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Effect of Admixtures on Concrete Bond Strength

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***Abstract* - Bond strength is one among the important property of hardened concrete. Bond between the reinforcement and concrete influences the behavior of structural concrete in many respects. The quality and quantity of ingredients used for making the concrete affect the bond strength of concrete. The addition of mineral admixtures like fly ash, silica fume, rice husk ash etc. into the cement by means of replacing the cement content is nowadays considering as an important matter for protecting the environment against any hazardous situations and also recycling the waste by-products into an effective manner. But, the addition of mineral admixtures affects the structural system of cement and also in concrete. It also leads to the variations in the properties of concrete both fresh and hardened state. With these in mind, the bond strength variations of ternary blended concrete were examined in this experimental investigation and compared with the normal strength concrete. The class F type Fly Ash (FA) was used for making the binary blended concrete. In addition to that Silica Fume (SF) and Rice Husk Ash were (RHA) considered for developing the ternary blended concrete. For studying the effect of rebar corrosion on the behavior of bond of concrete, experimental studies were carried out to accelerate the corrosion and to find out the variations in bond strength. In the binary mix with 20% FA improves the slump value about 80% more than the control concrete. The addition of SF and RHA as the second mineral admixture in the concrete mixes reduces the slump value of fresh concrete.**

Keywords: admixtures bond strength, fly ash, silica fume, rice husk.

I. INTRODUCTION

1.1 General

1.1.1 Pozzolanic materials

The use of pozzolanic materials is as old as that of the art of concrete construction. It was recognized long time ago, that the suitable pozzolans used in appropriate amount, modify certain properties of fresh and hardened mortars and concretes. Ancient Greeks and Romans used certain finely divided siliceous materials which when mixed with lime produced strong cementing material having hydraulic properties and such cementing materials were employed in the construction of aqueducts, arches, bridges etc. A number of structures stand today as evident of the superiority of pozzolanic cement over lime. They also attest the fact that Greeks and Romans made real advance in the development of cementitious materials. It has been amply demonstrated that the best pozzolans in optimum proportions mixed with Portland cement improves many qualities of concrete, such as:

i. Lower the heat of hydration and thermal shrinkage
ii. Increase the water tightness
iii. Reduce the alkali-aggregate reaction
iv. Improve resistance to attack by sulphate
v. Lower susceptibility to dissolution and leaching
vi. Improve workability
vii. Lower costs

In addition to these advantages, contrary to the general opinion, good pozzolans will not unduly increase water requirement or drying shrinkage. Pozzolanic materials are siliceous and aluminous materials, which in themselves possess little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide liberated on hydration, at ordinary temperature to form compounds, possessing cementitious properties. On hydration of tri-calcium silicate and di-calcium silicate, calcium hydroxide is formed as one of the products of hydration.

This compound has no cementitious value and it is soluble in water and may be leached out by the percolating water. The siliceous or aluminous compound in a finely divided form reacts with the calcium hydroxide to form highly stable cementitious substances of complex composition involving water, calcium and silica. Generally, amorphous silicate reacts much more rapidly than the crystalline form. It is pointed out that calcium hydroxide, otherwise a water soluble material is converted into insoluble cementitious material by the reaction of pozzolanic material.

The reaction can be shown as

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Pozzolanic materials + calcium hydroxide + water → C-S-H (Gel)

Fly ash, widely used pozzolanic materials, is finely divided residue resulting from the combustion of powdered coal and transported by the flue gases and collected by electrostatic precipitator. Fly ash was first used in large scale in the construction of Hungry Horse dam in America and the approximate amount of 30 percent by weight of cement. Later, it was used in Canyon and Ferry dam etc. In India, Fly ash was used in Rihand dam construction replacing cement up to about 15 percent. The use of fly ash as concrete admixture not only extends technical advantage to the properties of concrete but also contributes to the environmental pollution control.

1.1.2 Durability of concrete

Concrete durability is a subject of major concern in many countries. Number of international seminars is held on concrete durability and numerous papers written on failures of concrete structures. In the recent revision of IS 456 of 2000, one of the major points discussed deliberated and revised is the durability aspects of concrete.

One of the main reasons of deterioration of concrete in the past is that too much emphasis is placed on concrete compressive strength. It is now recognized that strength of concrete alone is not sufficient, the degree of harshness of the environmental conditions to which concrete is exposed over its entire life is equally important. Therefore, both strength and durability have to be considered explicitly at the design stage. It is interesting to consider yet another view point regarding strength and durability relationship.

Among the many factors that governs the durability and performance of concrete in service, type of cement receives greater attention. Durability of concrete is its resistance to deteriorating agencies to which it may be exposed during its service life, or which inadvertently, may reside inside the concrete itself. The deteriorating agencies may be chemical-sulphates, chlorides, CO_2, acids, etc, or mechanical causes like abrasion, impact, temperature etc. The steps to ensure durable concrete encompass structural design and detailing, mix proportion and workmanship, adequate quality control at the site and choice of appropriate ingredients of concrete. Type of cement is one such factor.

