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Study on Anchorage Bond in High Strength Reinforced Concrete Beams

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ABSTRACT: *This paper discuses experimentally the effect of steel bar diameter and embedment length on the bond stresses, bond stress versus slip relation, failure pattern and load versus deflection response of high strength reinforced concrete beams with dimensions (100 mm width x200 mm height x1100 length). Four beams specimens were provided with three embedment lengths (80 mm), (100 mm) and (120 mm) in addition to two different bar diameters (10mm) and (16mm). The test results concluded that the bond stresses and the relative displacement decrease with increasing the embedment length and bar diameter.*

Key words: *Bond Stress, slip, high strength concrete, embedded length, bar diameter.*

I. INTRODUCTION

Due to importance of bonding failure in concrete structures, several investigations have been developed to enhance the bond strength between steel bar and concrete. Most of the studies that dealt with the effect of development length on bond characteristics concluded that increasing the development length impact positively on the bond characteristics (1-6).

The effect of bar diameter has been studied by [Mohammad N.S Hadi](7) [Kazim Turk et.al](8), [Soroushain P. and Choik.](9) and [Al-Aukaily A. F.], these investigations concluded that the bond strength decreased with increasing bar diameter.

The increasing of concrete compressive strength have a beneficial effect in improving the bond characteristics and this is what has already been proven by [A. Forough – Asl et.al](11), [Kafeel Ahmed](12) , [Khodaie and Nahmat](13) and [M. Veera Reddy](14).

In recent decades, studies on the bond characteristic between steel bars and new type of concrete has emerged [Forough – Asl et.al](11) and [M. Mazloom and K. Momeni](15) studied the bond between reinforcement bars and self-compacting concrete. They concluded that bonding strength was increased when using self-compacting concrete in comparison with normal strength concrete.

Also, the bond between reinforcement bars and reactive powder concrete was studied by [Mahesh Maroliya](16), [Deng Zong - Cai](17) and [Lee M. et.al](18). The improvement of bond characteristics is clear when using reactive powder concrete.

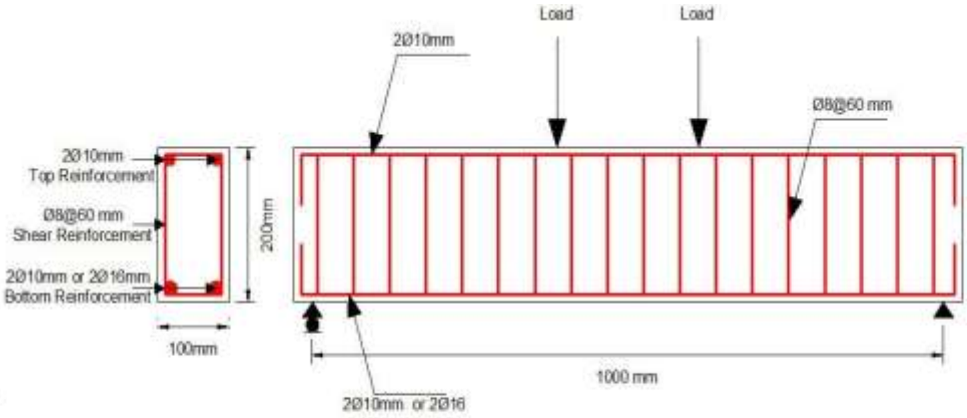

Figure 1 Experimental Detail of Tested Beams

II. EXPERIMENTED PROGRAM

The Experimented program of this study includes casting and examining four high strength reinforced concrete beams with dimensions (100 mm width x 200 mm height x 1100 length) to study the effect of development length and steel bar diameter on the bond characteristics between reinforcement steel and concrete, in addition to three specimens of cube, cylinders and prisms to evaluate the compressive strength, modulus of rupture and modulus of elasticity for concrete mix. The beams are tested under two points loads with (210mm) distance between them. The section dimensions, steel bars distribution and testing set up are shown in Figure (1) and Table (1).

