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Effect of Embedded Length and Bar Diameter of Reinforcement on Bond Strength Behavior of High Strength Concrete Subjected to Elevated Temperatures

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Abstract
In case of accidental fire, sabotages reinforced concrete structures get exposed to elevated temperatures, which results in deterioration of its mechanical strength. The deterioration in concrete is due to, its inhomogeneous volume change of concrete ingredients, generation of vapour pressure and decomposition of cement hydration products. Hence, it is significant to study the bond strength between concrete and reinforcing steel. In the present investigation a study has been carried out on bond strength between high strength concrete and reinforcing steel subjected to elevated temperatures. In order to find the variation in bond strength, various parameters were considered such as bar diameters, embedded length and different temperature levels with 1 hr retention period. In this investigation 12 mm, 16 mm and 20 mm diameter with two different embedded lengths 150 mm and 300 mm were adopted. Specimens were exposed to three different temperature levels 200°C, 400°C, 600°C with retention period of 1hr. The experimental results concludes that, under elevated temperatures, embedded length does not contribute more to change in bond strength, but bar diameter and temperature plays important role in change in bond strength and, which is also associated with statistical analysis. From experimental study an empirical formula is proposed to predict the bond strength by considering elevated temperatures, bar diameter and embedded length.
Keywords: Bond strength, Bar diameter, Embedded length, Elevated Temperatures

1. Introduction

Concrete is used widely as a construction material because it is strong and durable. The concrete has exceptional properties as a resistance to fire as compared to other materials. Even though concrete is a good material used for building, the confinement on these concrete is as less tensile stress and under high temperature, concrete cracks and it gets deteriorate.

When the concrete is revealed to the elevated temperatures the deterioration of the concrete occurs due to the pore pressure evolved in to concrete. Strength of the concrete decreases which leads to the structural failure. So concrete should posses good fire resistance properties. Bond between the concrete and steel is more significant which is essential for the structural performance of structures. It is important to study the bond behavior between concrete and steel subjected to elevated temperatures. The concrete bar bond strength increases with the increase in compressive strength of concrete and embedment length of the bar for normal strength concrete[1]. The bond stress increases with the smaller bond length and the bond strength was found to decrease as the bar diameter increase [2].

2. Experimental program

2.1 Materials Used

Ordinary Portland Cement (OPC) of 43 grade confirming to IS IS 8112 (1989) was used [3]. Fine aggregate used was natural Local River sand with specific gravity 2.74 and absorption 1.0%. Crushed gravel coarse aggregates were used of size 20 mm, having specific gravity 2.7 and absorption 0.5%. Reinforcement steel of grade HYSD Fe500 was used. Table 1 shows physical and Mechanical properties of steel reinforcement. The micro silica fume ‘CORNICHE’ has been used in the present study. The properties of silica fume presented in Table 2. In the present study BASF Super-plasticizer was used as a water reducing agent which having 1.18 specific gravity.

Table 1: 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

Table 2: Properties of silica fume

Item	SiO_2	LOI	Moisture	Pozzolane Act Index	Surface area	Bulk Density
Results	92.3%	2.7%	0.2%	137%	220 m^2/g	603 kg/m^3

2.2 Methodology

The experimental work consists of 72 numbers of pull-out cylindrical specimens having standard size of 150 mm Diameter and 300 mm height and 9 cubic standard specimens of size 150 mm were cast. After 28 days of curing the concrete cylinders and cubes specimens were kept for 1 day in laboratory, so that the specimens should get dry. The cylinders were used to determine the bond strength and cubes were used to obtain the compressive strength of concrete. Steel bars of diameter 12 mm, 16 mm, 20 mm were embedded into concrete specimens with embedded lengths of 150 mm and 300 mm. The specimens were exposed to 200ºC, 400ºC, 600 ºC temperatures. The pull-out test and compression test is done as per IS 2770 (Part I)–1967 [4] and IS 516:1959[5] . 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 was done as per IS 10262:2009[6]. Details of mix proportions are presented in Table 3.

Table 3 Mix proportion for cubic meter concrete

Cement	450 kg
Silica fume	45 kg
Fine aggregate	670.5 kg
Coarse Aggregate	1138.5 kg
Super- plasticizer	6.75 kg
W/C	0.35

2.3 Testing of Specimens

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 bond strength of concrete specimens. The testing was done as per IS 2770 (Part I)–1967[4]. Compression testing machine of capacity 2000kN was used to find the compressive strength of concrete. The mechanical strength testing was carried out as per IS-516:1959[5].

