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BEHAVIOR OF INTERACTION EFFECT BETWEEN TWO-BARS ON THE BOND BETWEEN REINFORCING BARS AND FIBER REINFORCED CONCRETE

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ABSRACT

This paper presents an experimental investigation on the behavior of interaction effect between two-bars on the bond between reinforcing bars and fiber reinforced concrete (FRC). This study contains two phases. The first phase included the studied bond behavior for specimens having a spacing between two-bars =25mm while the second phase focused on the study of bond behavior for specimens having a spacing between two-bars =50mm. The parameters considered are the variation in bar diameter and the effect of embedded lengths on bonding between two-steel bars and FRC. From the results of the experimental tests, the increase in the depth of embedded length, the ultimate load and the value of slip increased. The use of biggest bar diameter with the same embedded length increase both bond strength and toughness values. Further, behavior of specimens having a spacing between two-bars =25mm had the same behavior in resisting the influential loads during the test while for specimens having a spacing between two-bars =50mm, one of the bars slipped before the other at the initiating of loading and with the loading rate increased, the other reinforcing slipped.

Keywords: two-bars, embedded lengths, bar diameter, spacing between steel bars, pull-out bond load, toughness, mode of failure.

1. INTRODUCTION

Reinforced concrete is non-homogeneous materials and built up of reinforcing bars and concrete. Reinforced concrete elements are mainly designed so that the concrete can carry the compressive stresses and the steel can resist the tensile stresses. Therefore a good force transfer between the two materials is necessary which can only be achieved by an interaction between both materials, which is provided by bond between the reinforcing bars and the concrete. Bond between the concrete and the reinforcing steel bars plays a major role in the performance of reinforced concrete structures [1-4].

In reinforced concrete construction, efficient and reliable force transfer between reinforcement and concrete is required for optimal design. The bond consists basically of three components: chemical adhesion between the reinforcement bar and the concrete, frictional forces between the bars and the concrete due to the roughness of the surface of the bars in contact area with the concrete while the last was mechanical anchorage or bearing of the ribs against the concrete surface. After initial slip of the bar, most of the force is transferred by bearing. It is important to note that the role of the bearing of the ribs against the concrete surface constitutes the major bond forces compared to the roles of the chemical adhesion and the frictional forcens [5-8].

Many researchers have investigated the behavior of the bond between the reinforcing bar and the concrete and the following procedures summarized mechanisms of the bonding [9-12].

a) When a deformed bar moves with respect to the surrounding concrete, surface adhesion is lost, while bearing force on the ribs and friction forces and barrel of the bar are mobilized.

b) The compressive bearing forces on the ribs increase the value of the friction forces. As slip increases, friction on the barrel of the reinforcing bar is reduced, leaving the forces at the contact faces between the ribs and the surrounding concrete as the principal mechanism of force transfer.

c) The forces on the bar surface are balanced by compressive and shear stresses on the concrete contact surfaces, which are resolved into tensile stresses that can result in cracking in planes that are both perpendicular and parallel to the reinforcement.

Many factors affect the bond between the reinforcing bars and concrete. The major factors are studied by many researchers over the years [13-16]. These factors can be distinguished under the following three categories: structural characteristics/reinforcement detailing, bar properties, and concrete properties. The structural characteristics addressed include concrete cover and bar spacing, the bond length of the bar (development length), and the degree of transverse reinforcement, while the bar properties covered include bar size and geometry, steel stress and yield strength, and bar surface condition. The concrete properties include compressive strength, and aggregate type and quantity. It was found that the accuracy of such normalization is adequate up to compressive strength of 55MPa then decrease as the compressive strength increases. The bearing action between the rib of the reinforcing steel and the high strength concrete is

different than with normal strength concrete; as the bearing capacity increases more rapidly than the tensile strength preventing the crushing of the concrete in front of the ribs and thus reducing slip, this reduced slip results in fewer ribs transferring the load which increases the local tensile stresses and initiates the splitting failure in the concrete before achieving a uniform stress distribution along the splice or development length.

The bond strength of deformed bars is improved significantly. Many researches have been conducted to give the best expression of the bond strength of this type of reinforcing bars [17-19]. The force transfer in this case is governed by bearing of ribs against the concrete keys after breakage of adhesive elastic bond. These keys transfer the bearing forces to concrete up to a certain magnitude before crushing/shearing of concrete. These bearing forces are inclined to the bar axis, and decomposing these into parallel and normal components to the bar axis and summing the parallel ones will yield the bond force. The normal (radial) compressive components cause radial (splitting) cracks if the circumferential tensile stresses violate the concrete tensile strength. Formation of the first splitting crack marks the end of the second stage, and during the third stage bond is assured by the limited wedging action of the ribs on concrete.

