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A Comparative Study on Bond Strength of Reinforcing Steel in Bottom Ash Concrete and Controlled Concrete

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ABSTRACT: The use of thermal power plant waste such as bottom ash is an important issue in construction industry, since it enables reduction in construction cost and has beneficial effect on the environment. Concrete with 40 % of fine aggregate was replaced by bottom ash used as bottom ash concrete. An experimental investigation was conducted to compare the bond strength of reinforcing steel in bottom ash concrete (BAC) with controlled concrete (CC). This experimental program consisted of 6 pull-out specimens (Three bottom ash concrete and Three controlled concrete specimens). The Pull-out test was carried out for these specimens based on IS: 2770 (part I) - 1967. These comparisons indicate that BAC possesses bond strength almost same as CC. The pullout load Vs slip responses of the specimens were identified during the test.

KEYWORDS: Bottom ash concrete, Pullout test, Slip, Ultimate load, Bond stress, Bond stress-slip relation.

1. INTRODUCTION

Concrete reinforced by steel bars is a composite material that has been used in civil structures for decades. In spite of its long history of use, this composite material still needs improvement in terms of the interface between steel rebar and concrete. The interface affects the bond strength between rebar and concrete, in addition to affecting the corrosion resistance of rebar.

Bond in reinforced concrete (RC) refers to the resistance of surrounding concrete against pulling out of reinforcing bars. Anchorage bond is developed parallel to the direction of force over a contact surface in order to induce stress in rebar at critical sections. The bond resisting mechanisms in RC members are understood well in controlled concrete (CC) after the numerous studies performed in the last thirty years. If the bond resistance is inadequate, slipping of reinforcing bar occurs destroying composite action. In RC members sudden loss of bond between rebar and concrete in anchorage zones causes brittle failure. However, the information on bond strength of bottom ash concrete (BAC) is insufficient [1].

Bond is necessary not only to ensure adequate level of safety allowing composite action of steel and concrete, but also to control structural behaviour along with sufficient ductility.

This paper examines the bond stress and slipping of steel bars in pull out specimens of bottom ash concrete and is summarizing the results obtained with rib bars of diameter 16 mm.

Bond Behaviour:

Three factors define the bond strength: chemical adhesion, friction, and bearing of bar deformation (ribs on bar). The adhesion is less important in magnitude and resists only small stress. Friction is a mechanical interlock between irregularities of steel surface and concrete, with magnitude superior than adhesion and occurs after the adhesion is



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broken, and some small movement between steel and concrete take place. These two bond mechanisms are quickly lost and the tension is transferred by bearing of bar deformation [2].

For the plain bars the bond is formed by two parcels: the chemical and friction that depends of the deformed bar surface. The ultimate bond force is proportional to lateral bar area, where occur the adhesion effect, friction and deformed surface.

For deformed bar, the strength occurs mainly by the action of these ribs. The chemical adhesion is low and friction not happen even when the slipping between the bar and concrete occurs.

Bond failure on deformed bar happens by the followings modes: a) crush of the concrete surrounding to the ribs b) shear of the concrete surrounding to the bar c) or more frequently, by one longitudinal spalling of concrete cover d) one combination of these three modes [3].

Bond can be described ideally as a shearing stress between the surface of reinforced concrete and the surrounding concrete. This mechanism is evaluated by means of the relative displacement between the concrete and steel.

Several concrete researches were developed during the past century to the standardized steel bars and controlled concrete strength that are used today. In general these studies are focused simply for particular steel bar and controlled concrete strength. This study particularizes the bond analysis for steel bar and bottom ash concrete.

II. EXPERIMENTAL PROGRAM

2.1 Materials used for the preparation of test specimens:

Portland cement, Fine aggregate (River sand), Coarse aggregate (Broken stones of 10 mm and 20 mm in size), Bottom ash (by-product of coal thermal power plant), Deformed steel bars of 16 mm diameter and Mild steel bars of 6 mm diameter were used in this experimental program.

Bottom ash which is used in this study is obtained from Neyveli Lignite Corporation Limited (NLC). It is mainly composed of silica, alumina and iron with small amounts of calcium, magnesium, sulphate etc. Its chemical composition is controlled by the source of the coal.

2.2 Compressive strength test:

Compressive strength test was done in order to evaluate the strength characteristics of mortar. The compression test was done on standard cube specimens of size 150 mm. The compressive load was applied at a rate of 5.3 kN/sec using compression testing machine as shown in Figure 1. For both BAC and CC, 3 cubes were tested at the age of 7 days, 28 days and the average strength of these cubes were reported.



