Experimental Investigation on The Effect of Bond-Strength of Steel Bars

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Abstract— This paper investigates about the Bond-Slip behaviour of steel rebars in reinforced concrete for Plain and Ribbed reinforcing bars. Bond strength is influenced by the rib pattern of the bar and RILEM suggested some recommendations to increase the bond strength of the concrete. Two grades of concrete M25 and M30 were casted. A total of 20 specimens were casted using 25mm bar. Twelve cube specimens were casted without reinforcement and casting done in horizontal position and Eight flexure beams were casted. The bond stress-slip response was studied. Pullout test was used to test the cube specimens. Graphical comparison were done between the Load vs Slip and Load vs Displacement for RILEM standards. Slip was measured using LVDT at both ends. Ribbed bars showed better bond strength compared to plain bars and bond strength obtained from both tests produced same results.

Key words: Bond strength, Slip, Ribbed bars, RILEM, Reinforced concrete, Rib geometry, Flexure

I. Introduction

The bond between steel and concrete is one of the main problems in the study of the concrete and it is still not completely studied. Due to the lateral displacement in any structure the first failure will be the bond failure. According to the literature, the bond-slip behaviour of the steel reinforcing bar is found out by flexural beam test – RILEM, usually there are two main experimental tests are available for finding the bond behaviour of steel bars, 1) pullout test embedded in a concrete cube at varying heights and the pull out of single bar placed in small cube specimen. 2) Beam specimens, due to its similarities with current structural elements subjected to bending, certainly provide a better estimative of bond strength. Bond is a necessary one for not only to ensure the composite action of steel and concrete but also to control behaviour of structural members.

The bond in beam specimens subjected to bending, certainly provide a better estimative of the bond strength. The transfer of forces between steel bar and concrete is a fundamental mechanism for the existence of reinforced concrete. Bond strength varies in function of three parameters they are adhesion, cohesion and friction that is the main factor for the bond strength and the contact interaction among the materials caused by the deformation of the bars in contact with the concrete [2]. In order to measure the bond slip the RILEM stands tall and the main influencing factors for bond in RC members depends on reinforcing unit and stress state in both reinforcing unit, surrounding concrete and others parameters such as concrete cover, space between rebars, number of layers and bundled bars, casting direction and also the bar position. The chemical adhesion and friction play key role in resisting the slip of the reinforcing bar. the maximum bond capacity decreases slightly with increasing bond resistance and it is not influenced by the bar diameter, lug spacing or relative rib area [1].

RILEM suggested some recommendations to study the flexural strength of the concrete beam and the bond – slip behaviour of the bar can be studied and the CEB/FIP widely accepted and treated as the local bond. The test is to determine the conventional bond characteristics of the steel used as reinforcement in reinforced concrete. Thus, test indicated the two curves that is representing the slip of the bar as a function of the load applied to the beam. The interfacial transition zone (ITZ) at the vicinity of the reinforcing bar affects the bond between steel and concrete. The ITZ depends on the constituent material used for making concrete. However, studies on the effect of bond strength between reinforcement and concrete with two different bars like plain bars and ribbed bars.. However, the bars with rib face angle of 600, rib spacing of 50% of bar diameter and rib height of 10% bar diameter would improve the bond performance. The bond ratio increases with increase of concrete cover, rib face angle and decrease of relative rib area. In plain reinforcing bar, due to the absence of ribs the friction or bonding with the concrete will be less compared to the ribbed reinforcing bar. The longitudinal cracking that appears is due to the compressive force radiating out in an inclination that varies with rib pattern. Also the compressive forces in-turn produce tensile stresses cracks in the surrounding concrete and cause successive splitting cracks followed by some critical splitting surface line between the steel bar and the surface of the concrete element.

