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Bond Stress Evaluation of Embedded Steel in Self Compacting Geopolymer Concrete

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Abstract : This paper deals with evaluation of bond performance of steel with concrete when geopolymer is used instead of cement. Geopolymer technology is introduced to Self compacting concrete which was proved to be superior in bonding than ordinary concrete. Low calcium Fly ash is used as basic source material along with alkaline solutions of sodium hydroxide and sodium silicates. Self compacting concrete has been made with slight modifications to fit under the external exposure curing conditions. Modifications were made by introducing additives to improve the setting time. OPC are added in minimal amount and comparison has been made for the same based on bonding stress. Normal self compacting concrete, self compacting geopolymer concrete with added Portland cement are investigated using pull out tests and results proves appreciable properties for modified self compacting geopolymer concrete.
Key words : Self compacting geopolymer concrete, Ordinary Portland Cement , Pull out test, Compressive strength, External exposure curing.

Introduction

Self compacting concrete (SCC) is used extensively in precast as well as on-site construction which enables pouring of concrete into heavily congested reinforcement with zero compaction aids. SCC is capable of flowing under its self weight which is made by adjusting rheology in normal concrete mixing process. Normal SCC is made by a) increasing amount of fines b) introducing superplasticisers c) reducing size of aggregates. The self compacting concrete was first developed in Japan to improve the reliability and uniformity of concrete in 1988[1]. Prelimnary research work on SCC proposed a simple mixture proportioning system in which coarse aggregate, fine aggregate contents, w/b and percentage of SP dosage kept constant so that self-compatibility can be achieved[2]. Water/powder ratio is usually accepted between 0.9 and 1.0 in volume, depending on the properties of the powder.

Many other investigators have also dealt with the mix-proportioning problems of SCC and list out various methods such as empirical design method, compressive strength method, close aggregate packing method and methods based on statistical factorial model and rheology of paste model[3].

Some design guidelines have been prepared from the acceptable test methods such as EFNARC Guidelines, 2002. The Self compacting concrete contains more powder content, less coarse aggregates, high range water reducing superplasticizer (SP) in larger amounts and frequently a viscosity modifying agent. With the inclusion of geopolymer into SCC, a new technology has been laid up which gave prominent development in self compacting technology. Investigation on Self compacting geopolymer concrete (SCGC) was made using low calcium fly ash and mixture of Sodium hydroxide (NaOH) and sodium silicate(Na_2SiO_3) as alkaline activators.

Results proved 12 M concentration of NaOH in mix gave appreciable properties in SCGC[4,5]. Heat curing methods was adopted to achieve ultimate strength which gave importance of laying concrete in precast works[6]. Further blending of SCGC and using source materials other than fly ash was also tried to bring down the curing temperature and various other aspects[7]. Investigations on Geopolymer concrete with added OPC also stated that minimal additions of cement can be used as additive to operate geopolymerisation in ambient curing conditions[8]. Work on class C fly ash geopolymer concrete with OPC as additive also validates the same proof for better geopolymerisation process in normal climatic conditions[9]. From the above research it was able to channelize study on SCGC in reduced temperature by addition of additives or blending of byproducts.

Study on bond strength between concrete and steel is an important aspect to understand feasibility of using geopolymer in RCC. Works has been carried out to check the bond strength of RCC structures made of SCC[10, 11, 12, 13]. A comparison study on normal geopolymer concrete (GPC) and normal concrete also was also performed and proved superior bonding for GPC specimens [14, 15, 16,17]. The present study aims to make normal SCC and SCGC of similar mechanical properties and to evaluate bond strength of the same using pull out tests as prescribed in IS: 2770 Part 1:1967.

Experimental Observations

Materials

Class F Fly ash obtained from Mettur Power Plant, Tamilnadu was used as source material for the study. Specific gravity of fly ash was noted as 2.2. The chemical constituents of fly ash are given in Table 1. Referring to the given values it was inferred that fly ash is conforming to IS: 3812 (2003) specifications.

Table 1: Chemical composition of Class F Fly Ash

Chemical Properties (% By Mass)	**Maximum Range (%)**
SiO_2	58
CaO	3.6
SO_3	1.8
Na_2O	2
MgO	1.91
Loss on ignition	2

Table 2: Physical properties of Coarse and fine aggregate

Physical Properties	**Fine Aggregate**	**Coarse Aggregate**
Bulk Density Loose Compacted	1642 kg/m^3 1862 kg/m^3	1459 kg/m^3 1596 kg/m^3
Specific Gravity Loose Compacted	2.68 2.701	2.716 2.967
Void Ratio Loose Compacted	0.6 0.43	0.83 0.858
Porosity Loose Compacted	0.381(38.1%) 0.31 (31%)	0.459 (45.9%) 0.461 (46.1%)

The coarse aggregate chosen for SCGC is typically round in shape, well graded, and smaller in maximum size than that used for conventional concrete. The coarse aggregate should have a minimum size of 12 mm for SCC and SCGC. It was conformed to BIS specifications and specific gravity is 2.72. River sand is used as a fine aggregate and specific gravity of fine aggregate is 2.68. Physical properties of coarse and fine aggregate are given in Table 2.