3. Results and Discussion

3.1 Physical observation

Table 4 shows the variation in colour change and crack extents with different temperature exposures.

Table 4: Visual evaluation of colour and cracks extent

Temperature stages (°C)	Colour change	Crack extent
27	Grey	No cracks
200	No noticeable colour change	Less micro cracks
400	Red	More micro cracks
600	Whitish Grey	Large cracks, width and length are prolonged

3.2 Mechanical Strengths

3.2.1 Compressive strength

Figure 1 shows the variation in residual bond strength and temperature ranging from 27°C to 600°C with retention time of 1 hr. It is observed that, residual compressive strength decreases as the temperature increases and compressive strength decreases gradually from 27°C to 400°C and abrupt change are observed in compressive strength at 600°C.

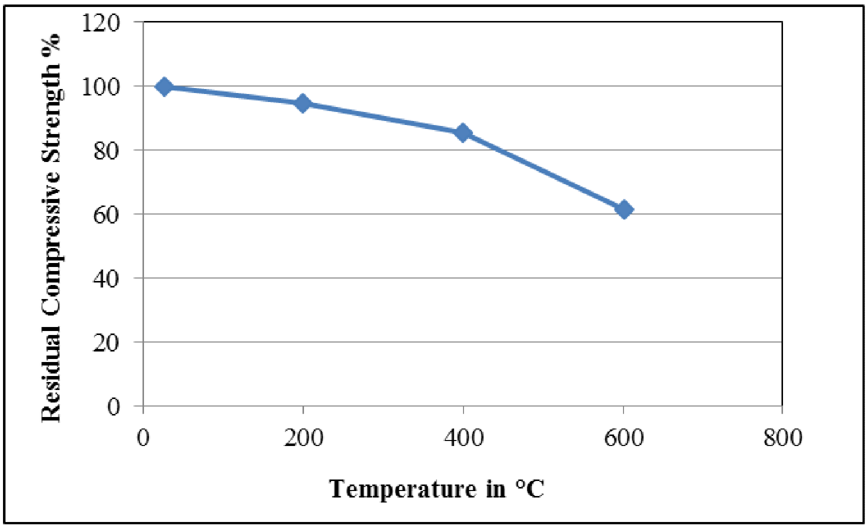

Fig. 1 Variation in residual compressive strength v/s temperature

3.2.2 Failure pattern of specimens

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

3.2.3 Effect of Embedded Lengths

Figure 2 and 3 shows the variation in bond strength and temperature with 150 mm and 300 mm embedded lengths respectively for all bar diameter sizes. From Fig. 2, it is observed that, for specimens of 150 mm embedded length the bond strength decreases as the temperature increases. It is also observed that as the bar diameter decreases, bond strength increases for same temperature level. The splitting failure mode is observed for all bar diameter sizes. From Fig. 3, it is observed that, for specimens of 300 mm embedded length the bond strength decreases as the temperature increases. The 12 mm bar diameter specimens at 27°C and 200°C temperature, specimens failed by steel rupture failure, which means the bond strength of the specimens is greater than the tensile strength of the bar. For 16 mm and 20 mm bar diameter specimens at 27°C, 200°C, 400°C, 600°C temperature levels specimens failed by splitting of concrete.

The bond 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 bond strength than larger bar diameter if the embedded length is small. The 150 mm embedded length has the larger bond 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).