In the last 15 years, the interest of bond strength between concrete and deformed bars for both normal strength and high strength concrete grows rapidly from many researchers. With the rapid development in the industry, synthetic fibers, i.e. metallic and non-metallic, are widely produced with various shapes and dimensions and added to concrete to enhance its properties and performance. These natural products fibers have the advantage of low environmental impact and low manufacturing costs [20-22]. In 2019, S.H. Chu *et al.* [23], and R. Hameed *et al.* [24], studied the effects of adding steel fibers on bond properties have been studied by conducting pull out tests of rebars embedded in steel fibers concrete. They are concluded to the addition of steel fibers could increase the bond strength by up to 62%. Such increase in bond strength may be attributed to: first, before cracking, the fibers provide confining stresses to arrest the initiation of splitting cracks inside the concrete and second, after cracking, the fibers control the splitting cracks through crack bridging and grip the rebar to restrain slipping.

Other researches efforts have been made to examine the bond performance of reinforcement bars embedded in hybrid fibers concrete. Almatrudi *et al.* [25], Ganesan *et al.* [26] and J. Lu *et al.* [27] investigated the effect of hybrid fiber (i.e. steel and polypropylene fibers) on high performance concrete by varying the volume fractions of the hybrid fibers, diameters and embedded length of rebars in concrete. The results showed the combination of a 1% volume fraction of steel fiber with 0.1% volume fraction of polypropylene fibers significantly improve the bond stress for 12mm, 16mm, and 20 mm diameter rebars by about 50%, 46% and 33%, respectively.

In this paper, an experimental investigation on the behavior of interaction effect between two-bars on the bond between reinforcing bars and fiber reinforced concrete (FRC). The variables considered are the variation in bar diameter, the effect of development depth (Ld) and impact of the distance between steel bars on bonding between steel bars and fiber reinforced concrete (FRC).

2. EXPERIMENTAL PROGRAM

In the present study, this program included eighteen cylindrical specimens divided into three parameters: the first parameter was used to investigate the effect of change in bar diameters, where the embedded reinforcing bars in the concrete specimens are of three sizes: 8mm, 10mm, and 12mm grade 420 deformed bars (high tensile steel), respectively as seen in Figure-1, while the second parameter studied the effect of embedded of two-bars length (L_d) on the bonding between reinforcing bars and FRC are investigated. Embedded length (L_d) are used in this study were 5d,10d, and 15d, respectively for all diameters used in the first parameter, as shown in Figure-2. However, impact of the spacing between two-steel bars on the bonding behavior between FRC and steel was studied in last parameter. The spacing between two-bars used for this parameter were 25mm and 50mm, respectively. Figure-3 demonstrates the variation of spacing between two-bars. Figure-4 summarizes the different groups used in the present investigation.

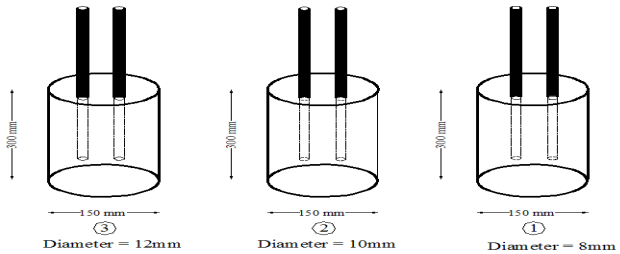

Figure-1. Diameters used in the first parameter.

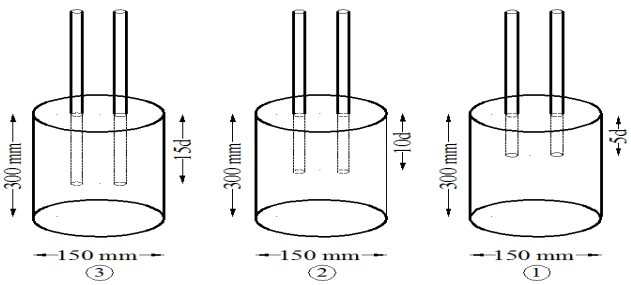

Figure-2. Embedded length (L_d) used in the Second parameter.