Synthesising chemicals used for geopolymerisation are sodium hydroxide (available in pellets) and sodium silicate solution. Sodium Hydroxide pellets obtained from Modern Scientific Company, Coimbatore with specific gravity and pH of about 1.47 and 13 was used for the study. Sodium hydroxide pellets of minimum assay-97 %, Carbonate-2%, Chloride-0.01 %, Sulphate-0.05 %, Potassium-0.1 %, Silicate-0.05 %, Zinc-0.02 %, Heavy metals-0.002 % and Iron-0.002 % was mixed in water in order to achieve the required molarity in solution. The concentration of NaOH was maintained as 12 M prepared by dissolving 36.1% solids into 1 litre solution[18].

The sodium silicate solution available in gel form and is obtained from Shardha silicate and chemical industries, Coimbatore. The specific gravity of Sodium silicate solution is 1.6 and the colour of sodium silicate solution is light yellow liquid (gel). Ordinary Portland Cement (OPC) of 53 grade conforming to IS: 12269 (2013) was used for the study.

Modified carboxyl ether based superplastciser cum retarder Sika viscocrete was used for the present study. This SP is especially suitable for the production of concrete mixes which require high early strength development, powerful water reduction and excellent flowability. For concrete of high workability dosage of 1.0 - 2.0% by weight of cement has to be decided according to trials. Relative density noted down is 1.08 g/l.

Fe500 HYSD deformed bars are used for reinforcement of pull out specimens. 12 mm and 16 mm were employed for comparison of bond strength in RCC.

Mix design

Various number of laboratory trials were conducted on SCC and SCGC and finally mix was designed based on EFNARC guidelines. The EFNARC guidelines recommend quantity of binder to be used from 400 to 600 kg/m^3 [19]. Here Fly ash content was fixed to 500 kg/m^3 based on workability aspects. Alkaline solution to fly ash ratio was fixed as 0.5 and extra water was limited to 12% of binder. Based on trials Na_2SiO_3 solution was taken twice the amount of NaOH solution. An addition of OPC for about 5% of source material was included in the design to reduce the setting time of cement in normal curing conditions[8]. Workability and strength properties were checked for SCGC and finally SCC was designed matching to the strength criteria of SCGC for comparison purposes. Proportion of materials taken for SCC and SCGC are given in Table 3.

Table 3: Proportion of materials taken for design of SCC and SCGC

Type of concrete	Binder	Additive	Fine	Coarse	NaOH	Na_2SiO_3	SP	Water
SCC	520	-	961	821	83	167	8.32	187.5
SCGC	475	25	650	900	-	-	10	60

*Proportions of materials in kg/m^3

Mixing and mix proportioning

The concrete mixing procedure consists of dry and wet mixings. The solids components of SCGC, i.e. the fly ash and the fine and coarse aggregates, were dry mixed in the pan mixer for about 2.5 minutes. Aggregates used were taken in saturated surface dry condition and manual mixing was employed. The liquid part of the mixture, i.e. the sodium silicate solution, the sodium hydroxide solution, extra water and the super plasticizer, were premixed thoroughly and then added to the dry mixture. The wet mixing was done for 3 minutes and has to be performed 1 hour prior to the use. The chemical reaction of wet mix played an important role in giving the required workability for SCGC and compressive strength of hardened concrete. The fresh SCGC had a flowing consistency and with high tendency of filling ability, passing ability and resistance to segregation. Mixing method SCC was performed in similar way as given in EFNARC guidelines. Slight differences in mixing of SCGC from SCC were that water along with superplasticiser need not be mixed 1hour prior like SCGC.

Curing

Curing method for OPC additions in SCGC was altered to external exposure curing conditions taking account of previous research. Care has to be taken to protect specimens from rain and extreme weather conditions for at least 7 days to protect from shrinkage cracks. The external exposure curing is shown in Figure 1. For the purpose of pull out tests, specimens were made in laboratory so as to avoid disturbance of external agencies. After demoulding specimens were kept for external exposure curing. For normal SCC normal water curing of 28 days was performed.