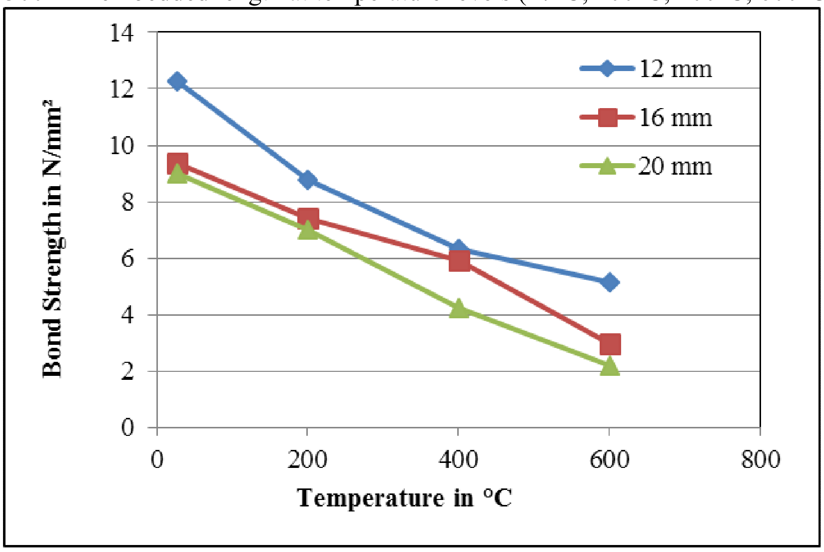

Fig. 2 Variation in bond strength and temperature for 150 mm embedded length

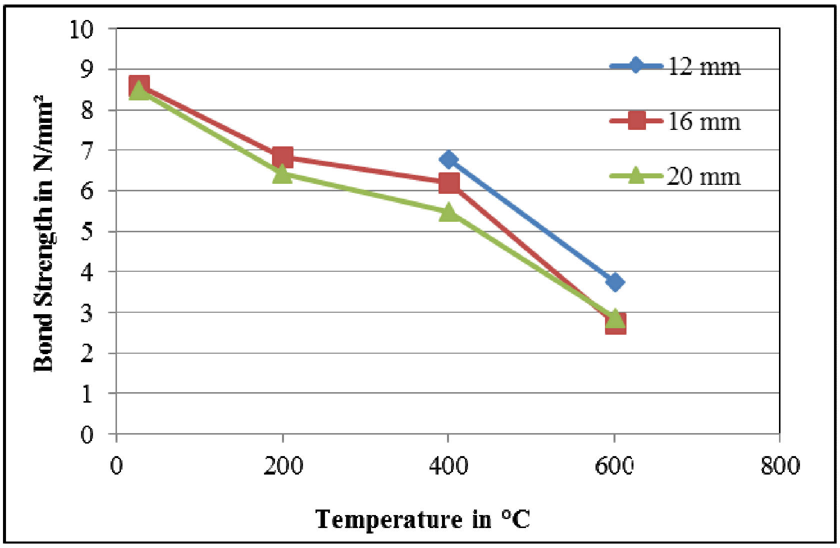

Fig. 3 Variation in bond strength and temperature for 300 mm embedded length

3.2.4 Residual Bond Strength

Figure 4 and 5 shows, the variation in residual bond strength and bar diameter with different embedded lengths at elevated temperatures. Residual bond strength for 27°C is taken as reference, thus the residual bond strength decreases as the temperature increases for all bar diameter sizes for both 150 mm and 300 mm embedded lengths.

Figure 4 and 5 shows that, for 12 mm bar diameter specimen at 200°C, 400°C and 600°C about 28.3%, 48.6% and 58.2% reduction in bond strength observed as compared to ambient temperature. Whereas, for 16 mm and 20 mm bar diameter specimen showed almost equal strength reduction of its 12 mm bar diameter specimen, at 200°C about 20.8% ,22.4% and at 400°C about 36.8% , 53.0% reduction in bond strength observed as compared to ambient temperature respectively. For 16 mm and 20 mm bar diameter specimen at 600°C shows significant loss in bond strength about 68.4% and 75.7% as compared to ambient temperature specimen.

From Fig. 4 and 5 it is shows that, for 12 mm bar diameter specimen failed due to steel rupture failure at 27°C and 200°C. Whereas, for 16 mm and 20 mm bar diameter specimen showed almost equal strength reduction of its 12 mm bar diameter specimen, at 200°C about 20.6% , 28.1% and at 400°C about 24.4.8% , 35.7% reduction in bond strength observed as compared to ambient temperature respectively. For 16 mm and 20 mm bar diameter specimen at 600°C shows significant loss in bond strength about 68.3% and 66.3% as compared to ambient temperature specimen.

