Experimental Study on Bonding Strength of High Strength Concrete Subjected to Elevated Temperatures

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Abstract - *The study presents an experimental investigation on bond strength of high strength concrete subjected to elevated temperatures. The main analyzed parameters were the effect of temperature, diameter of the bar, embedded length and the effect of silica fume. The work involves two type mixes; the first is plain concrete mix, second one with of 10% of silica fume (SF) as replacement to cement. Three different diameter of High Strength Deformed (HSD) bars are used (12mm, 16mm, and 20mm) with embedded length of 300mm and 150mm. All specimens are cured in water for 28 days and the specimens are heated for different temperatures (27°c, 200°c, 400°c and 600°c). Using Universal Testing Machine (UTM) all specimens PULLING OUT strength values and slip are determined. The result shows that the bond strength decreases as the bar diameter increases and with smaller embedded length the bond stress was found to be higher. The bond strength is found to be decreases as the temperature is increases. And the replacement of silica fume enhances the bond strength.*

Key Words: Pulling Out Strength, Temperatures, Silica Fume, Fly Ash, Compressive Strength, UTM, CTM.

1. INTRODUCTION

Bond strength in reinforced concrete is the resistance of the surrounding concrete against the pulling out of reinforcement. The bonding strength is considered in two ways, bonding strength between the paste and the reinforced steel, and between paste and aggregates. Bond strength is important not only to ensure the composite action, but also to ensure the ductile behaviour of the structure. Bond strength is influenced by [2],

- Bar geometry
- Concrete properties
- Amount of confinement around the bar
- Surface condition of the bar.

Study on bond strength of concrete has been done over past years, but a few studies have been done on the bond strength of the concrete subjected to high temperature [1]. At the time of concrete is revealed to the raised temperatures the deterioration of the concrete occurs due to the pore pressure evolved. Due to which strength of the concrete decreases which lead to structural failure. So that the concrete should posses good fire resistance properties also. So it is very important to study the bonding behavior between concrete and steel subjected to elevated temperatures.

In this study the bond strength of concrete is tested for various temperatures. The parameter studied were the diameter of the bar and embedded length. The mix was prepared by partially replacing the cement with 10% of silica fume and the grade of concrete is M60.

2. MATERIALS

2.1 Cement:

OPC 43 grade Cement is used for concrete. The physical properties of cement are presented below

Table -1: Properties of OPC concrete

Properties		
Fineness (in sq meter)		225
Setting Time In Minutes	Initial (min.)	30
	Final (max.)	600
Soundness	Le Chatelier (mm)	10
	Auto Clave(%)	0.8
Specific Gravity		3.1

Fine Aggregates and Coarse Aggregates:

The Fine aggregates used was natural local river sand and coarse aggregates used were crushed gravel of size 20 mm. Crushed coarse aggregates are used with sand and silica fume with Ordinary Portland cement for preparing mixtures. The Characteristics of fine and coarse aggregates are listed below

Table -2: Characteristics of Fine aggregates

Properties	Content
Loose unit wt	1.69
Sand Absorption	1.0%
Sieve 200	6.85%
Sand Specific Gravity	2.64

Table -3: Characteristics coarse aggregates

Properties	Content
Gravel Absorption	0.5%
Loose unit wt	1.345
Maximum Aggregate Size	20 mm
Gravel Specific Gravity	2.74
Sieve 200	1.15

Reinforcement steel:

Reinforcement steel of grade HYSD steel bars Fe500 was used. Three different bar diameters 12 mm, 16 mm and 20 mm were used.

Table -4: Physical and Mechanical properties of steel reinforcement.

