

EXPERIMENTAL STUDY ON EFFECT OF HIGH TEMPERATURE ON BOND OF HYSD STEEL BARS WITH FLY-ASH

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ABSTRACT

Concrete is the most consumed man-made material in the world. Unfortunately, due to the production of cement, concrete has a large carbon footprint. Replacement of cement with fly ash, an industrial waste product, offers a sustainable alternative. The goal of this research was to explore the feasibility of using fly ash concrete for structural applications by testing the material's reinforcement bond properties.

Bond behavior between concrete and reinforcing bars was observed under elevated temperatures. Four different concrete compositions were used. Hundred and twenty pull-out specimens ($\varnothing 100$ mm, 100 mm) were prepared. Maximum temperatures of specimen (33 °C, 100 °C, 150 °C, 200 °C and 250 °C). Specimens were then cooled down in laboratory conditions. Finally the specimens were tested at room temperature. In order to check the compressive strength standard cubes were cast, cured, and then tested to compressive strength. The results showed considerable changes in steel-concrete bond under high temperatures. This experiment presents a study about the bond of concrete with high strength steel. The concrete strength was about 30 MPa and the steel was a 500 MPa grade. Bar diameters used were 12 and 16 mm. In order to investigate the effect of fly ash with 30%, 40% and 50% replacement of cement by weight 100 mm diameter cylinder were used.

It can be stated that the pullout specimen with the smaller bar size has greater bond strength than the specimen with the larger diameter bar.

Keywords: concrete, reinforcement, bond strength, elevated temperature, fly ash.

I. INTRODUCTION

Concrete is a heterogeneous material with a wide variety of usage in structural design. The design of fire resistant structural elements requires realistic

knowledge on the behavior of concrete at high temperatures.

Concrete's thermal properties are more complex than for most materials because not only is the concrete a composite material whose constituents have different properties, but its properties also depend on moisture and porosity. Because thermally induced dimensional changes, loss of structural integrity, and release of moisture and gases resulting from the migration of free water could adversely affect plant operations and safety, a complete understanding of the behavior of concrete under long-term elevated-temperature exposure as well as both during and after a thermal excursion resulting from a postulated design-basis accident condition is essential for reliable design evaluations and assessments. Because the properties of concrete change with respect to time and the environment to which it is exposed, an assessment of the effects of concrete aging is also important in performing safety evaluations. In some areas of bond behavior (like fatigue and especially high temperatures) limited information is available. The main reasons are complexity of the experiments and the high cost. During the exposure to high temperatures, concrete undergoes changes in its chemical composition, physical structure and water content. These changes primarily occur in the hardened cement paste. The resulting physical changes and chemical decomposition of major concrete constituents are

demonstrated by e. g. cracks, explosive spalling or both. Investigations on the bond strength between concrete and reinforcing steel at room temperature have been carried out over many years however, only few experiments have been carried out to study the effects of high temperature on the bond characteristics. The percentage reduction of bond strength for ribbed bars at elevated temperatures is less than that for plain round steel bars.

1.1 BEHAVIOR OF BOND

The transfer of axial force from a reinforcing bar to the surrounding concrete results in the development of tangential stress components along the contact surface. The stress acting parallel to the bar along the interface is called bond stress. For reinforced concrete to function effectively as a composite material it is necessary for the reinforcing steel to be bonded to the surrounding concrete. Bond ensures that there is little or no slip of the steel relative to the concrete and the means by which stress is transferred across the steel-concrete. Bond resistance is made up of chemical adhesion, friction and mechanical interlock between the bar and surrounding concrete. In the plain bars, only the first two of these components contribute to the bond strength. In the deformed bars, the surface protrusions or ribs interlocking with and bearing against the concrete key formed between the ribs contribute more positively to bond strength, and is the major reason for their superior bond effectiveness.