Two significant aspects in fig.1.1 deserve notice. The first is that the production of Portland Pozzolana Cement (PPC) and Portland Slag Cement (PSC) taken together is greater than that of Ordinary Portland Cement (OPC) which indicates gradual acceptance of such blended cements for structural concrete. The other aspect is that all other varieties, which are required to impart special characteristics of strength development or durability, comprise only one percent. On the phase of it, this will appear to be surprising. In a large country like India where weather, environmental and ground water conditions vary widely in different parts, the need of functionally efficient cements should be large.

This anomaly is resolved to some extent by having ordinary portland cement, which fulfills the intents of more than one specification. These may be called multifunctional or multi-blended cements.

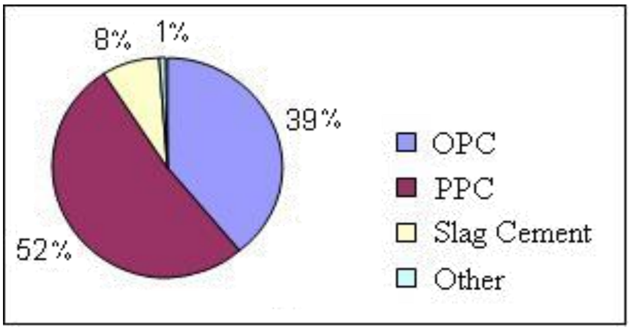

Figure 1.1: Production trend of different varieties of cement in India

Fly ash or ground granulated blast furnace slag can be used in cement and concrete in two different ways. Fly ash or slag can be used in the manufacture of PPC or PSC in the cement plant, by blending or inter-grinding with cement clinkers and gypsum. Alternately, fly ash or ground granulated slag can be added to OPC and other ingredients of concrete in the concrete mixer at the construction site and RMC plant. The prevalent practice in any country depends upon the way the industry has grown.

IS 456 - 2000 recommends the use of blended cement like PPC and PSC, or the mineral admixtures like fly ash, granulated slag and silica fume for improving durability of concrete. Reservations in many agencies in the public sector are also being removed. Recent constructions in many prestigious projects like Delhi Metro, Atomic Power projects and others have used concrete containing fly ash or granulated slag. Use of fly ash and slag are particularly resorted to in case of aggressive foundation conditions.

1.1.3 Use of silica fume and triple-blends

Silica fume is used in India for high performance concrete, requiring high strength, greater impermeability and durability or both. As a result, its use for normal concrete mixes (M20 to M40 range) has not received due attention. There is much to be gained in using silica fume at about 5 to 7 percent of cement by weight in such mixes. It results in saving of cement content, increased durability and corrosion resistance, higher strength, increased pumpability all of which are vital in every construction.

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1.2 Bond Strength

Bond strength between cement paste and steel reinforcement is of considerable importance. A perfect bond, existing between concrete and steel reinforcement is one of the fundamental assumptions of reinforced concrete. The bond strength arises primarily from the friction and adhesion between concrete and steel. The roughness of the steel surface is also one of the factors affecting bond strength. The bond strength of concrete is a function of compressive strength and is approximately proportional to the compressive strength up to about 20 MPa. For higher strength, increase in bond strength becomes progressively smaller.

The bond strength is also a function of specific surface of gel. Cement which consists of a higher percent of C2S will give higher specific surface of gel, thereby giving higher bond strength. On the other hand, concrete containing more C3S or the concrete cured at higher temperature results in smaller specific surface of gel which gives lower bond strength. It has been already pointed out that high pressure steam cured concrete produces gel whose specific surface is about 1/20 of the specific surface of the gel produced by normal curing. Therefore, bond strength of high pressure steam cured concrete is correspondingly lower.

Debonding of concrete cover may lead to loss of confinement and reduction of bond strength at interfacial zone between the two materials. In addition, when deformed bars are used, the deterioration of ribs of such bars causes considerable reduction of the interlocking force between the ribs and the surrounding concrete. This seriously affects the primary mechanism of the bond strength between deformed bars and concrete hence the bond strength decreases significantly.

1.3 Objectives

The main objective of this project work is to evaluate the bond strength of blended concrete. For this purpose, the mix proportion of normal strength concrete is found using IS code procedure (IS 10262:1982 Recommended guidelines for concrete mix design). The variations in fresh concrete properties of binary and ternary blended concretes are evaluated using various admixtures like fly ash, silica fume and rice husk ash. The variations in compressive strength, tensile strength along with the bond strengthof blended concretes are identified. Finally, the effect of rebar corrosion on the behavior of bond between the reinforcement and concrete is determined.