Nominal bar diameter (mm)	Actual bar diameter (mm)	Ultimate Tensile strength (MPa)
12	11.8	732.4
16	15.8	663.5
20	19.7	662.3

Silica Fume:

The micro silica fume is used in the present study. Silica fume is added as the replacement to the cement, 10% of the cement is replaced with silica fume. The chemical specification of the used materials is given in the table no.5

Table -5: Chemical specification of used material

Chemical specification of used materials		
Materials	PC(%)	SF(%)
Chemical Composition : wt %		
SiO2	21.82	78.5
Al2O3	6.49	1.22
Fe2O3	1.93	1.27
CaO	60.74	2.13
MgO	1.08	5.32
SO2	2.62	0.15
Na2O	0.14	1.78
K2O	0.65	4.11
CI	0.012	0.036
LOI	1.65	4.93
Free CaO	0.84	-
Reactive SiO2	-	76.2

1.3 METHODOLOGY

In this present study, the experimental work consists of 144 numbers of pull-out cylindrical specimens having standard size of 150 mm Diameter and 300 mm height. And 8 cubic standard specimens of size 150 mm are cast for each mix. The cylinders were used to determine the bonding strength and cubes were used to obtain the compressive strength of concrete. Steel bars of diameter 12 mm, 16 mm and 20 mm are embedded into concrete specimens with embedded lengths of 150 mm and 300 mm. The specimens were exposed to 200ºC, 400ºC, 600ºC temperatures. The pull-out test and compression test is done as per IS 2770 (Part I) – 1967 and IS 516:1959 respectively. High strength concrete is prepared by partial replacement of cement by silica fume; concrete mix is produced with initial compressive strength of 60 MPa. The concrete mix design is done as per IS 10262:2009. The details of specimens test matrix are presented in Tables below.

Mix Design:

Mix Design is done as per is IS 10262.2009. In this study, cement contents is (450 kg/m3). Two types of concrete mix are chosen, the first one (type I) was combination of plain concrete (PC) and silica fume (SF) and the second one (type II) was of PC. The mix design proportion is adopted as 1:1.49:2.53. The details of the mix design for 1 cubic meter of concrete is given.

Table -6: Details of the Mix Design for 1m³ of concrete

Cement kg/m³	Silica fume kg/m³	Fine Aggregate kg/m³	Coarse Aggregate kg/m³	Water content lit/m³
450	50	672	1138	175

Preparation of Specimens:

Different test specimens are prepared with different diameter of bars and for different embedded length. For 300mm embedded length the bar is inserted into the mould and the bar is held vertically until the mould is filled completely with concrete. Because the bar should not get inclined in the mould so another horizontal bar is kept above the mould and wired by iron wire to the embedded bar. For 150 mm embedded length a horizontal bar is wired at 150 mm from the bottom of the bar, concrete is poured in mould and compacted. Concrete is poured in three parts of 100 mm by height of the mould, and is compacted by the standard compacting rod and soon the smoothing is done for surface of concrete for uniform surface. After 24hours unmoulding is done and specimens are kept for curing for 28 days. Figure 1 shows the specimens curing.

Fig -1: Curing of specimens

Specimens Subjected To Heat Treatment:

After the 28 days of curing the concrete cylinders and cubes specimens were kept for 1 day in laboratory, so that the specimens should get dry. Then the specimens are subjected to different raised temperatures (200ºC, 400ºC, 600ºC) for 1hour retention time in the electrical furnace.

The specimens when heated to different temperatures are kept for one day for air cooling to avoid sudden temperature change, then the specimens are been used for testing. Figure 2 shows the specimens heating electrical furnace.

Fig -2: Electrical furnace

Testing of Specimens

Pull-out test

Before the specimens are taken to pull-out test, physical observations such as colour change and crack variation are made. The pullout test is conducted on the Universal Testing Machine of capacity 1000 kN for finding out the bonding strength of concrete specimens. The testing was done as per IS 2770 (Part I) – 1967. Fig 3 shows the specimen loaded on Universal Testing Machine. Figure 4 and Fig 5 shows the failure pattern observed on the specimen when subjected to pull-out load.