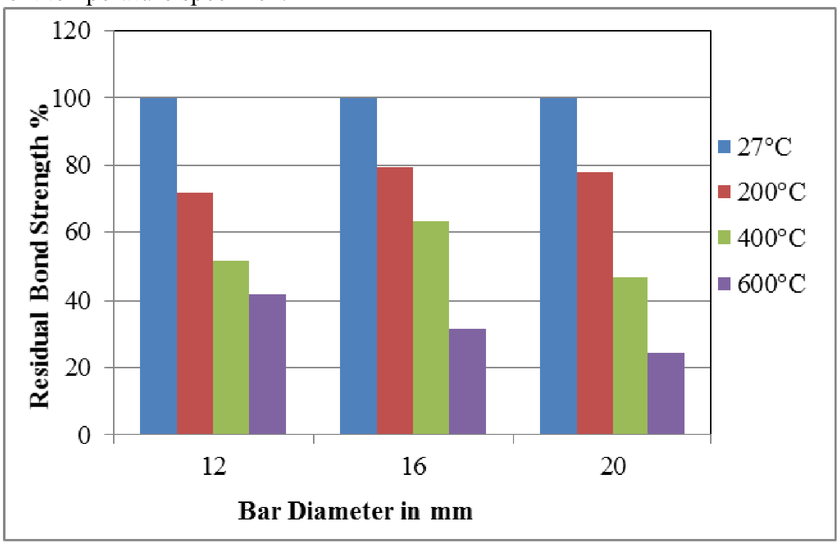

Fig. 4 Variation in Residual bond strength and temperature for 150 mm embedded length

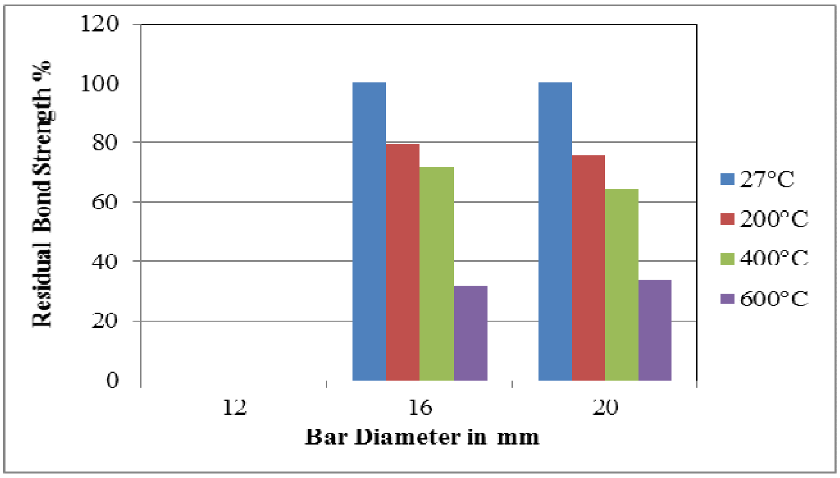

Fig. 5 Variation in residual bond strength and temperature for 300 mm embedded length

3.2.5 Effect of Steel Bar Diameter

Figure 6, 7 and 8 shows, the variation in bond strength and temperature with 12 mm, 16 mm and 20 mm bar diameters for 150 mm and 300 mm embedded lengths for exposure temperatures. From Figure (6, 7 and 8) it is observed that, bond strength decreases as the temperature increases for both 150 mm and 300 mm embedded lengths for all bar diameter sizes. The 150 mm embedded length has the greater bond strength than the 300 mm embedded length for 27°C and 200°C temperature level for 12 mm, 16 mm and 20 mm bar diameters. But for the temperatures levels at 400°C and 600°C the 300 mm embedded length has the greater bond strength than 150 mm embedded length for 12 mm, 16 mm and 20 mm bar diameters.