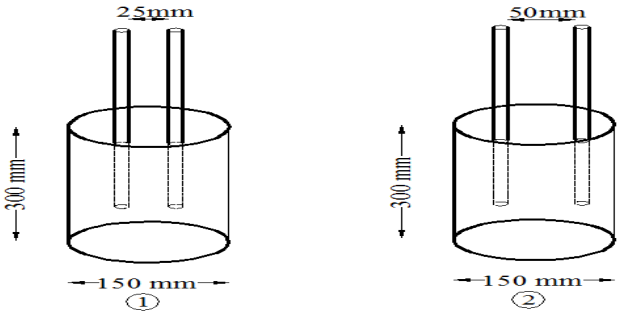

Figure-3. Spacing between two-bars used in the third parameter.

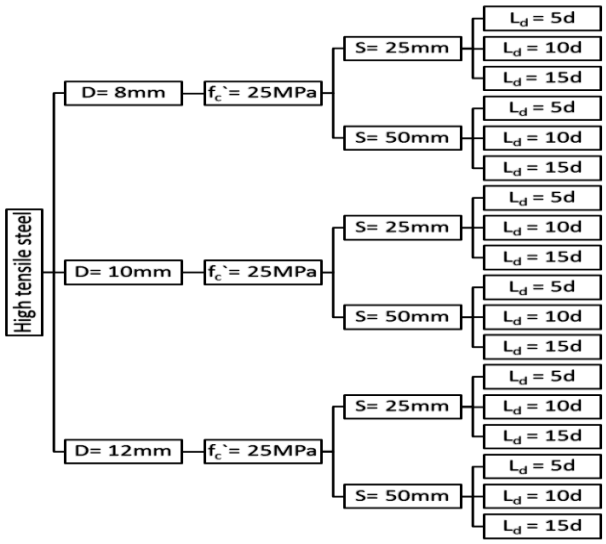

Figure-4. Flow chart of overall work.

2.1 Constituent Materials

The mix proportions of concrete used for all specimens were designed according to the Saudi Building Code. The concrete mix was designed to obtain target strength of 25MPa at 28 days for all cylindrical specimens. The concrete materials used in casting the specimens consisted of Ordinary Portland cement (Type I) from Qassim Cement factory (QCC) which coincided with the requirements of the Saudi standard specifications. Local crushed stone (coarse aggregate) and fine aggregate (sand) from Qassim region in Saudi Arabia are used in this investigation. The water used in all mixes was clean drinking fresh water free from impurities. The trail of mixes was carried out until the required workability was achieved and this was accomplished by water/cement ratio = 0.50. Steel fibers were added to the concrete to improve the concrete's mechanical properties. These fibers were hooked end round steel fibers comply with the limits of ASTM A820. The shape of these fibers are shown in Figure-5 and the dimensions and the tensile strength of the fibers are listed in Table-1.

All tested specimens were casted from concrete mixtures that contained a similar proportion of the following basic materials: 350kg/m3 of cement, 750kg/m3 of sand, 1090kg/m3 of coarse aggregate, 175kg/m3 of water, and 0.5% steel fiber ratio. To determine the compressive strength of concrete after 7 and 28days from casting, 18 standard cylindrical tests 150mm diameter and 300mm height had been made; 9 concrete cylinders were tested after 7days while the remaining concrete cylinders were tested after 28days. The cylinders were filled with concrete in three layers while tamping each layer with a steel rod for 25times according to the Saudi Building Code was done. After testing of cylinders, the mean of compressive strength was 22.43MPa at 7days, while at 28days the compressive strength mean value was 28.63MPa.

Figure-5. Hooked end round steel fibers.

Table-1. Properties of steel fibers.

Type of Fiber	Length (mm)	Diameter (mm)	Ultimate Tensile Strength (MPa)
Steel Fibers	35	0.55	134.5

2.2 Specimens Fabrication, Casting and Curing Procedures

In this paper, a total of 18 pull-out cylindrical specimens were made in three main groups. Each group consists of six specimens. The reinforced concrete specimens were casted in standard cylindrical molds of 150mm in diameter and 300mm in height. Two-reinforcing steel bar were partially embedded along the longitudinal axis in the center of the cylinder, using a steel base made in a U-shape and fixed on cylinder sides by two nails. The reinforcing bars passed through the middle of the base to maintain an embedded length and same concrete cover from all sides while concrete casting, as illustrated in Figure-6. The reinforcing bars had extensions outside the concrete cylinders of 250mm to allow for the testing machine's gripping of the bars.

Figure-6. The molds used for casting in experimental specimens.