Bonding stress:

Bonding stress can be calculated by the following equation,

$$S = P_{max} \times 1000 / (\pi \times D \times L)$$

Where, S=Bonding stress (MPa)

Pmax= Maximum pull-out load (N)

D= Diameter of bar (mm)

L= Embedded Length (mm)

π= Constant (3.142)

Fig -3: Specimen Loaded On Universal Testing Machine (UTM)

2. RESULTS AND DISCUSSION

The specimens were tested to find the compressive strength, bond strength and slip values. The parameters are considered are, exposure temperatures, bar diameters and embedded lengths for silica fume and plain concrete. The analysis of results is performed and various relationship are derived between bonding strength v/s temperature for all bar diameters for different embedded length and slip v/s temperature for all bar diameters for different embedded lengths

The failure of pull-out load is obtained for all specimens and it has observed that the specimens which are tested has failed in two modes of failure namely splitting failure and Steel Rupture Failure (SRF). And there is no specimen failed in pull-out (slip) mode. Splitting failure type of mode is predominant type of failure for tested specimens

Fig -4: Failure pattern for 150 mm embedded length (splitting)

Fig -5: Failure pattern for 300 mm embedded length (splitting)

Fig -6: Failure pattern for 300 mm embedded lenth (steel rupture)

Fig -7: Failure pattern in (slip)

Effect of Embedded Lengths

It has observed that, for the specimens of 150 mm embedded length the bonding strength decreases as the temperature increases. It has also observed that as the bar diameter decreases the bonding strength increases for same temperature level. Splitting type of failure mode is observed for all bar diameter sizes. For the specimens of 300 mm embedded length the bonding strength decreases as the temperature increases.

It is also observed that as the bar diameter decreases, the bonding strength increases for same temperature level. And for 12 mm bar diameter specimens at temperature levels of 27°C and 200°C,the specimens failed by steel rupture failure, which means that the bonding strength of the specimens is greater than the tensile strength of the bar for large embedded lengths. When the temperature levels are at 400°C and 600°C specimens were failed by splitting of concrete. For the 16 mm and 20 mm bar diameter specimens at 27°C, 200°C, 400°C and 600°C temperature levels specimens failed by splitting of concrete.

The bonding strength is larger than the tensile strength of the steel bar for small bar diameter with large embedded lengths. The small bar diameter has greater bonding strength than larger bar diameter if the embedded length is small. The 150 mm embedded length has the larger bonding strength for all bar diameter sizes (12 mm, 16 mm, 20 mm) than 300 mm embedded length at temperature levels (27°C, 200°C, 400°C, 600°C).

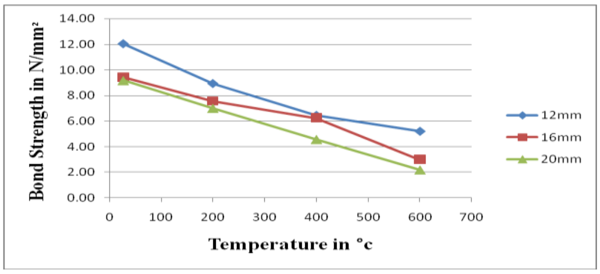

Chart -1: Variation In Bonding Strength And Temperature For 150 mm Embedded Length (Silica)

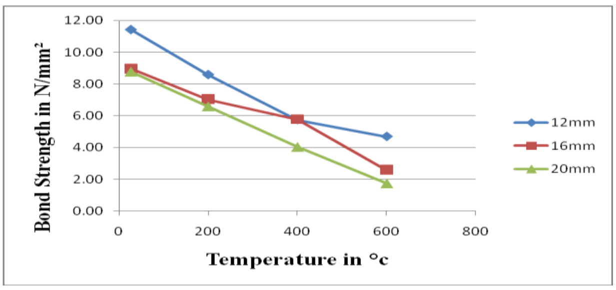

Chart -1: Variation In Bonding Strength And Temperature For 150 mm Embedded Length (Plain)