1.2 FLY-ASH

Fly ash is finely divided residue that results from the combustion of coal and transported by flue gas. India is a resourceful country for fly ash generation with an annual output of over 110 million tones, but utilization is still below 20% in spite of quantum jump in last three to four years. Availability of consistent quality fly ash across the country and awareness

of positive effects of using fly ash in concrete are pre-requisite for change of perception of fly ash from 'A waste material' to 'A resource material'. Nowadays due to strict control on quality of coal and adopting electrostatic precipitators, fly ash of consistent quality is separated and stocked, and it is gaining popularity as a good pozzolanic material for partial replacement.

Fly ash is classified into three classes depending on its calcium content, in recognition of the difference in behavior between low and high lime fly ashes. These classes are as follow:

- a) Type F, low calcium, 8% CaO
- b) Type CI, intermediate calcium, 8–20% CaO
- c) Type CH, high calcium, 20% CaO

Low CaO fly ashes generally provide good resistance to alkali-silica reaction (ASR) and sulphate attack. The spherical shape of fly ash particles causes an improvement in the workability, and the particles alter the flocculation of cement, with a resulting lowering of the quantity of water required. The addition of fly ash causes a reduction in the water required for a given slump, typically in the order of 5-15 % when compared with a Portland cement only mix. The improvement in ultimate strength obtained with the use of fly ash is due to its pozzolanic action and the ability of small fly ash particles to fit in between cement particles.

Fly ash causes an increase of strength because of the “packing” of the fly ash particles at the aggregate-cement interface, but the beneficial impact of fly ash on both strength and workability is not extended beyond 30 % of the cementitious material.

TABLE I.1
PHYSICAL PROPERTIES OF FLY-ASH

S. No	Physical Properties	Test Results
1	Color	Grey (Blackish)
2	Specific gravity	2.13
3	Lime reactivity- Average compressive strength After 28 days of mixture	4.90 MPa

TABLE I.2
CHEMICAL PROPERTIES OF FLY-ASH

S.No	Constituents	% By Weight
1	Loss of ignition	4.17
2	Silica (SiO ₂)	58.55
3	Iron oxide (Fe ₂ O ₃)	3.44
4	Alumina (Al ₂ O ₃)	28.20
5	Calcium oxide (CaO)	2.23
6	Magnesium oxide (MgO)	0.32
7	Total Sulphur (SO ₃)	0.07
8	Insoluble residue	-
9	Alkalies	
	a) Sodium oxide (Na ₂ O)	0.58
	b) Potassium oxide (K ₂ O)	1.26

2. PROCEDURE

2.1 FIGURES AND TABLES

- By observing the existing literatures, this work is carried out with different percentages of fly ash as the replacement of cement;

the percentages of fly ash used were 30%, 40% and 50%. In the previous research papers no work is done to study the effect of elevated temperatures on bond strength of concrete with partial replacement of cement with fly ash.

- The percentage replacement of Fly-ash is 70% in one literature. The drawback for the HVFA concrete was that once the concrete began to crush around the reinforcing bar, bond strength reduces at a higher rate.
- The percentage reduction of bond strength for ribbed bars at elevated temperatures is generally less than for plain round steel bars.
- Bond strength is reduced as temperature increases and the reduction rate is greater compared to concrete strengths.
- The difference in the diameter of bar have significant effect on bond strength.
- The type of aggregate in the concrete affects the bond strength at elevated temperatures.

3.OBSERVATION AND DISCUSSION OF TEST RESULTS

To study the effect of high temperature on concrete one hundred and twenty cylinders were tested and compare with specimens at room temperature. The specimens were heated at varying temperature from 100°C to 250°C. The target temperature was maintain for one hour and the specimens then cool down to room temperature before testing. Results obtained from experimental investigation to study the bond loss between the concrete and HYSD steel at elevated temperature with and without fly ash are discussed in detail as given below

3.1 TEST RESULTS

3.1.1 PULL OUT TEST

The steel rebar was pulled out using a universal testing machine with a maximum capacity of 100kn.the BS was calculated from external load (p) on the bar and total surface area of the embedded portion of the reinforcing bar, assuming a constant stress along the bonded length of the bar (i.e., $BS = P / (\pi d l)$, where d and l are the diameter of the bar and embedded length, respectively). the pair of specimens tested for bond behavior showed similar results. the effect of replacement of fly ash in different proportions with cement on bond strength for m30 grade was investigated by preparing a cylindrical specimen of (100mm dia and 100mm height). the replacement level of fly ash was 30%, 40%, and 50%. specimens were cured in water and tested at age of 28 days. after removing the specimens from curing pond they are heated at elevated temperatures.pull out test results of 12mm dia bar are given below in table 3.1 and are represented graphically in fig 3.1.pull out test results using 16mm dia bar., are given below in table 3.2 and are represented graphically in fig 3.2.