Before casting the concrete in the molds of pull out test, the internal surfaces of these molds were oiled. Two-reinforcing bars were positioned vertical in the molds, lying in the middle of cylindrical specimens and the development lengths were varied according to the type of the parameter. Fresh concrete was placed in three layers into the mold and each layer was vibrated by vibrators, with special consideration in order not to disturb the verticality of the bars. Each layer was compacted by 25blows using the standard compacting rod and later the concrete surface was smoothed to eliminate voids and minimize geometric irregularities. After molding, specimens were transferred to the curing room for 24hrs. Thereafter, the concrete cylinders were demolded, marked and transferred again in the curing room with a temperature of 20±2^{oC} and a humidity of about 95% and the concrete specimens were cured in a water tank for 28 days as shown in Figure-7.

Figure-7. Curing process for pull-out and compressive strength tests.

2.3 Experimental Set-Up and Testing Procedures

A universal testing machine (UTM) with 100kN capacity was used to conduct pull-out tests and assess the bond-slip behavior of 18 specimens. During testing, the cylindrical specimen was enclosed by a custom-made rigid loading base securely fixed to the testing machine's bottom plate, as seen in Figure-8. To avoid concrete of cylinder damage, the setup consisted of two thick steel plates (250mm Length, 250mm width and 20mm thickness). The bottom plate was fixed to the UTM by welding the big pin, and the top plate has a hole in the central zone to allow the passing of deformed reinforcing bars and the connection with the bottom plate via four steel nails 20mm diameter, as illustrated in Figure-9. The loading base was used to fix the specimen to the bottom plate and only apply it on the bar. To confirm the bonding between two-embedded bars in the concrete, a strong weld was made between the two-bars and another bar from the same diameter. The welded bar was the attached in the upper grip of the machine. The pull-out test was performed by monotonically applying a tensile load at the extended side (top) of the reinforcing bar away from the specimen at a slow loading rate to ensure a quasi-static behavior. The pull-out load and total displacement (i.e., slip measurements and axial deformations of the bar) were recorded automatically by the testing machine.

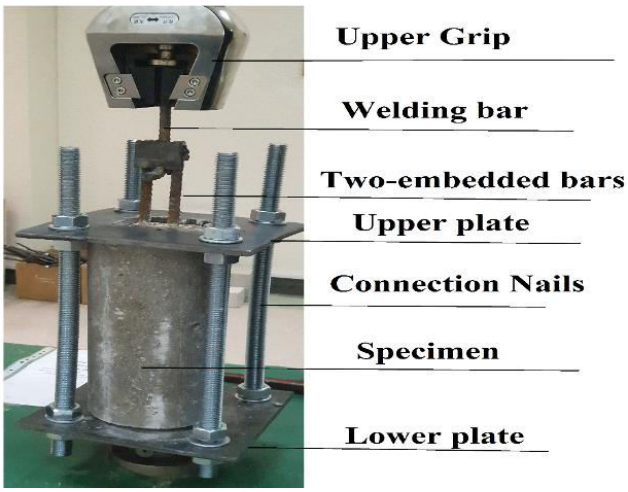

Figure-8. Test setup.

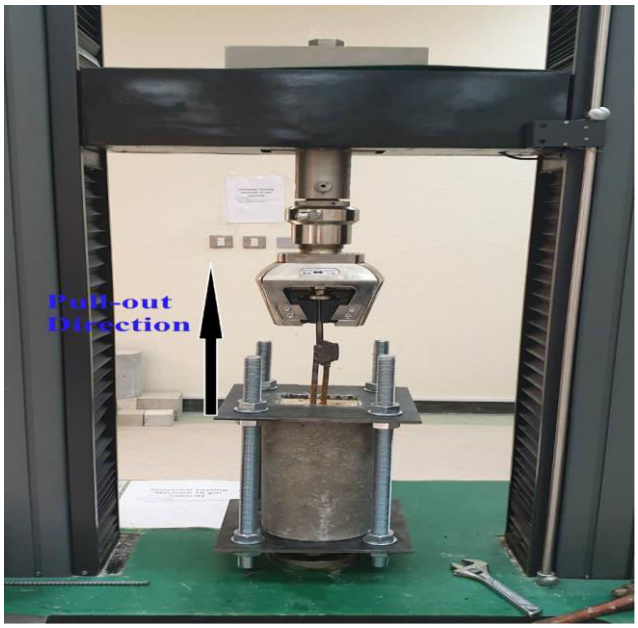

Figure-9. Pull-out test setup on cylindrical concrete specimen with embedded rebar.