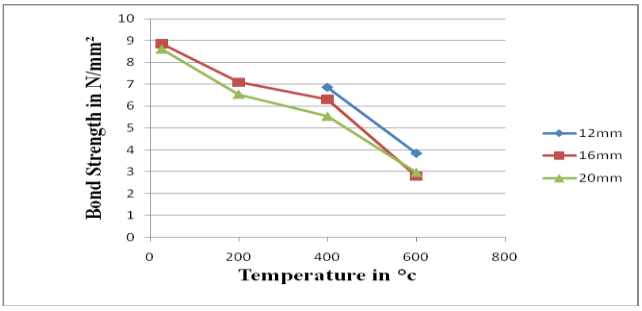

Chart -3: Variation In Bonding Strength And Temperature For 300 mm Embedded Length (Silica)

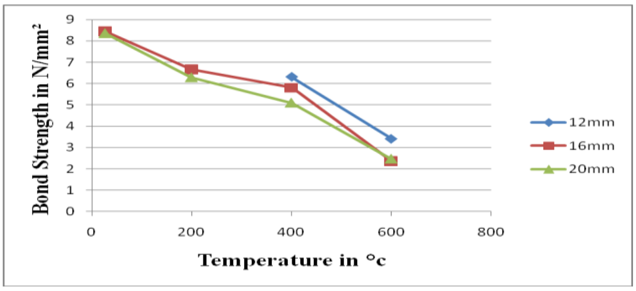

Chart -4: Variation In Bonding Strength And Temperature For 300 mm Embedded Length (Plain)

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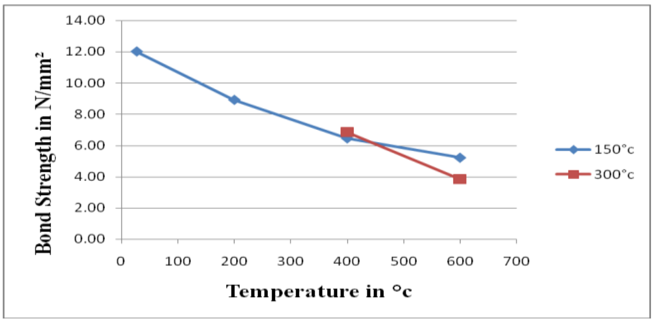

Chart -5: Variation In Bonding Strength And Temperature For 12 mm Bar Diameter (Silica)

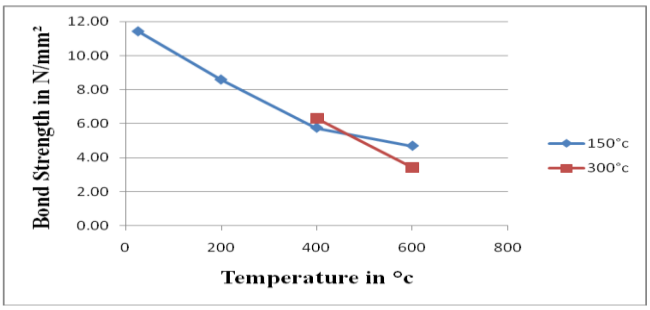

Chart -6: Variation In Bonding Strength And Temperature For 12 mm Bar Diameter (Plain)

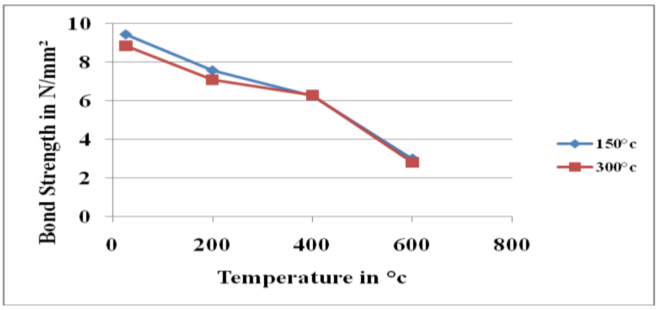

Chart -7: Variation In Bonding Strength And Temperature For 16 mm Bar Diameter (Silica)

