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Experimental and Analytical investigations on bond strength between concrete and steel subjected to elevated temperatures

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ABSTRACT
In this work 4 mixes (including control mix) were designed with mixes having M-Sand and GGBS (50%) with varying percentage of polymer (2% and 3%). Total 12 cubes, 12 cylinders, 48 pull-out cylindrical specimens were casted. A study has been carried out on bond strength between concrete and reinforcing steel subjected to elevated temperatures, compressive strength and split tensile strength tests were also carried out.To find the variation in bond strength the parameters considered are bar diameters, embedded length and different temperature levels with 1 hr retention period. In this investigation 2 bar diameters 16mm and 20mm with two different embedded lengths 150mm and 300mm were adopted. Out of 4 mixes attempted, mix containing 50% Cement, 50% GGBS and 2% polymer performed better showing an increase in compressive strength and tensile strength. Also the experimental results concludes that, the bond strength of concrete decreases as the bar diameter increases for both embedded lengths at ambient and elevated temperatures.

Statistical analysis also carried out in the present investigation which shows that, temperature affects the bond behavior between concrete and steel at high temperatures. An empirical formula is proposed to predict the bond strength by considering elevated temperature, bar diameter and embedded length.

Keywords-Bond strength, Compressive Strength, Elevated temperature, Embedded length,Tensile strength

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I. INTRODUCTION

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in hard matrix of cement or binder that fills the space among the aggregate particles and glues them together. In modern times, researches have experimented with the addition of other materials to create concrete with improved properties such as higher strength or electrical conductivity concrete can be formulated with high compressive strength, but always has tensile strength. For this reason it is usually reinforced with materials that are strong in tension(often steel).

As the pore pressure is evolved in to the concrete, the deterioration action takes place when the concrete is subjected to higher temperatures. The concrete should have good resistance in fire otherwise its strength decreases leading structural failure. In order to achieve better structural performance of the structures, the bond between the structural steel and concrete is of more significance. So it is necessary to study the bond strength between structural steel and concrete at elevated temperatures.

The bond strength is greatly influenced by the concrete properties, bar geometry, amount of confinement around the bar. It is necessary to create the suitable bond between the steel bars and the concrete surrounding it for the reinforced concrete. A loss of bond between the concrete and the bars may lead to the failure of the structure. The bond should be ensured that there is small or no slip between the steel bar and the concrete surrounded by it. If the embedded length is small, the small bar size have the greater bond strength than the larger bar sizes for polluted or non-polluted steel bars.

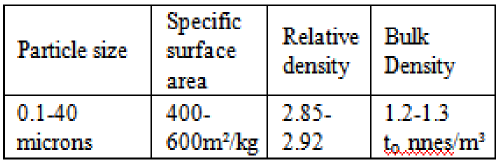
II. MATERIALS USED

Ordinary Portland Cement (OPC) of 43 grade confirming to IS 8112 (1989) was used. Fine aggregate used was manufactured sand with specific gravity 2.74 and absorption 2.0%. Crushed gravel coarse aggregates were used of size 20 mm and down, having specific gravity 2.92 and absorption 0.5%.Mineral admixtures or pozolanas like GGBS were used Reinforcement steel of grade HYSD Fe500 was used.Table1shows physical and Mechanical properties of steel reinforcement. The properties of GGBS 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)
16	15.8	663.5
20	19.7	662.3

Table 2 Properties of GGBS



Particle size	Specific surface area	Relative density	Bulk Density
0.1-40 microns	400-600m^2/kg	2.85-2.92	1.2-1.3 to nnes/m^3

III. METHODOLOGY

A.Mix Design

Mix design was carried out for M40 grade concrete with reference to IS 10262-2009. Total four mixes were prepared first is control mix/ reference mix without any admixture, second mix Mix-2 contained 50%GGBS by weight of cement, Mix-3 contained 50% of GGBS by weight of cement with 1% of polymer and 2% of super plastisizer, and the fourth mix Mix-4 had 50% of GGBS with 2% polymer and 2% of SP. Table 3 gives quantity of materials used for preparation of mixes.

B.Casting of Specimens

The experimental work consists casting and curing of 48 numbers of pull-out cylindrical specimens having standard size of 150 mm diameter and 300 mm height. Also to test the compressive strength, 18 cubes of standard size 150 mm were cast. Steel bars of diameter 16 mm, 20 mm were embedded into concrete specimens with embedded lengths of 150 mm and 300 mm respectively. These cylinders were used to determine the bond strength.