3. PULL-OUT TEST

The pull-out test for 18 concrete cylinders specimens with 150mm diameter and 300mm height was carried out for three bars diameters, first diameter was 8mm and the others two were 10mm and 12mm, all experimental tests were performed after 28 days of curing. The maximum load was noted and also the mode of failure. Bond stress is calculated as average stress between two-bars and the surrounding concrete along the embedded length of two-bars. In general, the bond stress corresponding to the maximum pull out load can be regarded as the bond strength or the ultimate bond. The bond stress was calculated as following:

$$\tau_{av} = F / (2 \pi d L_d), \quad (1)$$

Where τ_{av} is the bond stress, F = Maximum Pull-out load of two-bars, d = Diameter of the bar, L_d = Embedded of two-bars length

In order to test the viability of the above formulas and their applicability for FRC and high grade steel, pullout test specimens were produced to determine the bond between FRC and two-high grade steel bar. For each specimen pull-out load, bond stress, slippage value, toughness and mode of failure were recorded in Table-2.

Table-2. The experimental test results.

Diameter	Specimen Notation	Spacing (mm)	L_d (mm)	Max. Pull-out load (kN)	Bond Stress (MPa)	Slippage at Max. load (mm)	Toughness (kN.mm)	Mode of failure
8mm	A1	25	5d = 40	9.02	4.48	9.28	54.29	PO
	A2	25	10d = 80	18.65	4.63	10.64	114.74	PO
	A3	25	15d = 120	30.02	4.97	13.43	219.25	PO
10mm	B1	25	5d = 50	15.12	4.81	9.55	75.98	PO
	B2	25	10d = 100	31.46	5.00	11.36	178.19	PO
	B3	25	15d = 150	48.19	5.11	14.04	352.65	SP
12mm	C1	25	5d = 60	23.73	5.24	10.30	69.51	PO
	C2	25	10d = 120	56.82	6.28	13.32	402.19	SP
	C3	25	15d = 180	90.05	6.63	14.39	672.43	SP
8mm	D1	50	5d = 40	8.43	4.19	7.37	31.55	PO
	D2	50	10d = 80	17.69	4.39	8.49	71.94	PO
	D3	50	15d = 120	27.55	4.56	8.15	103.87	PO
10mm	H1	50	5d = 50	14.31	4.55	7.92	65.66	PO
	H2	50	10d = 100	30.15	4.8	9.01	132.34	PO
	H3	50	15d = 150	46.98	4.98	11.18	232.37	SP
12mm	L1	50	5d = 60	21.49	4.75	9.65	83.39	PO
	L2	50	10d = 120	53.37	5.90	9.51	213.39	SP
	L3	50	15d = 180	85.69	6.31	12.54	584.03	SP

Note: **PO**: Pull out failure, **SP:** Splitting failure

4. RESULTS AND DISCUSSIONS

4.1 Bond Load-Slip Behavior for Specimens Having a Spacing Between Two Bars 25 mm

Tensile pullout bond test was carried out using cylindrical specimens with two bars embedded in fiber reinforced concrete. Embedded length is a significant factor influencing bond load and slip relationship. Bond stress distribution depends upon the development length and size of diameter. Figures 10 to 12 show tensile pullout bond load-slip relationships for deferent development lengths with spacing between the reinforcing bars 25mm for diameters 8mm, 10mm and 12mm, respectively. From these figures, it is shown that as the slip increases the bond load increases in almost a constant rate till a certain point after which the slope of the curve changes until it reaches the ultimate strength then the curve goes down. Two development lengths showed consistent trends of behavior. Furthermore, it was obvious that the behavior of different diameters of 8mm, 10mm and 12mm was close for the embedded lengths 10d and 15d, while the behavior of these diameters at embedded length 5d differs from the other two embedded lengths. Also, it was found that the two-bars diameter size were directly proportional to maximum tensile pullout bond load where with increase the embedded length and the bond load for cylinders with

rebar of diameter 12mm was higher than the bond load of cylinders with rebar of diameter 10mm and 8mm. as shown in Figure-13.

In this experimentation, the embedded length was changed from 5d to 10d and from 10d to 15d for fiber reinforced concrete (FRC). For diameter 8mm, the results of the experimentation showed that by increasing the development length from 5d to 10d, bond strength increased by 3.24% and in case of increasing the development length from 10d to 15d, bond strength increased by 7.33%. When the embedded length was increased from 5d to 10d and from 10d to 15d for diameter 10mm, the bond stress increased by about 3.80% and 2.2%, respectively, while in case of diameter 12mm, the bond stress was increased 16.56% and 5.57% for increasing embedded length from 5d to 10d and from 10d to 15d, respectively as seen in Figure-14.