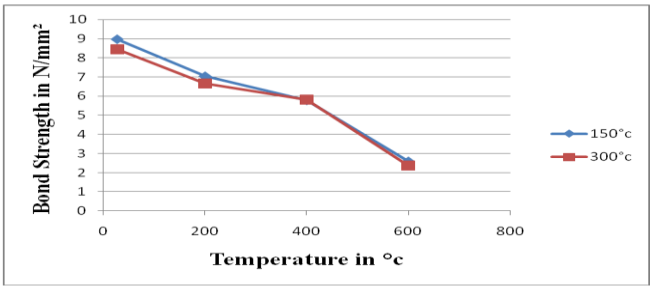

Chart -8: Variation In Bonding Strength And Temperature For 16 mm Bar Diameter(Plain)

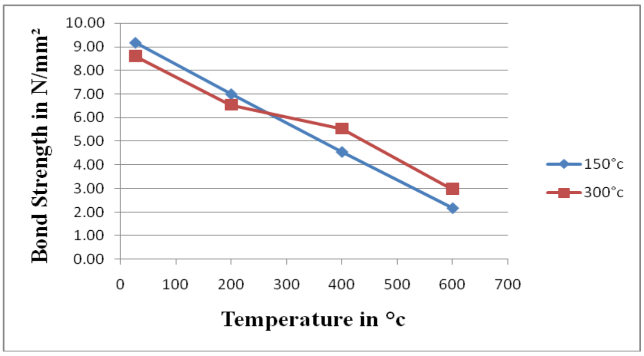

Chart -9: Variation In Bonding Strength And Temperature For 20 mm Bar Diameter (Silica)

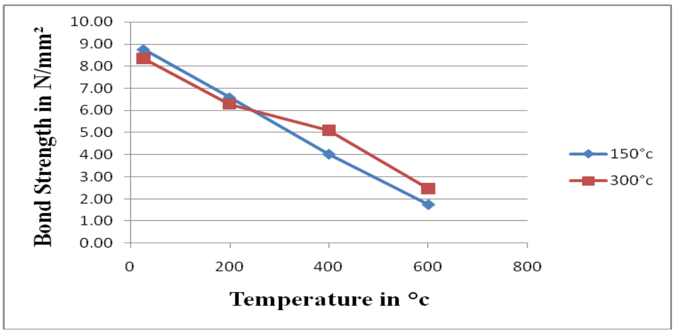

Chart -10: Variation In Bonding Strength And Temperature For 20 mm Bar Diameter (Plain)

Results of Slip Resistance

The variations in slip and temperature with different bar diameter for 150 mm and 300 mm embedded lengths for retention time of 1 hr. The slip value decreases as the temperature increases for all bar diameter sizes and for both embedded lengths. The bar of 16 mm diameter has the lowest slip values followed by 12 mm and 20 mm bar diameters. The Failure occurs because of local crushing of concrete at the tips of the bar ribs, followed by sudden splitting of concrete along the reinforced bars. Hence, all of the specimens tested showed typical splitting failure along the pulled rebar with radial cracking on their cross-section. Steel rupture failure occurs when the bonding strength is greater than tensile strength of steel bar for small bar diameter sizes and large embedded lengths.

