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Experimental Analysis of Behavior of Bond Strength for Different Forms of Concrete

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Abstract: The bond between reinforcement steel and concrete have to proper for the homogeneity as well as for high strength achieved. However, in other words the bond stress may be define as the stresses responsible for holding of steel bars in concrete in concrete after it's setting.

By performed pullout test various the bond strength between the concrete and steel bars is checked. For experimental work grades of concrete used are M 20 and M 25 with bar size varied from 8 mm to 20 mm. Various mix design used are standard mix design of concrete, mix design using marble aggregates instead of normal aggregates, a combination of GFRP mesh fiber with marble aggregates and replacement of 30% fine aggregates by crushed sand. Also the Steel mesh welded bars are also used for checking bond strength, so as it acts as headed bar. These pullout test results in high bond strength of specimens of crushed sand also the increased bond strength is observed in samples casted with steel mesh. Here M 20 grade of concrete failed to give desired results as well as marbles aggregates are not feasible for replacement of normal aggregates while considering bond strength.

***Keywords* — *Bond, Pullout Test, GFRP, headed bar, bond strength, Mix design*.**

I. INTRODUCTION

All the reinforced concrete structures depend on the bond relationship between the concrete and steel reinforcement bars. The behavior of the reinforced concrete elements depends on the steel-concrete bond and the strength capacity is directly related with the bond. Bond study is the relationship between the bond stress and the slipping of steel bar in pull out specimens.

When steel bars are embedded in concrete, the concrete, after setting, adheres to the surface of the bars and thus, resist the force i.e. pull or push to the rod. This intensity of adhesive force is called as bond stress.

Bond strength between reinforcement and concrete is mainly due to friction and adhesion and is affected both by properties of steel as those of concrete and the relative movement due to volume changes, such as concrete shrinkage. Bond stress varies along the length of reinforcing bar in magnitude. The cracks are created due to large variation of bond stress. Various parameters such as bar anchorage length, the lap splices, tension stiffening between cracks, cracking control and minimum reinforcement ratio depends on the bond for the structural design.

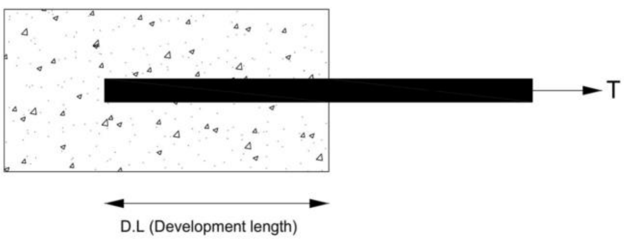

Fig. 1: Bond mechanism between Steel & Concrete

Bond strength is the amount of adhesion between bonded surfaces and is measured in terms of stress required to separate a layer of material from base to which bonded. In other words, it is the measure of transfer of loads between concrete and reinforcement. The bar anchorage length and the tension stiffening are the most important parameters in the bond stress analysis. Bond study is the relationship between the bond stress and slipping of steel bar in pull out specimens. Bond stress is influenced by bar geometrics: This deal with ribs and the surface of the steel bars as shown in fig. 1. The bond stress is identified by the shearing stress between the bar and the surrounding concrete and the slipping of the steel bar is identified by the relative displacement between bar and the concrete. The compression and the tension strength of the concrete influences the anchorage length and the transmission of tensions concentrated on the ribs of the bar.

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Fig. 2: Bar Geometrics

II. LITERATURE WORK

D.A. Abrams was first to study the bond between concrete and steel in a clear scientific manner (1913). He concludes that the adhesive component was the most important component of bond. A.P. Clark looked at the effect of deformation patterns on the strength bond (1946). R.M. Mains (1951) was the first to conduct a series of tests that measured the actual distribution of bond stress rather than assuming a uniform distribution of the bond. Lutz (1967) demonstrated that the bond fails either by pullout of the bar or by cracking of the concrete around bar. Orangun, Jirsa and Breen (1977) conduct a study on past research because they felt that the current code requirements did not accurately reflect the proper bond length required. Maria Teresa Gomes Barbosa[1], Souza Sanchez Filho[1] focused on the experimental study consisting of pull out tests of the Brazilian's steel with five different concrete strength 20,40,60,80 and 100MPa and three different steel bars of 16, 20 and 25mm diameter. Muhammad N.S Hadi[2] in his paper an attempt was made to study the bond strength of High Strength Concrete with High Strength Reinforcing Steel. For determining the bond strength fourteen pull out tests were carried out. The concrete strength was about 70MPa and steel was 500 MPa grade. The bar diameters used were 12, 16, 20, 25, 28, 32 and 36 mm and based on the results it was concluded that the pullout specimen with smaller bar size had greater bond strength that specimen with larger diameter bar. NipunVerma[3], Anil Kumar Misra[3] focused on the characteristics of reinforced TMT bars in Self Compacting Concrete and Normal Cement Concrete. In this work, the bond strength was measured using Universal testing machine (UTM) with some modified arrangements. The bond between the concrete and steel reinforcement was investigated for two different kinds of concretes. Using reinforcing bars bond strengths were measured using Self Compacting Concrete (SCC) specimen and Normal Cement Concrete (NCC) specimen. The castings of the SCC specimens were carried out without compaction, while the normal concrete specimens were casted with substantial compaction and vibration. The study revealed that the SCC specimens generated higher bond to reinforcing bars in comparison with NCC specimens.