In the pullout test, specimens without the reinforcing steel, on the other hand, show the influence of concrete compressive strength and the bar diameter. Choi (1989) reported on local bond strength of deformed bars with different diameters in confined concrete. The bond strength decreases as the bar diameter increases. R. Tepfers and L. De Lorenzis (2003), This paper explains about the bond of ordinary steel reinforcement in concrete depends on many factors, such as the pullout resistance, the geometry of a concrete member, the placement of a bar in the member cross section, the cover splitting, the confinement caused by concrete and the surrounding reinforcement. F. Sultana (2010), this paper investigates about the lateral confinement increased the bond strength significantly and the extension of the post-peak curve increased showing improved ductility. The bond stress varies along the larger embedment length while it is more or less uniform in smaller length. The present study evaluates the bond behavior between steel bars and self-compacting concrete and ordinary concrete performed in monotonically loaded beam tests, using the Finite Element Method. In the numerical model, concrete and steel bars were represented as non-linear behavior materials, combined with a model of the interaction between steel bars and concrete. Fernando M. de Almeida Filho (2007) The present study evaluates the bond behavior between steel bars and self-compacting concrete and ordinary concrete performed in monotonically loaded beam tests, using the Finite Element Method. In the numerical model, concrete and steel bars were represented as non-linear behavior materials, combined with a model of the interaction between steel bars and concrete. The pull-out tests, very easy to perform, were the first considered to evaluate the bond strength.

But since the beam tests are more reliable, and they also reflect the influence of the flexure, they were also considered, and among the several types of beam tests proposed to evaluate the bond strength, the Rilem standard test seemed to the best choice for this study purpose.

II. RESEARCH SIGNIFICANCE

This paper presents a study of the behaviour of beams and pull-out specimens through an experimental program. The main objective was evaluating the load vs displacement and load vs slip behaviour and the bond strength, regarding the influence of 25 and 30 Mpa and bar diameter of 25 mm.

III. EXPERIMENTAL PROGRAMME

A. Materials

A 53 grade Portland Pozzolanic Cement (PPC) was used. Specific gravity of cement was 3.15. The fineness of cement was 5.2 %. The initial and final setting time was 47 and 247 minutes respectively. Fe 500 grade high strength deformed bars of diameter 12mm as main reinforcement and 8mm mild steel (MS) bars for spirals as confinement reinforcement were used. Specific gravity of coarse aggregate was 2.75. Flakiness index was 24.5 and bulk density was 1530 kg/m3.Fineness modulus of coarse aggregate was found to be 5.32 and the average impact value was 14.28 % and average crushing value was 21%. Specific gravity of fine aggregate was found to be 2.66, water absorption was 1% and fineness modulus for fine aggregate was 2.44 with the bulk density of 1615 kg/m3. It belongs to zone II grade of sand. Two different grades of concrete were selected 25 and 30 Mpa respectively. In 25 Mpa concrete, weight of the cement 300 kg/m3 and water cement ratio was 0.45. The concrete mix proportion were 1:1.25:2.3:0.45. In 30 Mpa concrete, weight of the cement was 300 kg/m3 and water cement ratio was 0.40. Mix proportions were 1:2.3:3.15:0.40. six standard cubes were casted to determine the compressive strength of concrete. Two types of bars were used that is plain rebar and ribbed rebar with Fe 500 grade. For plain rebar, diameter of the bar was 25 mm and its ultimate tensile strength was 649 N/mm2 and its yield strength was 529 N/mm2 and its elongation limit is 18.4 % and weight of the rebar is 3.792 kg. For ribbed rebar, ultimate tensile strength value was 653 N/mm2 and its yield strength was 537 N/mm2 and its elongation limit was 18.4 %. weight of the rebar was 3.8604 kg.

B. Test Specimens

1) Pull-Out Test Specimens

In the pullout bond tests were performed on RILEM beam specimens prepared according to RC6: RILEM-1983 using dimensions of 200 X 200 X 200 mm and the concrete is poured horizontally with the centrally placed hole and bar is projected and the embedment length of 100 mm in contact with the concrete. Sleeve of PVC is used to separate the bonding region with the debonding region.