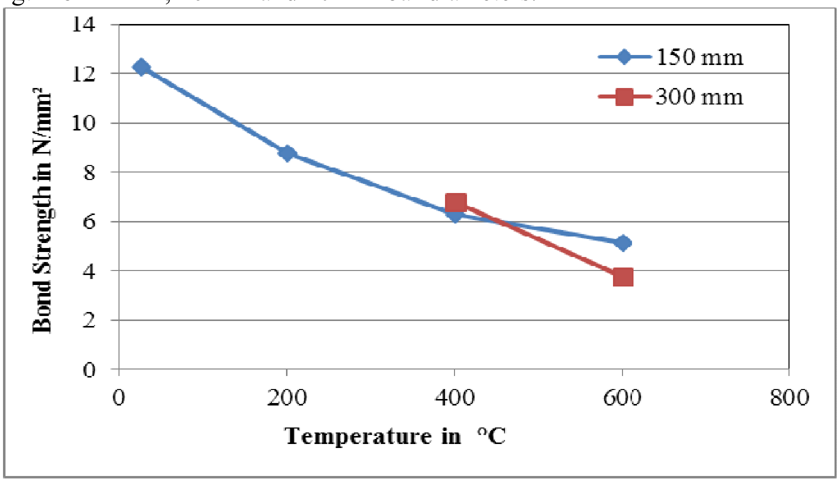

Fig. 6 Variation in bond strength and temperature for 12 mm Bar diameter

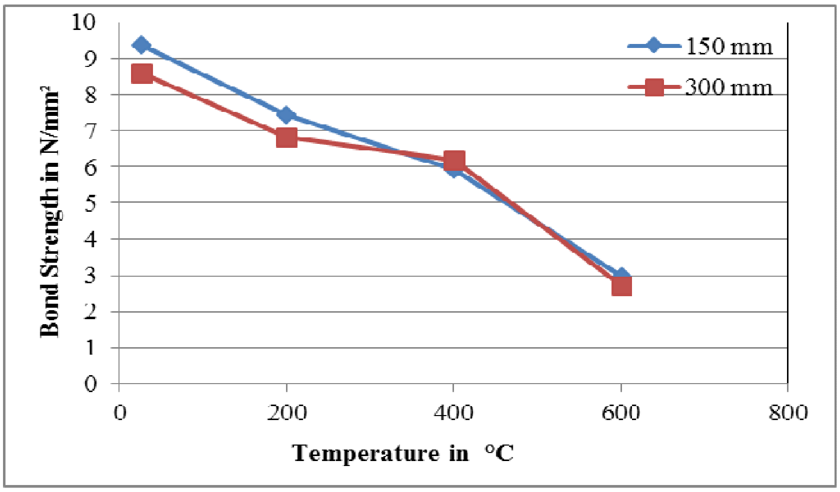

Fig. 7 Variation in bond strength and temperature for 16 mm Bar diameter

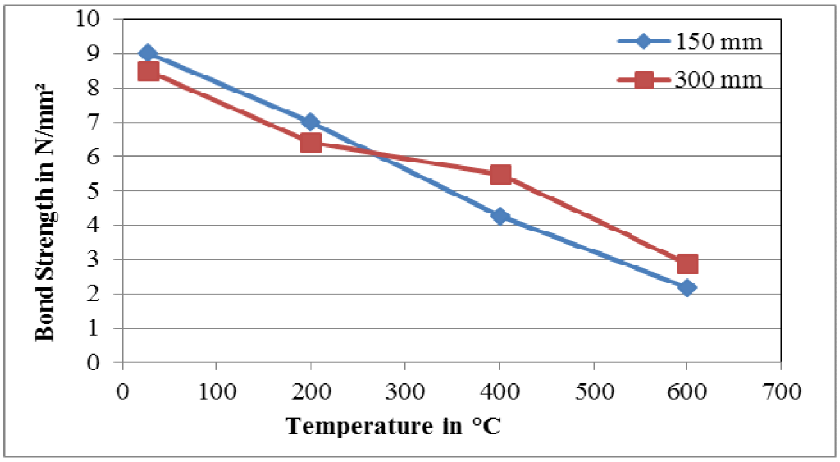

Fig. 8 Variation in bond strength and temperature for 20 mm Bar diameter

3.3 Statistical analysis

The experimental results are analyzed for Multivariate Analysis of Variance (MANOVA) and multiple regression analysis is also carried out. The details of analysis are presented in the following sections.

3.3.1 Multivariate analysis of variance (MANOVA)

MANOVA is a generalized form of univariate Analysis of Variance (ANOVA), although, unlike univariate ANOVA, it uses the variance-covariance between variables in testing the statistical significance of the mean differences. ANOVA tests for the difference in means between two or more groups, while MANOVA tests for the difference in two or more vectors of means. General MANOVA method is used for multivariate analysis of variance (MANOVA) for balanced and unbalanced designs. In the present study general MANOVA is carried by using statistical analysis software Minitab [7].

The analysis results of MANOVA are presented in Table 5. The p-values for the Wilks', Lawley-Hotelling, and Pillai's test statistic to judge whether there is significant evidence for model effects. From Table 5 a, b and c it is analyzed that, there is significant evidence for temperature and bar diameter as main effects for an alpha level of 0.05 because the F-test p-value is 0.000. The p-values for the model term temperature and bar diameter is 0.000, indicating that there is significant evidence for Temperature as a main effects. The corresponding p-values for embedded length is 0.346, indicating that there is no significant evidence for interaction, at a-levels of 0.05 or 0.10.