Table 3.1 BOND STRENGTH WITH % REPLACEMENT OF FLY ASH AT

PERCENT AGE REPLACE MENT OF FLY ASH	BOND STRENGTH IN MPA				
	TEMPERATURES				
	33 ° C	100 ° C	150 ° C	200 ° C	250° C
0%	9.01	8.48	8.04	7.29	6.23
30%	7.4	6.5	6.2	5.6	5.4
40%	7.6	7.1	6.7	6.3	5.8
50%	7.3	6.4	5.9	5.33	5.03

DIFFERENT TEMPERATURES

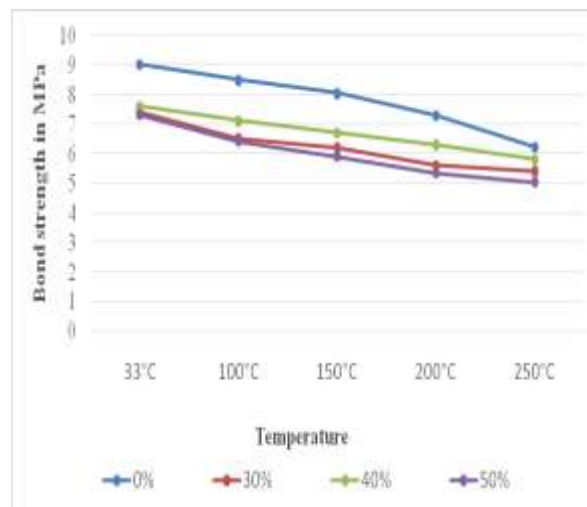


Fig. 3.1 Bond Strength vs Temperature Using 12mm Dia Bar

Table 3.2 Bond Strength with % Replacement of Fly Ash at Different Temperatures

PERCENT AGE REPLACE MENT OF FLY ASH	BOND STRENGTH IN MPA				
	TEMPERATURES				
	33 ° C	100 ° C	150 ° C	200 ° C	250° C
0%	8.02	7.5	7	6.43	5.96
30%	6.7	6.2	5.8	5.6	5.2
40%	7	6.5	6.2	5.8	5.5
50%	6	5.8	5.6	5.2	5.13

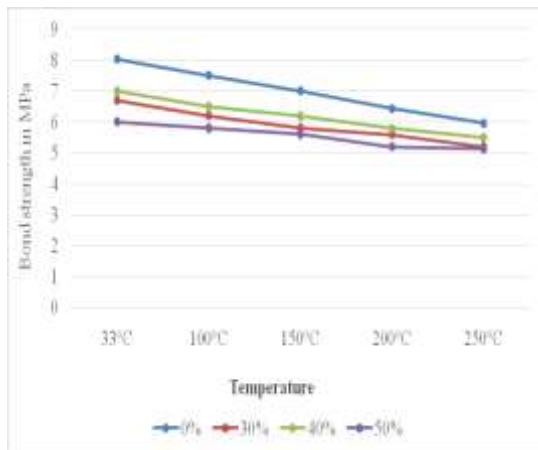
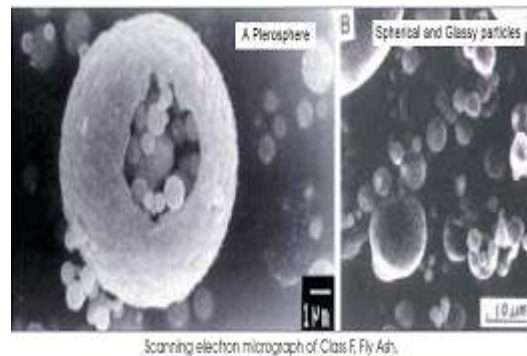