2) Flexural Beam Specimens

The bond tests were performed on RILEM beam specimens prepared according to RC5: RILEM-1978. The dimensions of specimen, reinforcement details and dimensions of steel hinge are shown in Fig.1(a). The overall size of the beam specimen is 1260x150x240 mm. the specimen comprises of two reinforced concrete blocks and is interconnected at the bottom by 25 mm test steel bar, whose bond strength is to be determined. A steel hinge is provided at the top of the specimen. The purpose of the steel hinge is to provide adequate rotation of the blocks during loading, which is necessary to obtain pure bond failure. The test bar extends outside the specimen to a distance of 120 mm at both ends of beam to measure the free end slip. The sizes of bars for reinforcement cage, spacing dimensions are shown in Fig.1(b) The bond length considered is 10 ϕ (ϕ = diameter of bar to be tested) and the remaining length on either side of the bonded portion of the bar is debonded using plastic sleeves. The concrete was cast carefully without disturbing the test bar and the hinge at the top of the specimen. Totally, RILEM beam specimens were cast in this work out with the plain bars and ribbed bars.

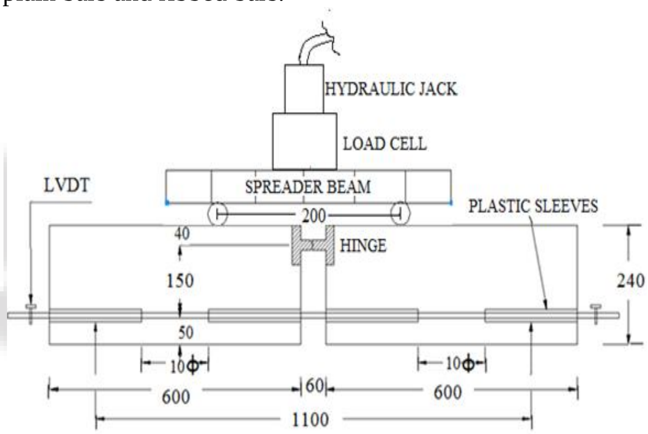

Fig. 1: Experimental Setup

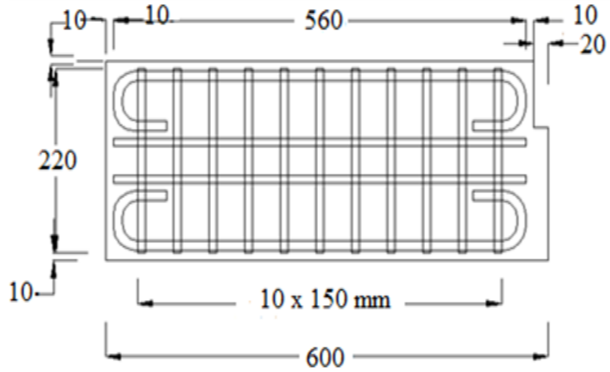

Fig. 2: Reinforcement Details

3) Casting Of Specimens

Fig. 2: Casting of Rilem Cubes

Fig. 3: Casting of M25 Beams

Fig. 4: Demoulded Specimens

4) Testing Of Specimens

The pullout tests were conducted with 1000 kN universal testing machine and the surface was supported on a 25 mm plate that had a hole drilled at the centre to accommodate the reinforcement. The bar was pulled axially from the concrete. At the end of the bar the LVDT is fixed to measure the slip.

The relative slip between the surrounding concrete and reinforcing bar id measured at every 5 kN interval and the displacement also noted. Flexural beams were tested with 1000 kN capacity frame and steel hinge is placed on the top of the concrete beam and loading is applied in vertical direction. The LVDT is fixed at both ends to measure slip value and deflector is fixed at both sides to measure deflection and the displacement and slip is recorded at every 5 kN interval. The loading is taken until the specimen failure due to crack on the specimen or the bending of the reinforcing bar.

Fig. 5: Testing Of Beam

Fig. 6: Testing Of Cube

IV. Results and Discussion

The recommendation considered in the Rilem provisions is to quantity the bond stress for the slip at the end of the steel bar. The determination of the bond stress for each bond stress for each slippage varies according to the test and the bar diameter. The equations below were used for determining the bond strength in the test.