Figure 1. Curing method adopted for SCGC

Fresh and Hardened Properties of SCC and SCGC

EFNARC guidelines suggests various workability tests to perform on SCC such as T_{500mm} slump flow, Abrams slump flow, L Box Test and U Box Test to study the characteristics of filling ability, passing ability and segregation resistance. Same tests were carried out on SCGC with added cement and normal SCC to evaluate the fresh properties of concrete. Design of SCGC has to be made in several trials and grade of concrete was fixed and analysing the compressive strength values at 28 days. Same trials were done on normal SCC to achieve similar properties as that of SCGC. Hardened properties were investigated in terms of compressive strength and results are plotted. Details of fresh properties are shown in Table 4. Hardened properties such as cube compressive strength, Splitting tensile strength and Beam flexural strength was carried to evaluate the variation of strength parameters based on IS: IS 516 (1959): Method of Tests for Strength of Concrete and stipulated in Table 5.

Table 4: Fresh Properties of SCC and SCGC

Type of SCC	T_{500mm} Slump flow(sec)	Slump flow dia. (mm)	L - Box Ratio	U - Box value (mm)
SCC	4	700	0.88	28
SCGC	5	700	0.87	28
Range as per EFNARC guidelines	2-5	650-800	0.8-1	30 mm max.

Table 5 : Hardened properties of SCC and SCGC

Type of SCC	**Compressive strength (N/mm^2)**	**Splitting Tensile Strength (N/mm^2)**	**Flexural Strength (N/mm^2)**
SCC	32	3.5	3.1
SCGC	33	2.9	2.6

Pull Out Test

Pull out test measures the force required to pull out a previously cast in steel insert with an embedded enlarged end in the concrete. In this operation, a cone of concrete is pulled out and the force required is related to the compressive strength of concrete. Bond stress is the tangential shear or friction developed between the reinforcement and the surrounding concrete that transfers the force onto 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 due primarily to the deterioration of the bond. Hence it is necessary to study the bond characteristics.

Bond stress is calculated as

$$\tau_b = \frac{P}{\pi\, d_b\, l_b}$$

where, τ_b - bond stress (MPa),
P - applied load (N),
d_b - diameter of bar (mm)
l_b - embedded length of bar (mm)

Casting Of Specimen

The specimen consists of concrete cubes 150×150×150 mm with a single reinforcing bar (12mm and 16mm dia) embedded vertically along the central axis in each specimen. Deviating from the original procedure of bar positioning, the bar was projected up by about 15 mm from the bottom of the cube to understand the bonding of steel and concrete when concrete cover is provided. Also, the bar was projected upwards by about 85 cm from the top face of the cube to provide an adequate length for gripping the specimen in the testing machine. The specimens were also reinforced with a helix of 6mm diameter plain mild steel bar at a pitch of 25mm to prevent splitting failure. Casting arrangement of pull out specimens is shown in Figure 2. De moulding was carried out after 24 hours and then the specimens were kept for external exposure curing. 10mm coating of cement plastering were done one day prior to testing to ensure the exact failure mode.

Figure 2.Casting arrangement of pull out specimens

Testing Of Specimen

The test was conducted as per IS 2770[20] using a universal testing machine of 2000 kN capacity. While testing, the pullout specimen was mounted on the testing machine in such a manner that the bar is pulled axially from the specimen. As per IS 2770 the end of the bar at which the pull is applied shall be that which projects from the top face of the cube as cast. Linear variable differential transformer (LVDT) was used to measure the displacement of the bar. The LVDT at the fixed end was placed in between the gripping length of specimen so that small deflection can be noted down as the load applied. Load was applied to the reinforcing bars monotonically at a rate not greater than 22.5 kN/min. The loading was continued until the specimen failed. The recording of loads and deformations were carried out. The loads recorded were then converted to bond stress. The testing arrangement is shown in Figure 3.

Figure 3. Testing of pull out specimens

Figure 4. Failure of specimens in shear due to pull out of bars

Table 6: Pull out test results

Type of Concrete	Dia. of steel rods (mm)	Bond stress at 0.025mm deflection (N/mm^2)	Max. Bond stress (N/mm^2)	Failure mode
SCC 1	12	10.62	15.73	Shear
2	12	11.4	14.55	Splitting
3	12	9.82	13.37	Shear
1	16	12.18	16.12	Shear
2	16	11.59	14.35	Shear
3	16	11.99	16.9	Shear
SCGC 1	12	14.55	18.68	Shear
2	12	15.33	19.68	Shear
3	12	15.73	19.27	Shear
4	16	15.73	19.66	Splitting
5	16	16.12	22.02	Shear
6	16	16.32	22.81	Shear