FIG. 3.2 BOND STRENGTH VS TEMPERATURE USING 16MM DIA BAR

INFERENCES ON TEST RESULTS:

Based on the test results of one hundred and twenty pullout specimens, it can be stated that the pullout specimen with the smaller bar size has greater bond strength than the specimen with the larger diameter bar. The maximum bond strength value occurred in specimen with 12mm diameter bar at room temperature whereas the minimum bond stress value was in specimen with 16mm diameter bar with 50% replacement of fly ash subjected to temperature of 250°C. Most considerable reduction of bond strength took place between 150°C and 250°C. At temperature up to 100 °c the concrete specimens resulted in smaller reduction in bond strength. Smaller the diameter of the bar more is the bond strength, larger the diameter of the bar less is the bond strength. 40 percent replacement level of the fly ash shows better bond strength when compare to 30 and 50 percent replacement level.



IV. RESULTS AND DISCUSSIONS

From the experimental study on the loss of bond strength with and without fly ash, with the fly ash replacement as 30, 40 and 50 percent. Bond behavior between concrete and reinforcing bars was observed under elevated temperatures. Four different concrete compositions were used. A Hundred and twenty pull-out specimens (Ø100 mm, 100 mm) were prepared. The temperature range used in study is (33 °C, 100 °C, 150 °C, 200 °C and 250 °C). Specimens were then cooled down in laboratory conditions. Finally the specimens were tested at room temperature. The results showed considerable changes in steel-concrete bond under high temperatures.

By conducting the pull out tests, the bond strength between concrete and reinforcements can be obtained from the pull out load. In general, the bond stress corresponding to the pull out can be regarded as the bond strength. Smaller the diameter of the bar more is the bond strength, larger the diameter of the bar less is the bond strength. From the results

it can be stated that 12mm diameter bar shows better bond when compare with 16mm diameter of the bar. as the exposure temperature increases the bond strength decreases.40 percent replacement level of the fly ash shows better bond strength when compare to 30 and 50 percent replacement level. Optimum replacement level was found to be 40 percent.

4.2 Conclusions:

- Based on the test results it can be stated the pullout specimens without fly ash shows better bond strength compare to specimens with fly ash.
- Based on the test results of one hundred and twenty pullout specimens, it can be stated that the pullout specimen with the smaller bar size has greater bond strength than the specimen with the larger diameter bar.
- The influence of high temperatures on bond strength. Pull-out specimens tested at cold state after heated up to (100 °C, 150 °C, 200 °C and 250 °C). The types of mixes were Convention, 30, 40 and 50 percent replacement of fly ash. Type of steel reinforcement was deformed rebar. Most considerable reduction of bond strength took place between 150°C and 250°C. As the temperature was increases to 250°C the bond strength of concrete decreased progressively to 30 percent of the strength at room temperature.
- At temperature up to 100 °C the concrete specimens resulted in smaller reduction in bond strength nearly 7 to 10 percent of the strength at room temperature.
- Optimum percentage of mix containing Fly ash as partial replacement of cement was found to be 40%.

Based on the test results it can be stated that, as the exposure temperature increases the bond strength decreases.