Table 1 Experimental Details of Tested Beams

Specimen Conf.	**Dimensions (mm)**			**Flexural Reinforcement**		**Shear Reinforcement**
	Width	**Height**	**Length**	**Tension Reinforcement**	**Compression Reinforcement**	
B1	100	200	1100	2Ø10	2Ø10	Ø8@60mm
B2	100	200	1100	2Ø10	2Ø10	Ø8@60mm
B3	100	200	1100	2Ø10	2Ø10	Ø8@60mm
B4	100	200	1100	2Ø16	2Ø16	Ø8@60mm

1. MATERIALS PROPERTIES

1.1. Cement

The physical and chemical properties of cement used in this work are listed in Table (2) and Table (3), the obtained results confirm ASTM C-150(19) standards. The cement was stored in a dry place to avoid the exposure to moisture.

Table 2 Physical Properties of Cement

Property	**Results**
Fineness using Blain air permeability apparatus (m2/kg)	386
Safety (soundness) using autoclave method (%)	0.013
Compressive strength for cement paste cube (70.7mm) at : (3days) in (N/mm2) or (MPa)	21.6
Compressive strength for cement paste cube (70.7mm) at : (7days) in (N/mm2) or (MPa)	25.6

Table 3 Chemical Properties of Cement

Components	**Results**
SiO2	19.93
Al2O3	5.42
Fe2O3	3.48
CaO	62.59
MgO	1.86
SO3	2.05
Insoluble Residue	1.19
Loss On Ignition	3.47
Tricalcium aluminates	8.34 (From X.Ray diffraction)
Lime Saturation Factor	0.81

1.2. Coarse Aggregate

The maximum size of coarse aggregate used in this study is (14 mm). Table (4) illustrates the grading of coarse aggregate which is confirm the ASTM C33M(20) limits.

Table 4 Grading of Coarse Aggregate

No.	Sieve size (mm)	Present work of coarse aggregate (% passing)	ASTM C33M(20) (% Passing)
1	25	100	100
2	12.5	95.15	95-100
3	4.75	53.23	25-60
4	2.36	4.4	0-5

1.3. Fine Aggregate

Table (5) illustrates the grading of the fine aggregate with maximum size (4.75 mm), the test results confirm the ASTM C33M (20) limits.

Table 5 Grading of Fine Aggregate

No.	Sieve size (mm)	Present work of fine aggregate (% passing)	ASTM C33M(20) (% Passing)
1	9.5	100	100
2	4.75	96.33	95-100
3	2.36	89.22	80-100
4	1.18	63.19	50-85
5	0.6	55.23	25-60
6	0.3	27.29	5-30
7	0.15	9.48	0-10

1.4. Steel Reinforcement

Three sizes of bars were used in this study, Ø8 mm, Ø10 mm and Ø16 mm. The strength properties of these bars are shown in Table (6), the test results confirm ASTM A615(21).

Esraa Kamal Jaafar

Table 6 Steel Bars Properties

Diameter (mm)	Yield Strength (fy) (MPa)	UltimateStrength(Fu) (MPa)	Δ (mm)
Ø 8mm	411	591	10.3
Ø 10mm	491	663	10.8
Ø 16mm	506	688	11.5

1.5. Super-Plasticizer

Gelinium 51 was used as a super plasticizer material, Table (7) illustrates the typical properties of Gelinium 51.

Table 7 Specifications of Gelinium 51

No.	Main action	Concrete super plasticizer
1	Color	Light brown
2	pH. Value	6.6
3	Form	Viscous liquid
4	Chlorides	Free of chlorides
5	Relative density	1.08 – 1.15 gm/cm3 @ 25□C
6	Viscosity	128 □□30 cps @ 20□C

7	Transport	Not classified as dangerous
8	Labeling	No hazard label required

III. MECHANICAL PROPERTIES OF CONCRETE

The concrete compressive strength, modulus of elasticity and modulus of rupture test were performed according to ASTM C39(22), ASTM C469(23) and ASTM C78(24) respectively. Table (8) includes the mechanical properties of concrete.