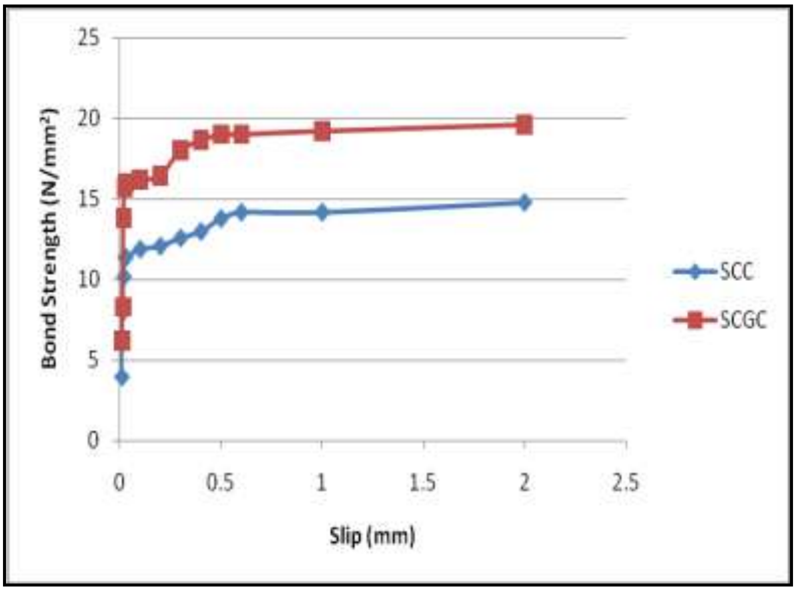

Figure 5. Bond Stress Vs. Slip of 12 mm Dia specimens

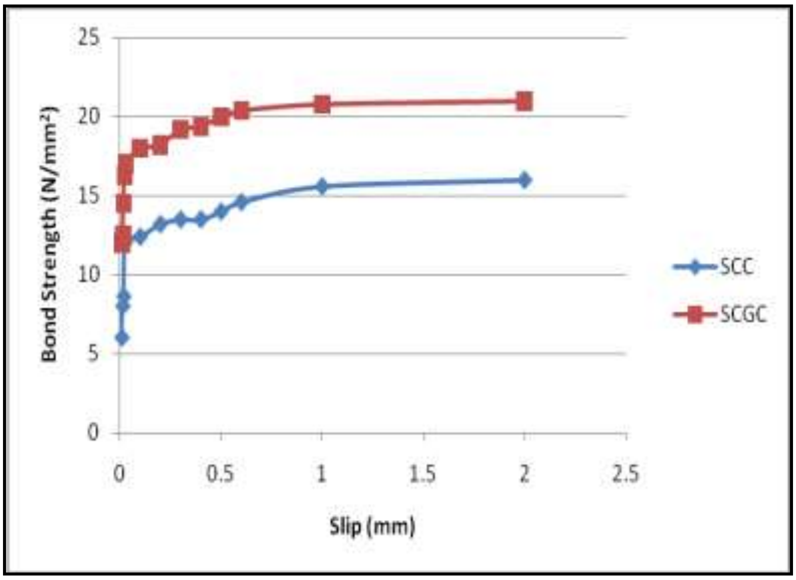

Figure 6. Bond Stress Vs. Slip variation of 16 mm Dia. Bar specimens

Results and Discussion

SCC and SCGC for pull out specimen were made using same strength aspects for the purpose of comparison and values are noted down. Diameter of steel rods was varied for both the sets with embedded length of 135mm. Test results are given in Table 6. From the test results it was noted down that failure mode is in pull out shear failure and illustrated in Figure 4. Deflections were noted down using LVDT from which relation between bond strength and slip are plotted down in Figure 5 and 6. Deformation of bar due to extension is found to be negligible. Hence slip of bar on loaded end was measured on varying loads upto 2 mm deflection for all specimens. Concrete cover provided in above tests will help to understand aggregate bonding to the steel which are usually seen in practical cases of slabs and beams. It was inferred that SCGC specimen shows better bonding to steel than normal SCC. The viscosity property of alkaline solutions taking part in SCGC helps in adhering tight to the steel rods within the concrete. In normal SCC whereas aggregate bonding is only achieved by rheology of cement paste and superplasticiser.

Conclusion

From the results following points are concluded:

Bond strength between concrete and steel is much higher for SCGC when compared to SCC of similar mechanical properties. Alkaline solution taking part in geopolymerisation processes helps in adhering materials together and to the embedded steel thereby facilitating concrete superior in bond strength.

Improving setting time and altering curing conditions helps in triggering geopolymerisation and achieving sufficient strength.

The bond strength of both SCC and SCGC increased with increase in compressive strength of concrete.

Bond strength increases by increase in diameter of steel rods which is valid for both SCC and SCGC.

Bond Strength vs. slip variation of graph is assumed to be bilinear. However more trials have to be conducted to validate the same.

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