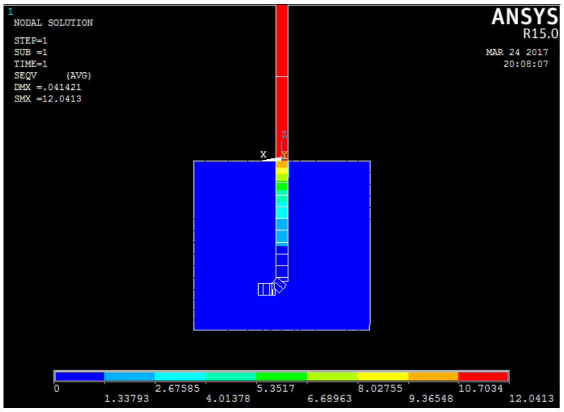
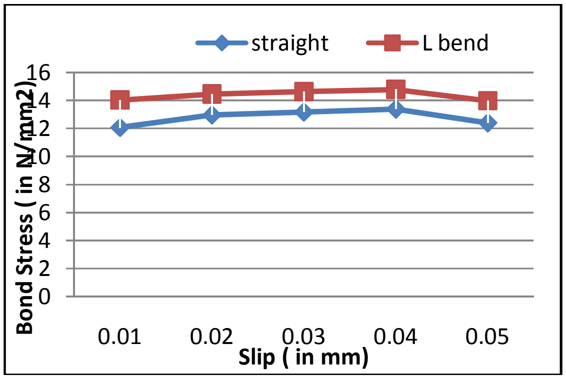


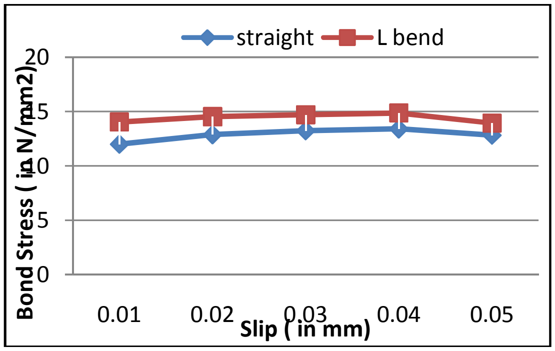
(d)

Figure 7: Numerically obtained Stress results for straight bars and L – bends of conventional concrete and geopolymer concrete

Figure 8(a) represents the curve of bond stress (in MPa) versus Slip (in mm) obtained through experiment and Figure 8(b) shows the curve of bond stress (in MPa) versus Slip (in mm) by numerically obtained results for OPCC.

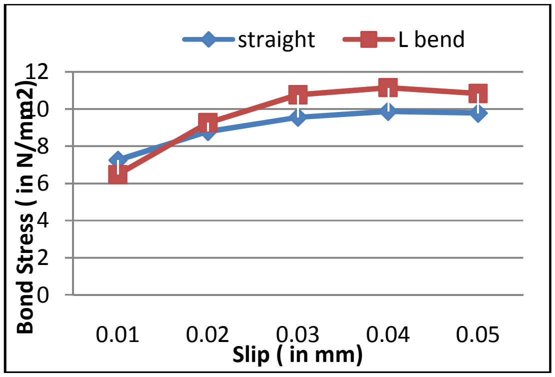


(a)



(b)

Figure 8(c) represents the curve of bond stress (in MPa) versus Slip (in mm) obtained through experiment and Figure 8(d) shows the curve of bond stress (in MPa) versus Slip (in mm) by numerically obtained results for GPC.



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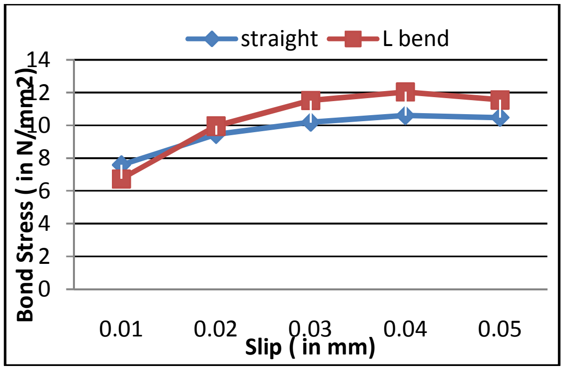

(d)

Figure 8: Experimental and Numerical Test Results for OPCC and GPC

VI. CONCLUSIONS

(1) The GPC80 had 28 days compressive strength of 39.8 MPa and this value for OPCC was 45.3 MPa. Thus, the GPC80 was having about 11.3% lower strength compared to OPCC.

(2) The bond strength at 0.025 mm slip in case of GPC80 was 4.5 MPa and this value for OPCC was 13.2 MPa. Thus, the bond strength of GPC80 was very much low compared to OPCC matrix; the bond strength of GPC80 was only about 30 % of bond strength in OPCC.

(3) The above observation indicates that even though the compressive strength of GPC80 was about 88% of that of OPCC indicating the reduction of only about 12%. However the bond strength of GPC80 was 35% of that of OPCC. Thus, the reduction in bond strength of GPC80was much less than the change in compressive strength of two mixes.

(4) This contrasting behavior may be attributed due to disturbances created at the interface of steel and surrounding GPC when the specimen is subjected to high temperature of 80^0 for 6 hours for curing purpose. Since, the steel and the concrete bond respond to high temperatures differently. This adverse situation in the test specimen does not occur when plain GPC specimens are subjected to curing regime.

(5) The literature shows that GPC has always high bond strength than OPCC at similar compressive levels, which was not the case in the present study as described above. In order to find out the bond strength of GPC mix with embedded steel, the GPC mix formulation should be such that the ambient temperature conditions are sufficient in the curing of GPC mixes. This is possible by increasing GGBS content of the mix and future bond studies on GPC's can consider this.

(6) Providing a 90^0 bend to the steel reinforcement at the end was found to increase the bond strength by about 10% and this increase can be attributed to the bend provided at a radius of 4 times the diameter of embedded steel rod.

Thus, values of bond strengths obtained from the investigation were found to be satisfactory with reference to those specified in IS: 456-2000 for the purpose of structural design computations.

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