For Pull-out specimens:

$$\tau_S = \frac{P}{\pi.\phi.l_d} \quad (1)$$

For beam specimens:

$$\tau = \frac{\sigma_S}{40} \quad (2)$$

From the Rilem recommendation, the following provision are to be used to calculate the stress in the reinforcement

$$\sigma_S = k.\frac{P}{A_S} \quad (3)$$

The parameter “k” in Eq. 3, varies accordingly to the bar diameter, where it assumes 1.25 for less than 16 mm diameter bar and assumes 1.50 for greater than 16 mm diameter bar.

SAMPLE	MAX.LOAD kN	MAX.DEFLECTION mm	AREA mm^2	BOND STRENGTH(N/mm^2)
M25-PLAIN BAR	41.17	5.52	9818	4.19
M25-RIBBED BAR	122.27	12.91	9818	12.45
M30-PLAIN BAR	48.33	6.77	9818	4.71
M30-RIBBED BAR	144.42	14.66	9818	14.70

Table 4.1. Test Results Of Pull-Out Specimens

SAMPLE	"Pu" MAX.LOAD kN	"δ" MAX.DEFLECTION mm	S_1 mm	S_2 mm	BOND STRENGTH (N/mm^2)
M25-PLAIN BAR	63	4.03	0.28	0.34	4.812
M25-RIBBED BAR	134	7.78	0.41	0.44	10.23
M30-PLAIN BAR	76	6.85	0.38	0.40	5.80
M30-RIBBED BAR	134	10.3	0.74	0.78	12.52