REFERENCES

- [1] *ACI 211.1 (1991). Standard Practice for Selecting Proportions for Normal, Heavyweight, Mass Concrete.* American Concrete Institute, Farmington Hills, MI.
- [2] *ACI 232R (2003). "Use of Fly Ash in Concrete".* American Concrete Institute, Farmington Hills, MI.
- [3] *ACI 318 (2008). Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary.* American Concrete Institute, Farmington Hills, MI.
- [4] *ACI 408R (2003). Bond and Development of Straight Reinforcing Bars in Tension.* American Concrete Institute, Farmington Hills, MI.
Bastami, M. and Aslani, F.: 2010, Preloaded High-Temperature Constitutive Models and Relationships for Concrete, SCIENTIAIRANICA, Transaction A: Civil Engineering, Vol. 17, No. 1, 11-25.
- [5] *Bazant, Kaplan and Huang (1996). "Temperature effects on bond between concrete and reinforcing steel."*
Bazant, P. and Chern, J.C. (1987), "Stress-induced thermal and shrinkage strains in concrete", ASCE, Journal of Engineering, Vol.113, No.10
- [6] *Bazant, Z., Kaplan, M. "Concrete at high temperatures Material Properties and Mechanical Models."Longman Group Limited, 1996.*
- [7] *Bentz, D. P. and Ferraris, C. F.. "Rheology and Setting of High Volume Fly Ash Mixtures." National Institute of Standards and Technology, Gaithersburg, MD.*
- [8] *Dept. of Civil Engineering, Karadeniz Technical University (2009), 61080 Trabzon, Turkey Email: spul@ktu.edu.tr*
- [9] *Dr. Jeffrey Volz, Advisor Dr. John Myers Dr. David Richardson (2009),Missouri university of science and technology, "Bond strength of high-volume fly ash concrete."*
- [10] *Haddad, R., Shannis, L. "Post fire behavior of bond between high strength puzzolan concrete and reinforcing steel". Consr. Build. Mater 18 (2004) 425-435.*
- [11] *IS 10262-2009 "Recommended Guidelines for Concrete Mix Design", Bureau of Indian Standards,New Delhi, India.*
- [12] *IS 12269-1987 "Specifications for 53 Grade Ordinary Portland Cement" Bureau of Indian Standards,New Delhi, India.*
- [13] *IS 2386-1963 "Method of Test for Aggregate for Concrete", Bureau of Indian Standards, New Delhi, India.*
- [14] *IS 383-1970 "Specifications for Coarse and Fine Aggregate from Natural Source of*

- concrete”, Bureau of Indian Standards, New Delhi, India.
- [15] **IS 456-2000** “Code of Practice for Plain and Reinforced Concrete”, Bureau of Indian Standards New Delhi, India.
- [16] **IS 516-1959** “Method of Tests for Strength of Concrete”, Bureau of Indian Standards, New Delhi, India.
- [17] Khoury G. A. “Effect of fire on concrete and concrete structures,” *Proc. Struct. Eng. Mater J. 2* (2000) 429-447
- [18] Kodur R. V., McGrath: *Fire endurance of high strength columns, Fire Technol.* 89 (2003) 73-87
- [19] Malhotra, H.L.(1985), “Design of fire-resisting structures,” London: Surrey University Press.
- [20] Malvar L.J. (1992) “Bond of Reinforcement under Controlled Confinement”, *ACI Materials Journal*, Vol. 89, No. 6, November – December, pp. 593-601
- [21] Milovanov, F., and Salmanov, G. D. “The Influence of High Temperature upon the Properties of Reinforcing Steels and Upon Bond Strength between Reinforcement and Concrete,” *Issledovanijapozharoupornymbetonu I zhelezobetonu*, pp. 203–223, 1984.
- [22] Morely P., Royles R.: *Response of the bond rein forcing concrete to high temperatures Mag. Concrete Res.* 35 (123) (1983) 67-74.
- [23] Naus, D. J.(2006), *The Effect of Elevated Temperature on Concrete Materials and Structures—A Literature Review*, U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, Washington, DC, 90-130.
- [24] Nestore Galati University of Missouri-Rolla, USA Bryan Vollintine University of Missouri-Rolla, USA(2004).
- [25] RILEM 7-II-28. (1994). “Bond Test for Reinforcing Steel. 2. Pull-Out Test.” E & FN Spon, London.
- [26] Savva, A., Manita, P. and Sideris, K.K.: 2005, *Influence of elevated temperatures on the mechanical properties of blended cement concretes prepared with limestone and siliceous aggregates, Cement and Concrete Composites*, Vol.27
- [27] Youssef, M.A. and Mofiah, M. (2007). “General Stress-Strain Relationship for Concrete at Elevated Temperatures.” *Journal of Engineering Structures*, Vol.29
- [28] Zhang, B., and Bicanic, N.: 2002, *Residual fracture toughness of normal and high strength gravel concrete after heating to 600°C*, *ACI Materials Journal*, Vol.99, No. 3