Table 8 Mechanical Properties of Concrete

Beam Configuration	**Compressive Strength (MPa)**	**Modulus of Elasticity (MPa x10^3)**	**Modulus of Rupture (MPa)**
B1	62.8	34.3	9.80
B2	61.25	34.8	8.86
B3	69.0	36.4	10.00
B4	67.5	35.4	9.92

IV. RESULTS AND DISCUSSIONS

1.6. Failure Pattern and Load – Deflection Behavior

As mentioned in Figures (2), (3), (4) and (5), the beams are not affected significantly by load application at the early stages of loading. The small deflections give an indication on high stiffness of tested beams. This behavior extends until initiation of cracks at the middle third of the beams under points loads. This stage of load–deflection curve is approximately linear called an elastic stage.

After that, the stiffness of beams start to decrease as a result of propagation of cracks, the values of deflections readings are larger than previous stage until yielding of steel bars. This stage of load- deflection curve is also approximately linear, the lack of bond between steel bars and concrete is more characterized at this stage. So, it is a non-elastic stage.

The later stage can be called a failure stage, which the deflection reading increase rapidly more than previous stages until failure by bond between steel bars and concrete, see Figures (6), (7), (8) and (9).

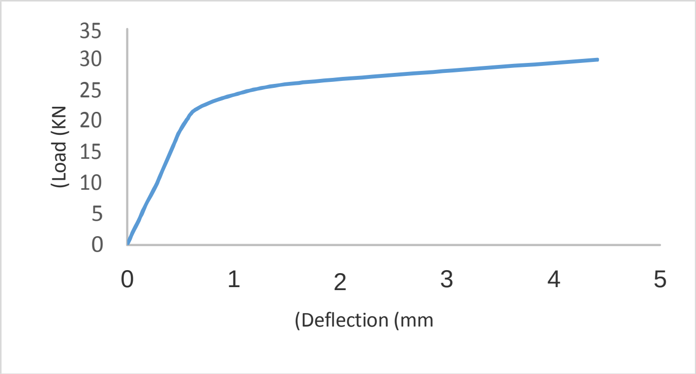

Figure 2 Load-deflection Curve of Beam (B1)

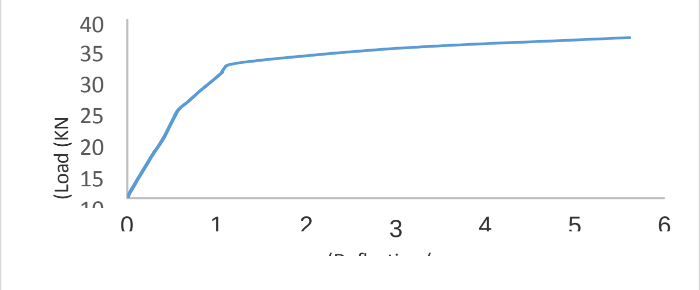

Figure 3 Load-deflection Curve of Beam (B2)

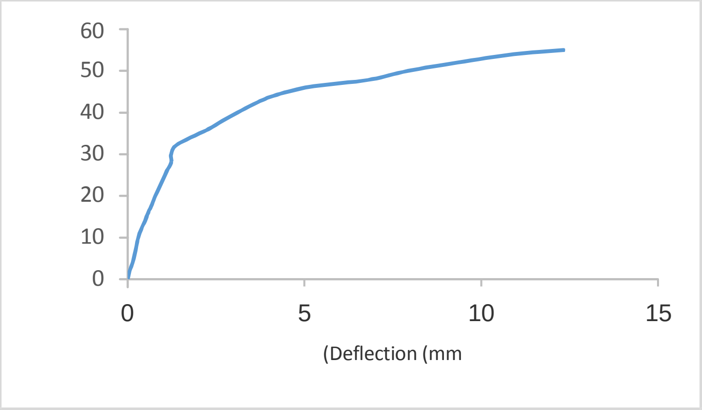

Figure 4 Load-deflection Curve of Beam (B3)