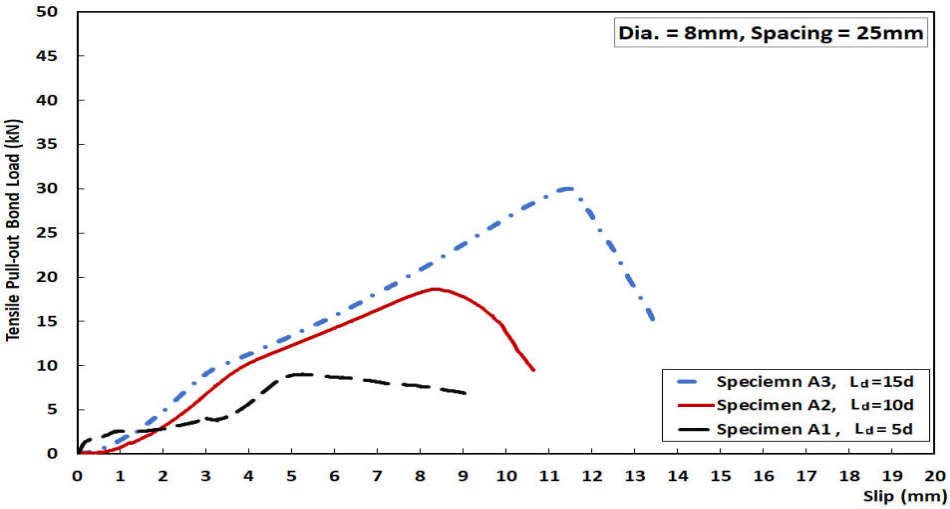

Figure-10. Bond load vs. slip curves for deferent development lengths with diameter 8mm.

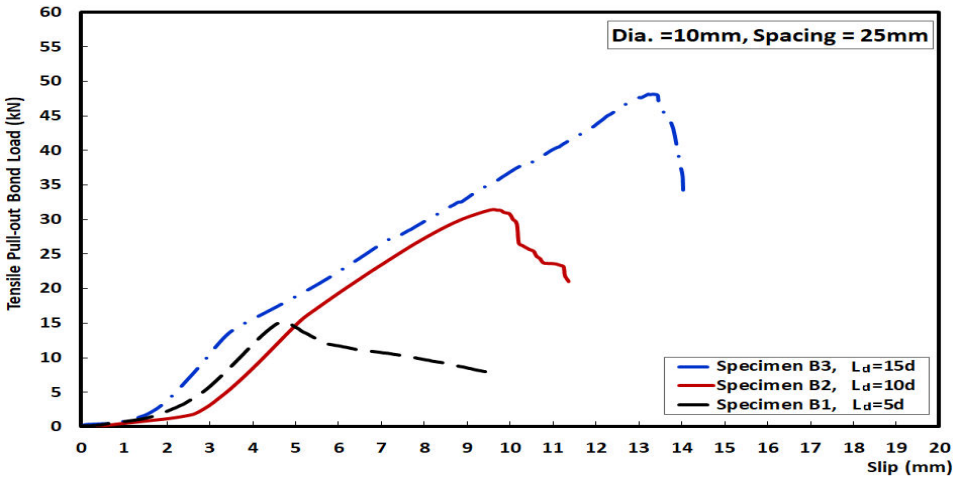

Figure-11. Bond load-slip relationships for deferent development lengths with diameter 10mm.

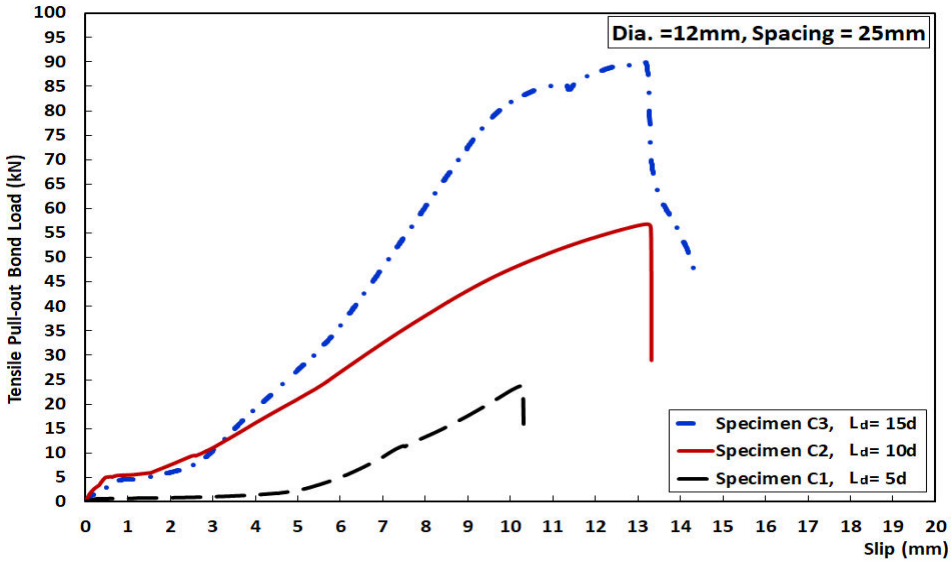

Figure-12. Bond load-slip relationships for deferent development lengths with diameter 12mm.