II. METHODOLOGY

2.1 Methodology

2.1.1 Methodology for experimental works

To determine the compressive strength, splitting tensile strength and bond strength the following methodology was employed. By adding pozzolanic artificial admixtures with concrete ingredients the blended concrete was obtained. There are two types of blended concretes. They are binary and ternary blended concretes. Binary blended concrete is the combination of cement with optimum quantity of fly ash. Ternary blended concrete is the combinations of cement with optimum quantity of fly ash and any one of the admixture of silica fume or rice husk ash. In ternary blended concrete the quantity of fly ash was maintained as constant. The test specimens 100mm size cubes and 100mm diameter and 200mm height cylinders were used for determining the compressive strength and splitting tensile strength respectively. For pull out test 150 mm size cubes were used. The workability of concrete by slump value was found by using slump cone apparatus. Hardened concrete properties like compressive strength, splitting tensile strength and bond strengths were found. Compressive strength and splitting tensile strength were determined in compression testing machine and bond strength was determined in Universal Testing Machine (UTM). The methodology of the project work was shown in the flow chart (Fig.2.1). The accelerated corrosion study was also considered to induce the corrosion of reinforcement in the various cementitious environment and the variations of the bond strength were compared with the control concrete.

The two parts of this experimental works are mentioned below:

- Part – I

(a) Binary blended concrete

Experimental works for finding the optimum replacement of cement by fly ash based on the compressive strength

(b) Ternary blended concrete

Experimental works for finding the best proportion of the ternary blended concrete by using the following combinations

- Cement + Fly ash + Rice husk ash
- Cement + Fly ash + Silica fume

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- Part II

Experimental works for finding the variations in bond strength due to corrosion of reinforcement

2.1.2 Method of testing bond strength

For finding the bond strength between rebar and the concrete, pull out test was conducted in a Universal Testing Machine (UTM) of 200 kN capacity. As per IS: 2770 (Part-I)-1967, pull out force corresponding to 0.25 mm slip is important. Therefore, load and the corresponding bond stresses at 0.25 mm slip were examined in this investigation. The test specimens were the concrete cubes of size 150 mm for 12 mm diameter TMT bars, with single reinforcing bars embedded vertically along a central axis in each specimen. The bar shall project down for distance of about 10mm from the bottom face of the cube as cast, and shall project upward from the top face whatever distance is necessary to provide sufficient length of bar to extent through the bearing blocks and the supports of the testing machine and to provide an adequate length to be gripped for application of load. Loose scale and rust were thoroughly removed from the bars by wire brushing and bars inspected to ensure that they were free from grease, paint, or other coatings which would affect their bond. The end reinforcing bars on which the stem of the dial gauge is to bear in the test was ground to a reasonably smooth surface normal to the axis of the bars. The concrete specimen was mounted in UTM in such a manner that the bar was pulled axially from the cube. The load was applied to the reinforcing bar at a rate not greater than 2250 kg/min. The slip at the loaded end of the of the bar shall be calculated as the average of the readings of the two dial gauges, corrected for the elongation of the reinforcing bar in the distance between the bearing surface of the concrete block and point on the reinforcing bar in the distance between the bearing surface of the concrete block and point on the reinforcing bar at which the measuring device was attached. For the purpose of this test, the average bond stress was obtained for each specimen, by dividing the applied load at the slip specified, by the surface area of the embedded length of the bar.

The formula for finding the average bond strength based on the bond stress and the slip relationship as

$$u = P/\pi\, d_b l_{bf}$$

Where,

u is bond strength in MPa
P is load at which 0.25mm slip
d_b is effective diameter of rebar
l_{bf} is embedment length(mm).

III. RESULTS AND DISCUSSIONS

To make the binary blended concrete, the cement was partially replaced by the FA. The FA content was varied as 5, 10, 15, 20 and 25% by mass of cement. The optimum dosage of FA content was found by means of comparing the compressive strength of binary blended concrete with the theoretical target mean strength, which was arrived during the mix design procedure (IS code method).

Table 3.1: Test results for compressive strength of binary blended concrete

S.No	Cement		Fly ash		Compressive Strength (MPa)	
	%	kg/m^3	%	kg/m^3	28 Days	96 Days
1	100	326.0	-	-	32.60	38.47
2	95	309.7	5	16.3	31.70	38.04
3	90	293.4	10	32.6	30.47	37.92
4	85	277.1	15	48.9	28.67	34.46
5	80	260.8	20	65.2	27.67*	30.07
6	75	244.5	25	81.5	25.33	26.67

Table 3.1 shows the results of 28 days and 96 days compressive strength of binary blended concrete in all the replacement levels. Based on the results, the optimum replacement level of FA was found as 20%.

IV. CONCLUSION

As per the experimental results the following points were concluded. In the binary mix with 20% fly ash, improves the slump value about 80% more than the normal concrete. The addition of silica fume and rice husk ash as the second mineral admixture in the concrete mixes reduces the slump value of fresh concrete. In the ternary system, the compressive strength during the early ages was more than the binary blended concrete based on the 28 days strength. The slump value of the control concrete was measured as 10mm. The slump value of the binary blended concrete (80% cement + 20% fly ash) was 18mm and it shows the workability increased about 80% when the cement was replaced by fly ash (20%) in the binary blended concrete.

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