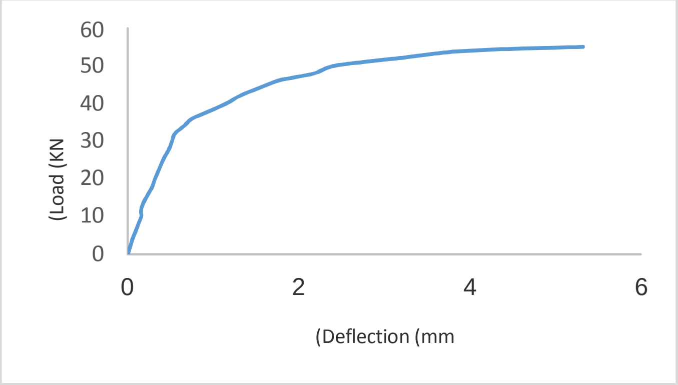

Figure 5 Load-deflection Curve of Beam (B4)

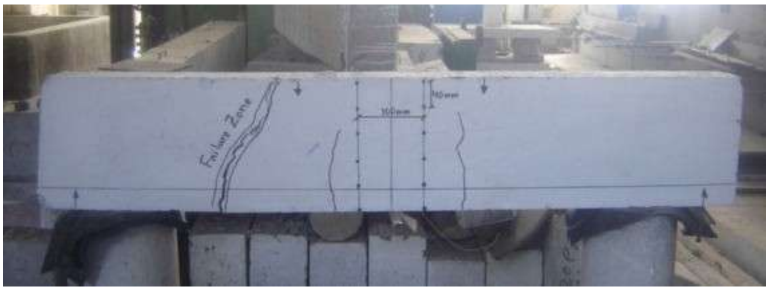

Figure 6 Failure Mode of Beam (B1)

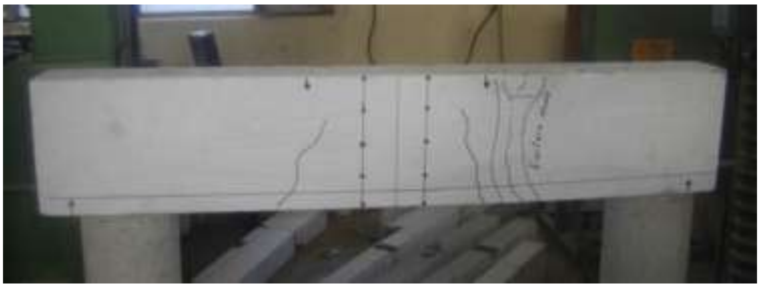

Figure 7 Failure Mode of Beam (B2)

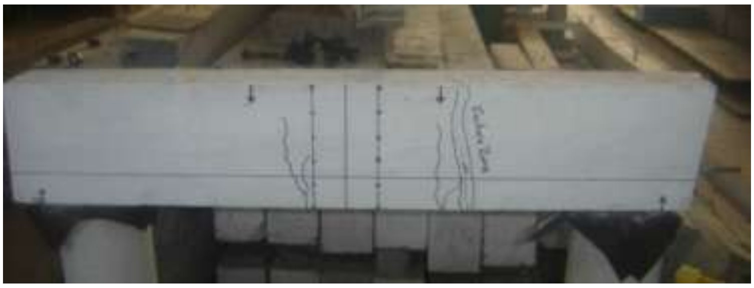

Figure 8 Failure Mode of Beam (B3)

Figure 9 Failure Mode of Beam (B4)

1.7. Bond Stresses Characteristics

As indicted in Table (9), the bond stresses decreased from 13.78 MPa to 13.23 MPa and from 13.78 MPa to 12.56 MPa when the development length was increased from 80 mm to 100 mm and from 80 mm to 120 mm respectively. The same trend can be seen when the diameter of embedded bars increased from 10 mm to 16 mm, the bond stress was decreased from 12.56 MPa to 11.29 MPa. In two cases (increasing the development length and diameter), the mentioned decrease in bond stresses is attributed to increase the frictional area between the steel bar and concrete.