Mo Alkaysi[4], Sherif El-Tawil[4] in this paper the bond between Ultra-High Performance Concrete and Steel Bars was studied. In this paper a series of bar pull out tests were conducted using plain and epoxy-coated grade 60 bars with nominal diameters of 13mm, 16mm and 19mm. Testing showed that bond stress achieved increases at low embedded lengths and 1% of fiber volume content in UHPC vs. 2% fiber volume content leads to reduction of approximately 24% in bond strength.

Mohamed H. Harajli[5], Bilal S. Hamad[5], Ahmad A. Rteil[5] in this paper the local bond aspect between steel bars and concrete confined with ordinary transverse steel was experimentally investigated. The tests were conducted for the diameter of the reinforcing bars, ratio of concrete cover to bar diameter and area of transverse reinforcement and the results were compared with similar specimens of concrete confined either internally using steel fiber reinforcement or externally using fiber-reinforced polymer sheets.

VlastimilBilek[6], Sabina Bonczkova[6], Jan Hurta[6], David Pytlik[6], MartinMrovec[6] presented a paper on discussing bond strength between reinforcing steel and three types of concretes. First concrete based on Portland cement, second concrete was alkali activated concrete and the third type was designed using hybrid cement. This paper also focused for the development of alkali-activated or hybrid cement based steel-fiber concretes.

P Eswanth[7], G Dhinakaran[7] presented a paper on bond behavior between GFRP bars and concrete for constructing corrosion free structures by implementing the material. In this paper, the bond strength of GFRP bars in normal and high strength concrete was studied. The comparison of bond properties of GFRP rebar in normal and high strength concrete showed that pull out load of non-metallic rebar fell within the range.

Michael HayseWolfe[8] presented a paper on bond strength of high-volume fly ash in which cement was replaced with fly ash which an industrial waste product is offering sustainable alternative. The motive of this research was to explore the feasibility of using high-volume fly ash (HVFA) concrete for structural applications by testing material's reinforcement bond properties.

Anna R. Lubbers[9] presented a thesis report on bond performance between ultra-high performance concrete and prestressing strands. The results showed that UHPC showed superior bond performance as compared to the conventional concrete.

Kyle Stanish[10] presented a thesis report on corrosion effects on bond strength in reinforced concrete. In this report, the bond strength of the corroded bars were studied. The ends of the bars were corroded to various corrosion levels and were tested in flexure.

Dr. Theresa M. Ahlborn, Mr. Timothy C. DenHartigh[11] presented a thesis report on comparative bond study of

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stainless steel reinforcement in concrete. One hundred and ninety one bond tests were performed with beam-end specimens similar to the ASTM A944 specimen. Different types of bars were used in bond tests.

Above all papers gives an idea about the bond between steel and concrete. To determine the bond strength generally pull out tests are carried out by using various assembly or different arrangement in UTM. The important factors which influence the bond stress are discussed such as bar size and type of concrete. High strength concrete or high grade concrete and various bar sizes are used to get higher yield of bond strength. Some changes in materials are also seen such as use of GFRP, fly ash, etc.

III. ADVANTAGES AND IMPORTANCE OF BOND STRESS

The bond stress between steel and concrete comes mainly from the friction and adhesion. It is affected both by the properties of steel as those of concrete and the relatively movement due to the volume change such as concrete shrinkage. Loss of adhesion can happen between steel bar and concrete. This effect can be harmful and lead to the poor performance of structure. (Loss of adhesion = loosing the tendency of dissimilar particles or surfaces to cling to each other) Bond between reinforcement steel and concrete is an important characteristic to access the performance reinforced concrete structure against seismic load. The study explains the importance of bond between steel and concrete which is essential for the two materials to act together. The bond stress study is important in factors like cement grade, concrete grade, steel grade decision making in construction.