The specimens were exposed to 400ºC and 600ºC temperatures.The pull-out test and compression test is done as per IS 2770 (Part I)–1967 and IS 516:1959

C.Subjecting Specimens to Elevated Temperature

After 28 days of curing, the specimens were removed from the curing tank and kept in the laboratory for drying for about a day. Then the cylindrical specimens having single central bar were subjected to elevated temperatures of 400ºC and 600ºC in an electric furnace for a retention period of 1 hour. Thereafter, specimens were kept under room temperature for 24 hours. Then the pull-out test was carried out on the specimens.

D.Testing of Specimens

Specimens of all four mixes were subjected to three different temperatures (27°C, 400 and 600°C). After bringing them back to room temperature, bond strength by means of pull out test was conducted.

Compressive strength test was conducted on 150mm cubes in accordance with IS 516:1959. Similarly split tensile strength was conducted on 150mm diameter and 300mm height specimens in accordance with IS 5816:1999.

E. Pull out test

The testing was done as per IS: 2770(part I)-1967. Universal testing machine(UTM) with the capacity of 1000kN was used. The specimen which has to be tested was mounted on the UTM in such a manner that the bar is pulled in the direction of the axis from the specimen. The load is gradually applied. The elongation of the bar from the specimen was noted carefully from the specimen to calculate the slip. The physical observation such as color change, crack pattern were checked before the specimens were taken out from the test. From the pull out test results bond strength for both 16mm and 20mm diameter bars with embedment lengths 150mm and 300mm are given below.

Table 3 Quantity of materials used in mixes

MIX ID	MX00	MX01	MX02	MX03
Cement (Kg/m^3)	406.3	203.15	203.15	203.15
GGBS (Kg/m^3)	0	203.15	203.15	203.15
M-Sand (Kg/m^3)	835.15	835.15	835.15	835.15
CA (Kg/m^3)	1145.8	1145.8	1145.8	1145.8
Water (Kg/m^3)	147.75	147.75	147.75	147.75
Polymer	0	0	2%	3%
SP	0	2%	2%	2%

IV. EXPERIMENTAL TEST RESULTS

A. Compressive Strength

compressive strength test results forcontrol mix and proposed mixes are as shown in the table 4.

Table 4 compressive strength ofcontrol mix and proposed mixes

Mix ID	Weight (N)	Failure Load(KN)	Compressive Strength(MPa)	Average
MX00	8.92 8.76 9.02	1050 1100 980	46.67 48.89 43.56	46.37
MX01	8.92 8.94 9.12	800 860 740	35.56 38.22 32.89	35.56

MX02	9.21 9.04 9.15	900 850 920	40.00 37.78 40.89	39.56
MX03	8.82 9 9.1	760 780 760	33.78 34.67 33.78	34.07

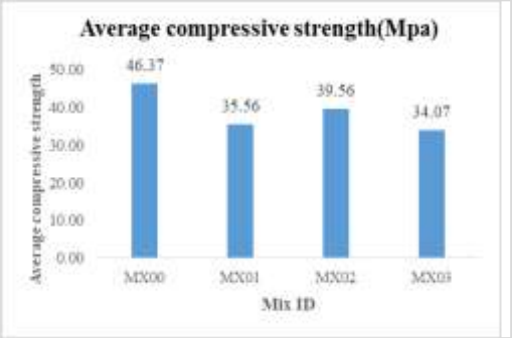


Figure 1 Variation in Average Compressive Strength of control mix and proposed mixes

B. Tensile Strength

Average Tensile strengthfor control mix and proposed mixes are as shown in the table 5.

Table 5 Split tensile strength ofcontrol mix and proposed mixes

Mix ID	Weight (N)	Failure Load(KN)	Tensile Strength(MPa)	Average
MX00	13.7 13.84 14.05	200 170 180	2.83 2.41 2.55	2.59
MX01	13.96 13.92 14.32	130 120 120	1.84 1.70 1.70	1.75
MX02	14.09 14.04 13.72	200 220 200	2.83 3.11 2.83	2.93
MX03	13.92 13.88 14.12	175 180 190	2.48 2.55 2.69	2.57

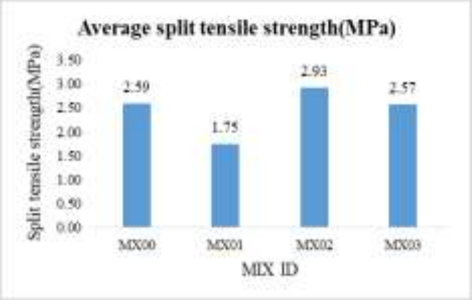


Figure 2 Variation in Average Tensile Strength of control mix and proposed mixes

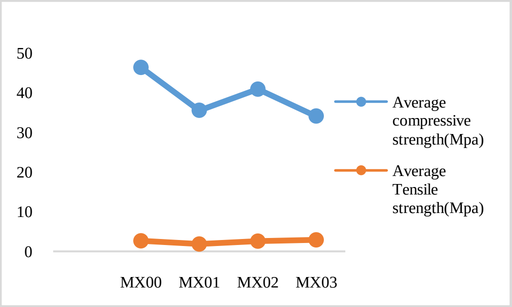


Figure 3 Variation of Average compressive strength and Split Tensile Strength of control & proposed mix after 28 days of normal curing

C. Pull out test

Variation in bond strength for different embedment lengths and diameters when subjected to normal and elevated temperatures are depicted in the following figures.