The F-test value for temperature, embedded length and bar diameter is 265.74, 0.936 and 31.918 respectively. The F results illustrate that, among the various parameters temperature contribute lot to the change in bond strength followed by bar diameter. Embedded length doesn't have much significant effect on bond strength.

Table 5: Results of MANOVA

Table 5 a. MANOVA for Exposure Temperature v/s Bond Strength

Criterion	Test Statistic	F	Degree of freedom	P
Wilks'	0.06344	265.744	18	0.000
Lawley-Hotelling	14.76357	265.744	18	0.000
Pillai's	0.93656	265.744	18	0.000
Roy's	14.76357			

Table 5 b. MANOVA for Embedded length v/s Bond Strength

Criterion	Test Statistic	F	Degree of freedom	P
Wilks'	0.95057	0.936	18	0.346
Lawley-Hotelling	0.05200	0.936	18	0.346
Pillai's	0.04943	0.936	18	0.346
Roy's	0.05200			

Table 5 c. MANOVA for Bar Diameter v/s Bond Strength

Criterion	Test Statistic	F	Degree of freedom	P
Wilks'	0.36059	31.918	18	0.000
Lawley-Hotelling	1.77324	31.918	18	0.000
Pillai's	0.63941	31.918	18	0.000
Roy's	1.77324			

3.3.2 Multiple Regression analysis

The experimental results are taken for multiple regression analysis. The analysis is carried out by using Minitab 15 Software. The experimental data points have been considered for regression analysis and a relation of bond strength with exposure temperature embedded length and bar diameter is proposed. The regression coefficient for the current proposed equation is 0.94. The prediction equation gives around 9.5 % error in estimation of bond strength.

$$fbo = 14.5 - 0.0110 \times T - 0.00187 \times EL - 0.258 \times BD$$

Where,

fbo	= Bond strength in N/mm2	T	= Exposure Temperature in °C
EL	= Embedded Length in mm	BD	= Bar Diameter in mm

3.3.3 Response Surface Regression

The experimental data points are considered for response surface regression analysis and a relation of bond strength with exposure temperature, embedded length, bar diameter and their interaction is proposed. The analysis is carried out by using Minitab 15 Software. The regression coefficient for the current proposed equation is 0.96. The prediction equation gives around 6.0 % error in estimation of bond strength.

$$fbo = 19.10 - 0.014 \times T - 0.0251 \times EL - 0.479 \times BD + 1.5 \times 10^{-5} \times T \times EL + 0.0011 \times EL \times BD$$

4. Conclusions

Based on experimental investigation following conclusions were made.

1) The bond strength of concrete decrease as the bar diameter increases for both embedded lengths at ambient and elevated temperatures. The loss of bond strength increases when the temperatures increase.

2) 12 mm bar diameter specimens fails in rapture at 27°C and 200°C for 300 mm embedded length. For 16 mm and 20 mm bar diameter specimen specimens failed in splitting for both the embedded lengths and at all exposure temperatures.

3) Concrete compressive strength decreases as the temperatures increases. There is a gradual decrease in compressive strength up to 400°C thereafter at 600°C, abrupt decrease occurs in compressive strength.

4) Statistical analysis reveals among the three input parameters, temperature affects more to the bond strength behaviour followed by bar diameter. Prediction equations developed in this study can be used to find out bond strength of concrete in forensic engineering.

References

1. Ferhat Bingol A. and Rustem Gul, (2009) "Residual bond strength between steel bars and concrete after elevated temperatures" Fire Safety Journal, Vol. 44, pp 854–859. doi:10.1016/j.firesaf.2009.04.001.
2. Appa Rao G., Pandurang K., Sultana F. and Eligehausen R., (2007) "Studies on the pull-out strength of ribbed bars in high strength concrete", FraMCos-6 (Italy), Proceeding, Paper no. 05-17.
3. IS 8112:1989, Specification for 43 grade ordinary Portland cement, BIS, New Delhi.
4. IS 2770 (Part I):1967, Methods of Testing Bond in Reinforced concrete, BIS, New Delhi.
5. IS 516:1959, Methods of tests for strength of concrete, BIS, New Delhi.
6. IS10262:2009, Concrete mix proportioning guidelines, BIS, New Delhi.
7. Minitab 15, "Statistical Analysis software" Minitab, Ltd., UK.