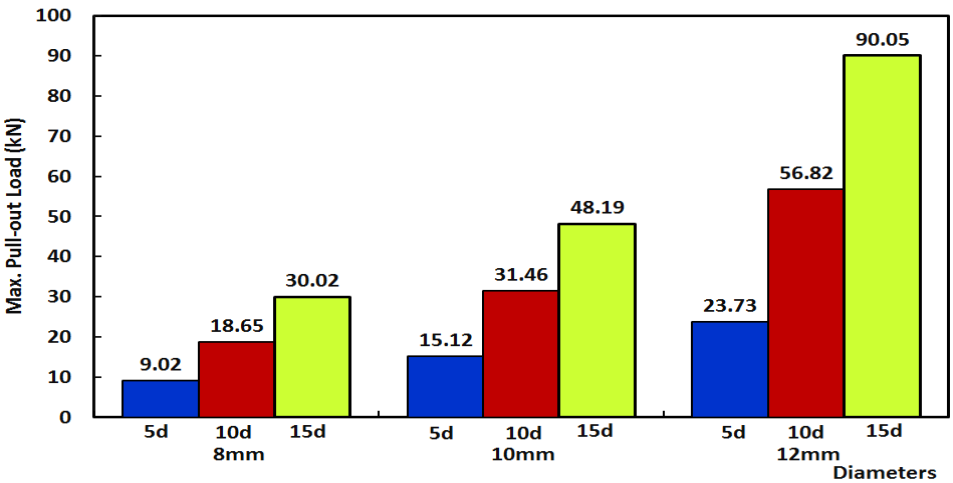

Figure-13. Effect of embedded length on ultimate tensile bond load.

Generally, toughness is an important index of the performance of the specimens under pull-out loading. Toughness of the system can be defined as the maximum energy that can be sustained by the system up to failure. It can be used as an indicator for the ductility where higher toughness means higher dissipation of energy and indicate increased bond strength and deformability, until the failure occurred leading to higher ductility. Consequently, it is of interest to evaluate the toughness values for the tested specimens. Toughness can be simply obtained by numerically integrating the area under the bond load-slip curve. Figure-14 illustrates comparison among all specimens having a spacing between two bars 25mm from the normalize toughness viewpoint.

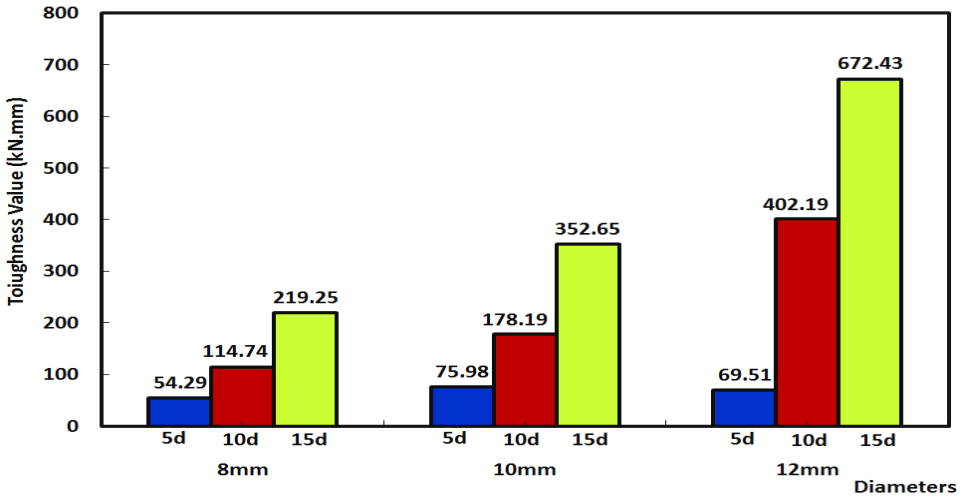

Figure-14. Effect of embedded length on toughness values.