Figure 1: Compressive strength test setup



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Name of	Compressive strength, N/mm ²		Average compressive	
specimen	at 7 davs	at 28 davs	strength (N/mm ²)	
CC1	18.92	29.10	, , , , ,	
CC2	18.46	28.40	28.456	
CC3	18.12	27.87		
BA1	18.14	27.90		
BA2	18.56	28.60	27.790	
BA3	17.47	26.88		

Table 1: Compressive strength of concrete

Comparing the results in Table 1, at the age of 28 days, the average compressive strength of Bottom ash concrete is 2.34% lower than that of Controlled concrete. Figure 2 shows the compressive strength of Controlled concrete and Bottom ash concrete with respect to age. It shows that there is only mild reduction in the compressive strength of Bottom ash concrete when compared to Controlled concrete.



Figure 2: Graph for Compressive strength of concrete

2.3 Pull-out test:

Several different methods are used to study bond between steel reinforcement and concrete. The four most common methods are pull-out test, beam-end pullout test, beam anchorage test and beam splice test. The last three methods provide more realistic measures of bond strength compared with pull-out specimen test. However, the pull-out test is more popular due to ease of construction and simplicity of the test. The main drawback with this test is that the stress state does not reflect the actual stress state within a reinforced concrete member. In the pull-out specimen test, the bar is in tension and the concrete surrounding the bar is in compression, but in most reinforced concrete members, both the bar and the surrounding concrete are in tension. However, Pull-out specimen test are valid in determining relative performance between different types of concretes or different types of reinforcing bar coatings [4].

2.3.1 Pull-out specimens:

The concrete was made with Portland cement, Fine aggregate and Coarse aggregate in the weight ratio 1:1.7:3. The water-cement ratio was 0.52. The pull-out specimens were designed using IS: 2770 (Part I) - 1967 as a guide. All the test specimens were cured for 28 days. The specimens were reinforced with a helix of 6 mm diameter plain mild steel reinforcing bar such that the outer diameter of helix was equal to the size of cube. The test specimens consist of concrete cubes of size 150 mm, with a single reinforcing bar of 16mm diameter, embedded vertically along a central



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axis in each specimen as shown in below figures. The bar is projected down for a distance of about 10 mm from the bottom face of the cube and is projected upward from the top face whatever distance is necessary to provide sufficient length of bar to extend through the bearing blocks and the support of the testing machine and to provide an adequate length to be gripped for application of load.



Figure 3: Casting of Pull-out specimens



Figure 4: Pull-out specimens before testing

2.3.2 Test setup and procedure:

The test specimens are mounted in a Universal testing machine in such a manner that the bar is pulled axially from the cube as shown in figure 5. The load is applied to the reinforcing bar at a rate not greater than 2.250 kg/mm, or at no-load speed of the testing machine head of not greater than 1.25 mm/min. Dial gauge is fixed at the free end of bar by using C-clamp. The movement between the reinforcing bar and the concrete cube, as indicated by the dial micrometers are read at a sufficient number of intervals throughout the test to provide at least 15 readings by the time a slip of 0.25 mm has occurred at the loaded end of the bar. The loading is continued and readings of movements recorded at appropriate intervals until a minimum slippage of 2.5 mm has occurred at the loaded end [5].



Figure 5: Test setup



Figure 6: Pull-out specimen after testing



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III. TEST RESULTS

Table 2: Ultimate load of Pull-out specimens

Ultimate load (kN)				
CC	BAC			
86.85	82.55			
93.00	92.05			
83.35	87.50			

Table 3: Comparison of percentage changes of load b/w CC and BAC

Load at 0.025mm slip (kN)		Load at 0.25mm slip(kN)		% changes at	% changes at
CC	BAC	CC	BAC	0.02511111	0.2511111
51.33	48.30	84.93	81.33	5.90	4.24
40.05	42.03	81.55	80.40	4.94	1.41
52.38	52.85	76.55	75.28	0.897	1.659

From Table 2, the ultimate load of BAC specimens are nearly equal to that of CC specimens. Table 3 shows the percentage changes of load at 0.025 mm and 0.25 mm slip at the age of 28 days. It shows that the bond strength of Bottom ash concrete is almost same as that of Controlled concrete. Figure 7(a) & 7(b) shows the Load-Slip behaviour of Pull-out specimens. It shows that there is no significant difference in the load-slip behaviour of Bottom ash concrete when compared to Controlled concrete.





Figure 7(b): Load Vs Slip for BAC

The design bond stress is defined as the shear force per unit nominal surface area of reinforcing bar. The stress is acting on the interface between bars and surrounding concrete and along the direction parallel to the bars. Slip is defined as the relative displacement of rebar with reference to the surrounding concrete. Figure 8(a) and 8(b) shows a typical bond stress-slip response with 16mm bars at 150mm size of cube for CC and BAC. It shows that there is no significant difference in the bond stress-slip values of Bottom ash concrete when compared to Controlled concrete.



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Figure 8(a): Slip Vs Bond stress for CC



Figure 8(b): Slip Vs Bond stress for BAC



IV. CONCLUSION

For the specimens studied in this investigation, it appears that bottom ash concrete possesses bond strength almost same as that of controlled concrete. Overall behaviour of Load Vs Slip and Bond stress Vs Slip of bottom ash concrete was very similar to that of controlled concrete.

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