IV MIX DESIGN

A. PREPARATION OF MATERIALS

The materials used like cement, natural & crushed sand, natural aggregate, marble aggregate, Glass Fiber Reinforced Polymer were brought to the room temperature, preferably at 270C, before the mixing is done. The cement samples were mixed dry either by hand or we can mix it with the help of suitable mixer in such a manner so as to ensure the greatest possible mixing and uniformity in silt material. The cement shall be stored in dry place, preferably in air-tight metal containers. Samples of aggregates for each batch of concrete were taken in air-dried condition and the aggregates were separated into fine and coarse fraction to fulfill the desired grading of mix.

B. PROPORTIONING & WEIGHING

The proportions of the ingredients of the concrete during the project work were specified by volume. They were calculated from the proportions by weight which has to be used in the test specimens. The quantities of cement, each size of aggregate, water and sand was determined by weight and taken on the site.

C. MIXING OF CONCRETE

The concrete was mixed in pan-type mixer. Firstly all the materials were collected on the site and their weight was taken. After that proper dry mix was prepared. First dry mixing of cement, sand and aggregate was carried out. Then water was added and the entire mix was carried out by batch mixing until the concrete appears homogeneous and has the desired consists.

D. Mix design of M20 grade concrete

M20 grade of concrete is used, for this the PPC of grade53 cement is used. From the study the mix design proportion for M20 grade of concrete is 1:1.5:3, as per this proportion the mix design is done by taking the w/c ratio as 0.5. This batch of M20 grade of concrete with w/c ratio of 0.5, it was observed that the water content for the mix design is high and the resulting concrete is highly workable and bleeding occurs for some specimens. By taking the factor of increase in bond strength and to obtain good workable concrete and in order to get high strength the w/c ratio for the same grade of conc. i.e. M20 was reduced to 0.4 for better results. Now the concrete having sufficient water content is obtained. Hence we decided to carry out the w/c ratio of 0.4 for all further specimens.

E. Mix design of M25 grade concrete

M25 grade of concrete is used, for this the PPC of grade53 cement is used. From the study the mix design proportion for M25 grade of concrete is 1:1:2, as per this proportion the mix design is done by taking the w/c ratio as 0.5. This batch of M25 grade of concrete with w/c ratio of 0.5, if was observed that the water content for the mix design is high and the resulting concrete is highly workable and bleeding occurs for some specimens. By taking the factor of increase in bond strength and to obtain good workable concrete if order to get high strength the w/c ratio for the same grade of conc. i.e. M25 was reduced to 0.4 for better results. Now the concrete having sufficient water content is obtained. Hence we decided to carry out the w/c ratio of 0.4 for all further specimens.

V. PROCEDURE FOR MIX DESIGN (AS PER IS CODE: 10262-1970)

A. FOR MIX WITH NORMAL AGGREGATE OF SIZE 20 MM.

Add the design proportion of respective grade of concrete (M25) to know the total volume fraction. i.e.1+1+2=4
Volume of dry concrete = 1.54 to 1.57 times volume of wet concrete,

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B. CALCULATION OF MATERIALS:

Wet Volume of one cube of size 150x150x150 mm = $0.0035m^3$

Dry Volume of one cube of size 150x150x150 mm

=0.0035x1.57
= $0.005\ m^3$
Hence, total dry volume of 30 cubes = 0.005 x 30 = $0.15\ m^3$
Volume of cement = $\frac{1}{4}$ x 0.15
= $0.0375\ m^3 = 0.04\ m^3$ But,
$1m^3$ of cement = 1440 kg,Hence,
Cement content for 30 cubes = 57.6 kg
Volume of sand = $\frac{1}{4}$ x 0.15 = 0.0375 m = $0.04\ m^3$
But,
$1m^3$ of sand = 1600 kg, Hence,
Sand content for 30 cubes = 64 kg
Volume of aggregate = $\frac{2}{4}$ x 0.1 = $0.0750\ m^3$ = $0.08\ m^3$ But,
$1m^3$ of aggregate (20 mm) = 1560 kg, Hence,
Aggregate content for 30 cubes = 124.8 kg

Calculation for water content:
Taking w/c ratio of 0.4 into consideration.
Water content = 0.4 x cement content,
0.4 x 57.6 = 23.0 = 23 = 23 liters

C. FOR MIX WITH MARBLE AGGREGATE.

For using marble aggregate of 20 mm same procedure for mix design is used as given above and only the amount of normal aggregate are replaced by marble aggregate having specific gravity 1.70.

D. FOR MIX WITH CRUSHED SAND.

For using crushed sand 4.67 mm same procedure for mix design is used for M20 as well as M25 as given above and from the total quantity sand only 30% sand is replaced by crushed sand.