Table 4.2. Test Results Of Beam Specimens

A. Graphical Comparison- Beam Results

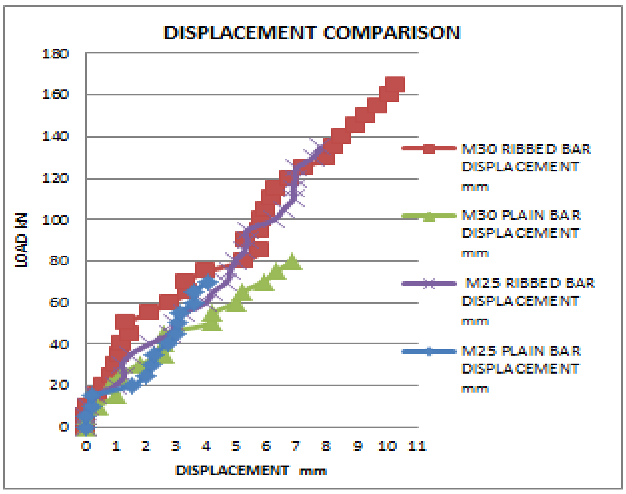

Fig. 7: Beam specimens-Displacement Comparison

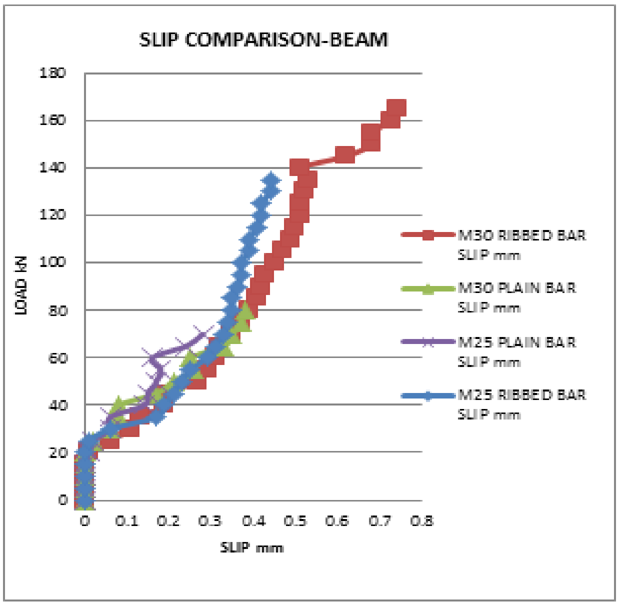

Fig. 8: Beam Specimens – Slip Compariso

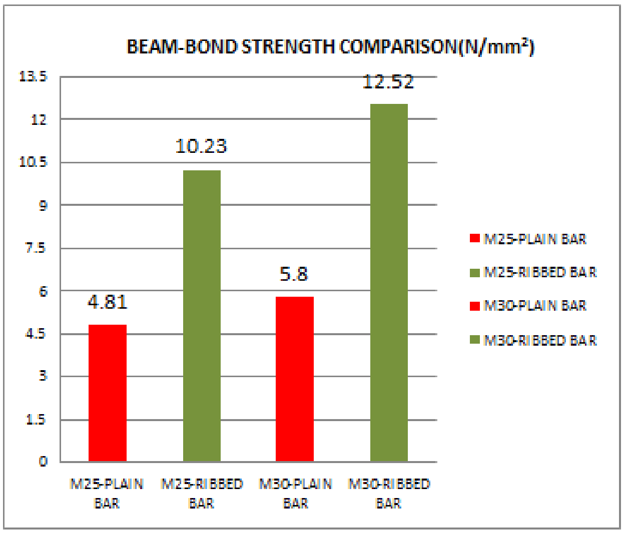

Fig. 9: Beam specimens-Bond Strength Comparison

B. Graphical Comparison-Cube Result

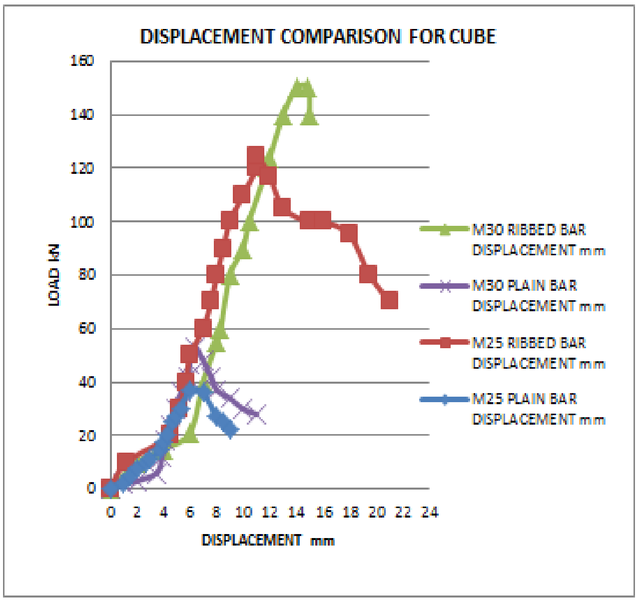

Fig. 10: Cube specimens-Displacement Comparison

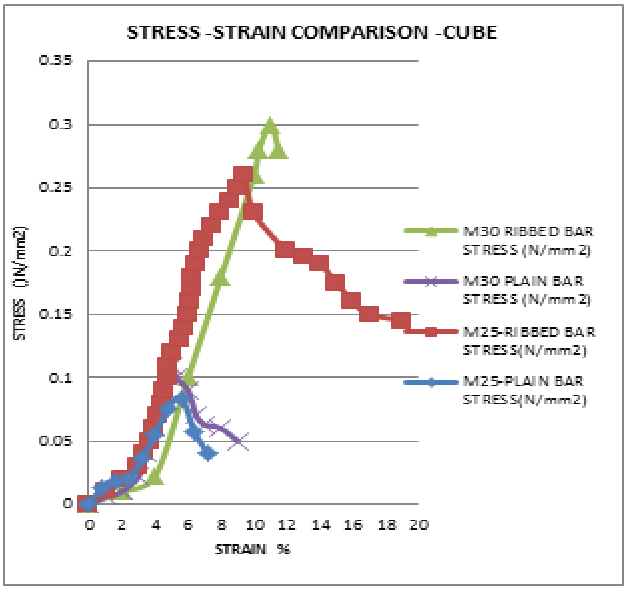

Fig. 11: Cube specimens-Stress-Strain comparison

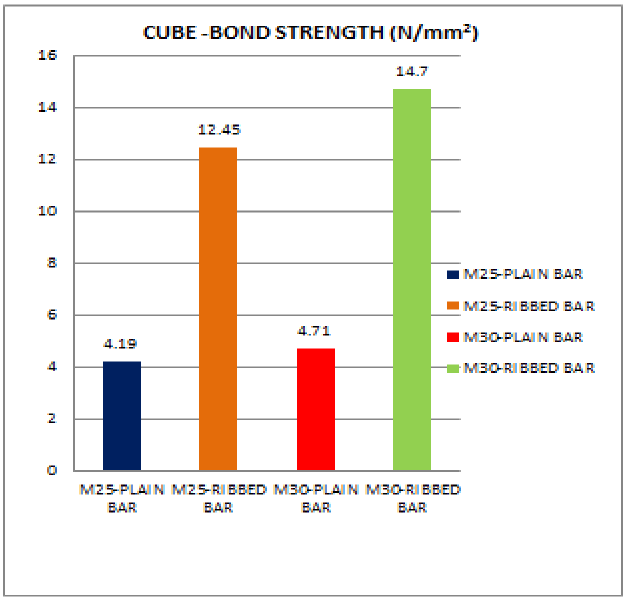

Fig. 12: Bond Strength Comparison For Cube

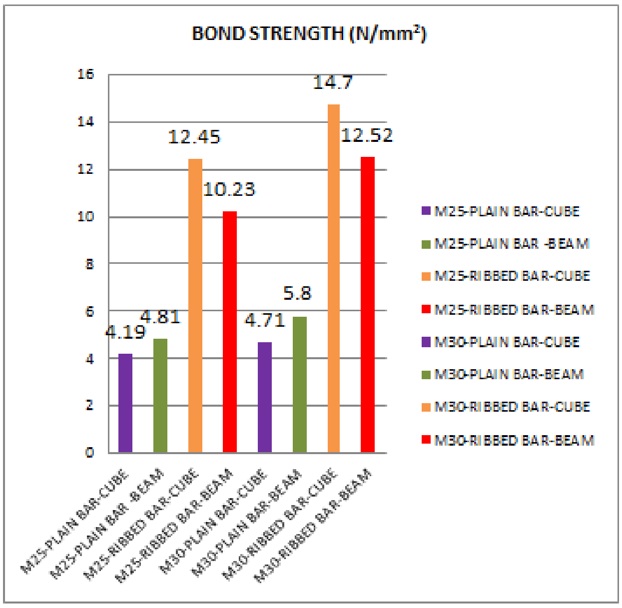

Fig. 13: Beam and Cube-Bond Strength Comparison

V. FAILURE OF BEAM SPECIMENS- PHOTOS\

Fig. 14: Failure Pattern –Bending of bar

Fig. 15: Crack Pattern near hing

VI. FAILURE PATTERN OF CUBE SPECIMENS-PHOTOS

Fig. 16: splitting failure in cube

Fig. 17: Failure specimens of pull-out tes

VII. Conclusion

From the present study, the following conclusions were drawn:

1) The comparison between the pull-out and beam specimens showed that the obtained results were quite nearer, demonstrating that this level of concrete strength, both specimens, pull-out and beam, achieves similar results.
2) The Ribbed bar shows twice the bond strength compared to plain rebar and its almost above 80%.
3) For Ribbed bar both in pull-out and beam specimens showed that the presented results were quite different. However the bond strength was similar, despite the difference presented in slip.
4) In pull-out and beam test the failure pattern well observed in mid-portion due to debonding of the bar with plastic sleeves especially for ribbed bar the failure pattern occurred exactly at mid-portion.
5) The bond strength also decreased as the embedment length increased.

From the tests performance, the both tests presented low variability, becoming reliable test; however, the beam test was a very difficult test to be made and as a recommendation must be reserved for some special cases. So, the pull-out tests must be used in usual cases, because of its simplicity, good accuracy and time consuming, since some care should be taken for the embedment length and bar diameter for the correct evaluation of result.

Notations

Pu = Maximum applied load, kN
ld = Embedment length, mm
S1 = Maximum slip for failure load in beam test for LVDT 1, mm
S2 = Maximum slip for failure load in beam test for LVDT 2, mm
τs = Bond stress, MPa
As = Nominal cross sectional area of test bar, mm2
ϕ = Diameter of test bar, mm
σs = stress in steel, MPa

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