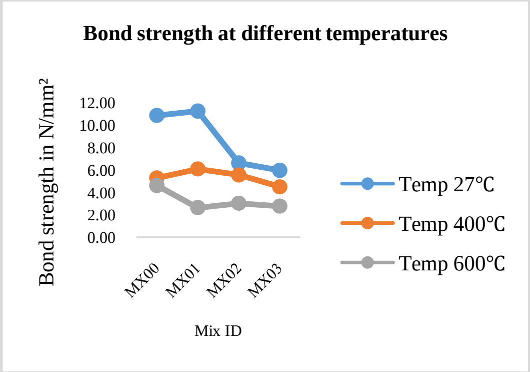


Figure 4 Bond strength at different temperatures of 16mm diameter bar with embedment length of 150mm

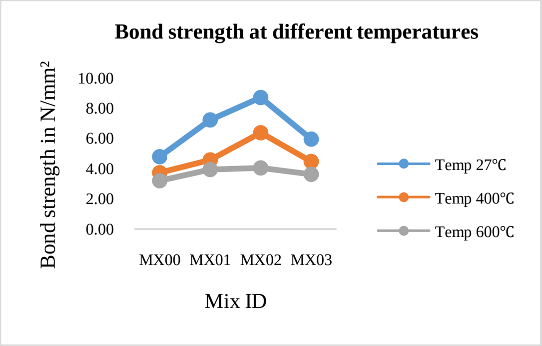


Figure 5 Bond strength at different temperatures of 20mm diameter bar with embedment length of 150mm

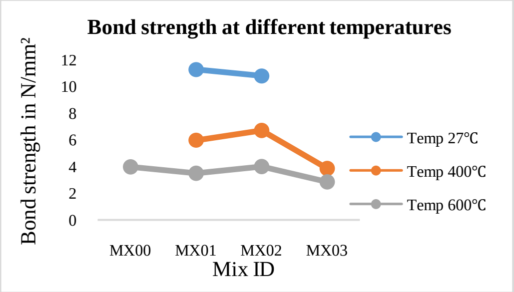


Figure 6 Bond strength at different temperatures of 16mm diameter bar with embedment length of 300mm

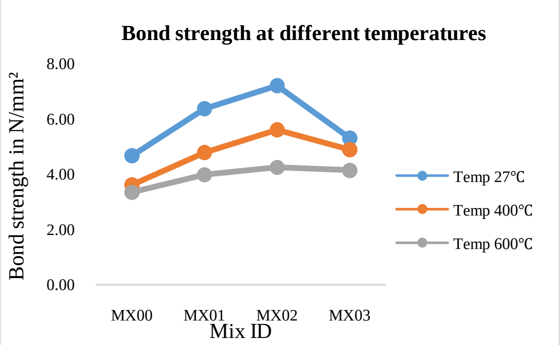


Figure 7 Bond strength at different temperatures of 16mm diameter bar with embedment length of 300mm

D. Multiple Regression analysis

Regression analysis was carried out using EXCEL software. Bond strength was taken as dependent variable and temperature, embedment length, bar diameter were independent variables.The generated equation yields theoretical values of bond strength which are in close agreement with experimental values.

$f_{bo} = 8.374 - (0.0055 \times T) - (0.0047 \times EL) - (0.0202 \times BD)$

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

V. CONCLUSIONS

Based on the experimental investigations, following conclusions are drawn

1. It is possible to produce concrete of almost same strength as that of control mix using GGBS at 50% replacement with cement.
2. Addition of polymer further improves the strength characteristics of concrete.
3. Out of different % of polymer addition tried, 2% addition of polymer results in peak values of compressive strength, split tensile strength and shear strength.
4. Hence, concrete containing 50% GGBS and 2% polymer which is economical than control mix can be recommended for all concrete applications.
5. The bond strength of concrete decreases as the bar diameter increases for both embedded lengths at ambient and elevated temperatures.
6. As the bar diameter and temperature increases the slip value decreases for both embedded length specimens.
7. Values obtained by regression analysis(using EXCEL) are in close agreement with the experimental values.

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