Table 9 Bond Stresses between Steel Bar and Concrete

Specimens No.	**B1**	**B2**	**B3**	**B4**
Diameter (mm)	10	10	10	16
Development Length (mm)	80	100	120	120
Bond Stress (MPa)	13.78	13.23	12.56	11.29

1.8. Bond Stress – Slip Relationship

The relative slip between steel bar and concrete measured by using dial gauge with accuracy (0.002). Figures (6) and (7) show a bond stress versus slip response in beams specimens with different bars diameters and development lengths. The obtained results significantly show that the initial stage of each curve has same slop which gives an indication that bond stress at this stage is negligible and the chemical bonding between steel bars and concrete is sufficient to carry the applied stresses. This stage of bond stress-slip curve is approximately linear called linear elastic stage and the stiffness is still appearing high.

With increasing the load, the stress in bar is increased with initiation relative displacement between steel bar and concrete. The chemical bonding between steel bar and concrete start to disappear and the interlocking between ribs and surrounding concrete becomes an important parameter in resisting the bond stresses. The micro cracks start to develop at the contact between ribs and concrete. The crushing of surrounding concrete around the ribs has obtained at the advanced stage of loading.

The relative displacement between steel bar and concrete start to increase until failure by pulling out due to an increase the diameter of hole around the steel bar.

The using of large diameter of steel bar negatively affect the amount of relative displacement between steel bar and concrete because the number of interlocking ribs with concrete are few compared with small diameters one with constant development length. The effect of increasing the development length causes an evident decrease in the amount of slip, this reduction is attributed to increase the frictional area which decrease the bond stress between steel and concrete.

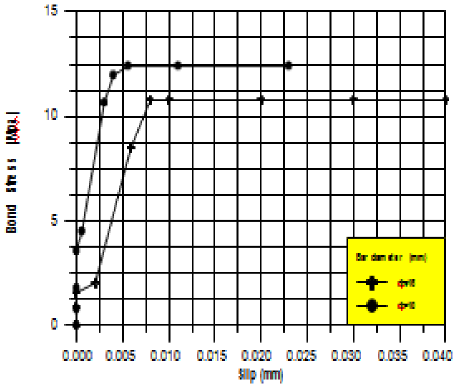

Figure 10 Bond Stress-slip Curves of different Bar Diameters

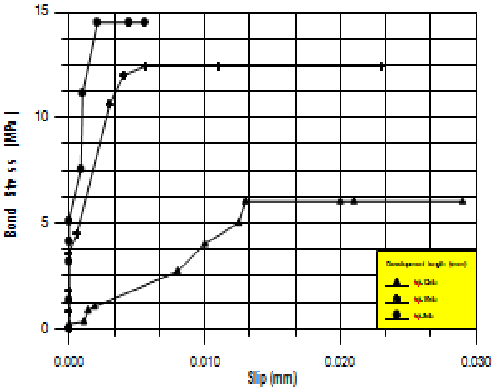

Figure 11 Bond Stress-slip Curves of different Development Lengths

V. CONCLUSIONS

The test results led to the following conclusions:

1 – Increasing embedment length has a significant effect on decreasing the bond stresses. 2 - Increasing bar diameter leads to a decrease in the bond stress.

3 – In the first stage of loading, the chemical bonding between steel bar and concrete is sufficient to carry the applied stresses.

4 – Due to increasing the frictional contact area, the slip between steel bar and concrete decreased when increasing the embedment length.

5 – The slip between steel bar and concrete decreased when increasing the bar diameter.

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