E. FOR MIX WITH GFRP.

For using GFRP mesh fibers of 3 to 5 mm long and 0.193 mm (145 GSM) is used and same procedure for mix design is used for M20 as well as M25 as given above. For this mix design the water cement ratio is increased from 0.4 to 0.6 and 100 ml for each batch of 6 cubes super plasticizer (polycarboxyl ether) is added to mix design. For this mix design, the amount of GFRP mesh Fibre added was 8.68% by weight of cementious material. (Note: 750 GSM = 1mm)

F. FOR MIX DESIGN USED WITH STEEL MESH.

For mix design used with steel mesh for both grade of concrete M20 as well as M25 standard mix with normal aggregate, sand & cement (PPC, grade 53) is used with w/c ratio of 0.4. For this same process as mentioned above is used.

Materials	Grade of Concrete							
	M20				M25			
	Normal Mix	Mix with Marble aggregate.	Mix with Crushed sand.	Mix with GFRP	Normal Mix	Mix with Marble aggregate.	Mix with Crushed sand.	Mix with GFRP
Cement	38.88	38.88	38.88	38.88	57.6	57.6	57.6	57.6
Sand	64	64	44.8	64	64	64	44.8	64
Aggregate	62.4	-	62.4		124.8	-	124.8	
Marble Aggregate	-	62.4	-		-	124.8	-	124.8
Crushed Sand	-	-	19.2		-		19.2	-
GFRP Mesh Fibers	-	3.37	-		-	5.00	-	

Table 1: Summary of Mix Design for 30 cubes (All values are in kg).

By reviewing the mentioned literatures in chapter 2, the bond strength by pull out test is to be determined with the help of UTM. In pull out test, the deformed bars are to be pull out from the concrete blocks or cubes casted by using the combination of various ingredients. For every combination of material, three cubes are casted and the average values of results are taken and hence, bond strength is calculated by using IS 456-2000. During this experimental work these specimens of concrete cubes casted are at room temperature i.e. 25°Cto 27°C. After casting these specimens, specimens are kept in water tank for curing purpose for 7 days and 28 days. The results of these testing results are discussed below.

VI: PULLOUT TEST RESULT

Bar size in mm	A	B	C	D	E	F	G	H	I
8	5.578	5.261	5.596	0.000	0.000	0.000	0.000	0.000	0.000
10	6.911	5.317	6.267	4.808	4.402	4.925	4.925	3.652	8.607
12	7.129	5.803	5.803	5.604	4.622	5.102	5.611	3.915	7.641
16	6.523	5.926	5.926	5.777	4.293	5.122	NA	1.243	5.629
20	6.669	6.053	6.053	5.933	5.429	5.675	NA	1.062	4.763

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Table 2: Comparative analysis of Pullout Test Result for M20 grade concrete

Bar size in mm	A	B	C	D	E	F	G	H	I
8	7.610	8.491	5.018	0.000	0.000	0.000	0.000	0.000	0.000
10	10.420	11.036	10.282	10.633	10.415	10.558	10.139	3.795	12.314
12	8.211	13.973	11.296	11.543	11.437	12.626	12.599	2.418	13.792
16	6.523	6.841	6.600	11.325	5.851	12.449		1.409	9.084
20	7.188	6.414	5.825	8.326	4.348	8.161		1.025	9.643

Table 3: Comparative analysis of Pullout Test Result for M25 grade concrete

Consideration:
A: Steel Mesh 7 Days Pullout Test
B: Normal Aggregate 7 Days Pullout Test
C: Normal Aggregate 28 Days Pullout Test
D: Steel Mesh + Normal Aggregate 28 Days Pullout Test
E: Marble Aggregate 7 Days Pullout Test
F: Marble Aggregate 28 Days Pullout Test
G: GFRC + Marble Aggregate 28 Days Pullout Test
H: Crushed Sand 30% Replacement 7 Days Pullout Test
I: Crushed Sand 30% Replacement 28 Days Pullout Test

VI. Conclusion

- As the bar size increases, the bond strength increased for 8 mm, 10 mm and 12 mm but for 16 mm and 20 mm bar size, the bond strength decreased for M 25 grade of concrete.
- The bond strength for 12 mm bar size has been found highest as compared to remaining bar size, such as 8 mm, 10 mm, 16 mm, and 20 mm in M 25 grade of concrete.
- For all types of combinations with M 25, the bond strength for 20 mm bar size has been found more.
- For M 25 grade of concrete, the value of bond strength for 30% replacement of crushed sand has been found high.
- When the steel mesh used in concrete, it is found more bond strength.
- When the marble aggregate used in concrete, it is found less value of bond strength than normal aggregate for M 25 grade of concrete.
- Crack developments were found high in the concrete blocks with marble aggregate, so marble aggregate shall not feasible for bond between concrete and steel.
- When the GFRP and marble aggregate used in concrete, it is found more bond strength for M 25 grade of concrete.

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