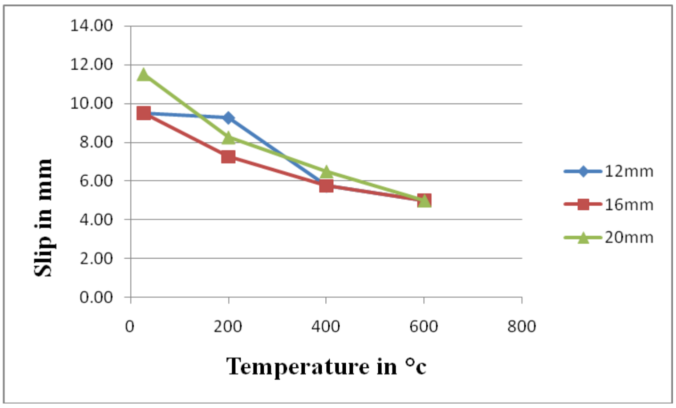

Chart -11: Variation In Slip For 150 mm Embedded Length(Silica)

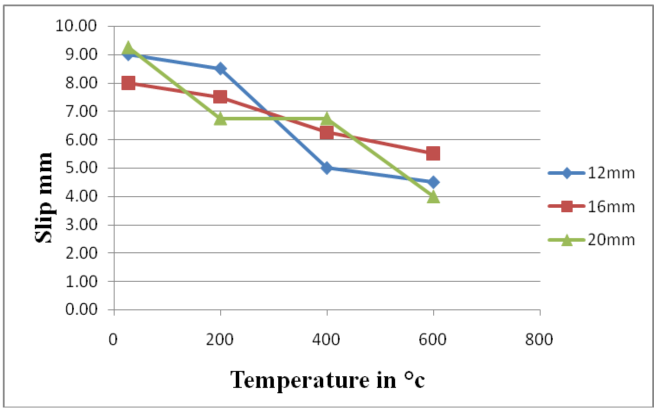

Chart -12: Variation In Slip For 150 mm Embedded Length (Plain)

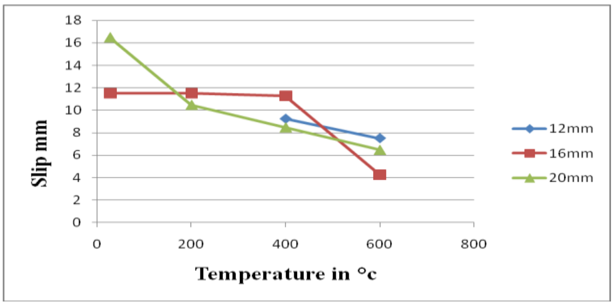

Chart -13: Variation In Slip For 300 mm Embedded Length (Silica)

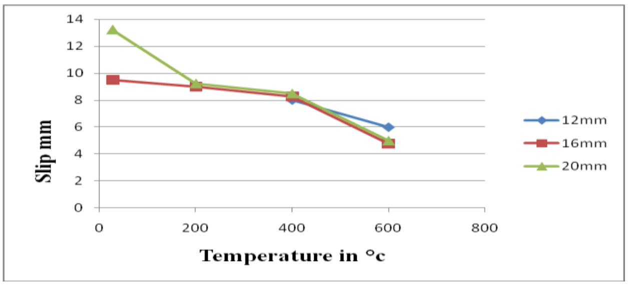

Chart -14: Variation In Slip For 300 mm Embedded Length (Plain)

3. CONCLUSIONS

Based on experimental study the following conclusions were drawn:

1) The bonding strength increases as the diameter of bar decreases for the concrete specimen with different embedded length. For the concrete specimens, smaller bar diameter has the greater bonding strength than larger bar diameter for half embedded lengths.

2) Loss of the bonding strength increases when the temperatures increase.

3) Concrete specimens of small bar diameter fails in pull-out test at 27°C and 200°C for large embedded lengths due to steel rupture failure in all mix, which means bond strength of concrete is more than the tensile strength of steel bar. Whereas the mode is splitting failure for large bar diameter and small embedded lengths.

4) The specimens for small embedded length has greater bond strength than the large embedded lengths for all the bar diameter and mix at room temperature and when subjected to raised temperatures.

5) The bounding strength give more resistance against increasing temperature for silica fume mix compare to M60 plain concrete.

6) For the specimens, the slip value decreases as the temperature increases for all bar diameters for both embedded lengths. And for 16 mm bar diameter has the lower slip value.

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