From the previous comparison; it was clear that the toughness values are increased with the increase of the embedded length. For the specimens tested in this study, in case of the increase in embedded length from 5d to 10d and from 10d to 15d, the increase in toughness ranges from 52 to 91%, respectively for diameter 8mm. however, in case of 10mm diameter the value of toughness increased from 57% to 98% for the embedded length was changed from 5d to 10d and from 10d to 15d, respectively. For the last diameter, when the embedded length was varied from 10d to 15d and from 5d to 10d, value of toughness increased from 67% to 470%, respectively. Furthermore, it can be concluded from the results of the experimentation showed that by increasing the embedded length increases the toughness values for the same diameter. This may be due to more number of concrete keys resisting the slip and bond strength increased.

4.2 Bond Failure Mode for Specimens Having a Spacing Between Two Bars 25mm

There were mainly two types of failure modes for experimental specimens: pull-out failure and splitting pull-out failure of the reinforcing bar. It was clear that the type of failure changed when the embedded length increased and bar diameter increased where pull-out failure was for all embedded lengths for diameter 8mm, 5d and 10d embedded lengths for diameter 10mm and 5d for diameter 12 mm, while splitting pull-out failure was for embedded length 15d for diameter 10 mm and embedded lengths 10d and 15d for diameter 12 mm.

Pull-out failure refers to the mode of failure which the reinforcing bar was pulled out of fiber reinforced concrete (FRC) materials due to the concrete teeth between the ribs of high grade steel being sheared off. This mode of failure was very common in all experimental specimens with shorter embedded lengths. On the other hand, splitting pull-out failure usually occurred in the pull-out test of high tensile steel bars with longest embedded lengths. The circumferential tension (cracking) of the surrounding fiber reinforced concrete (FRC) would occur under the action of the radial component of the squeeze force of the steel deformed rib on the concrete, and when this force exceeded the tensile strength of concrete, the concrete cover layer would be split and this cracking extended to the outer circumference of the cylinder over the entire of embedded lengths. It is also noted that the mode of failure for this system occurred by pulling the two reinforcing bars simultaneously, due to the close spacing between the two bars. This means that two reinforcing bars had the same behavior in resisting the influential loads during the test. The pictures of typical failure modes were shown in Figures 15 to 17.

L_d= 5d = 40mm L_d= 10d = 80mm L_d= 15d = 120mm

Figure-15. Specimens with diameter 8mm after testing with pull-out failure mode.

L_d= 5d = 50mm L_d= 10d = 100mm L_d= 15d = 150mm

Figure-16. Specimens with diameter 10mm after testing.

L_d= 5d = 60mm L_d= 10d = 120mm L_d= 15d = 180mm

Figure-17. Specimens with diameter 12mm after testing.

4.3 Bond Load-Slip Behavior for Specimens Having a Spacing Between Two Bars 50mm

In the second phase, Figures 18, 20 demonstrate tensile pullout bond load-slip relationships for diameters 8mm, 10mm and 12mm for various embedded lengths with spacing between the reinforcing bars 50mm.

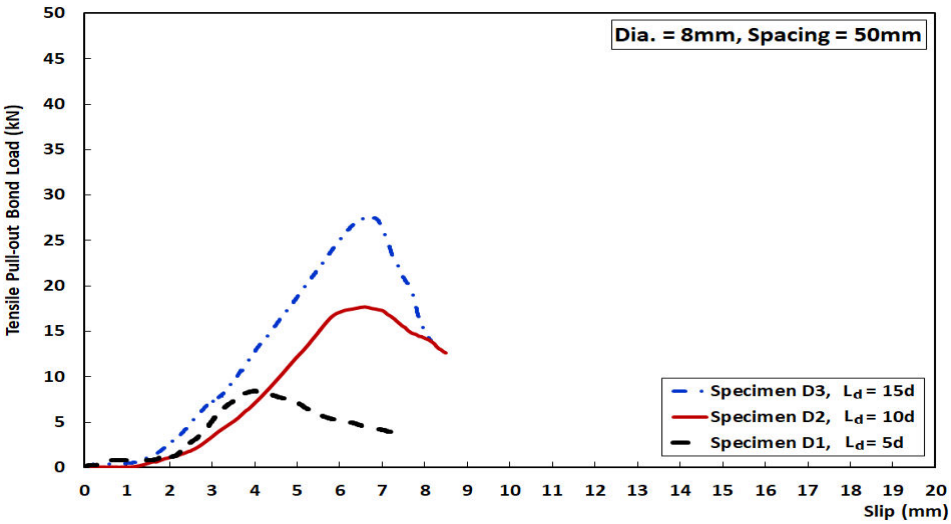

Figure-18. Bond load-slip relationships for deferent development lengths with diameter 8mm.

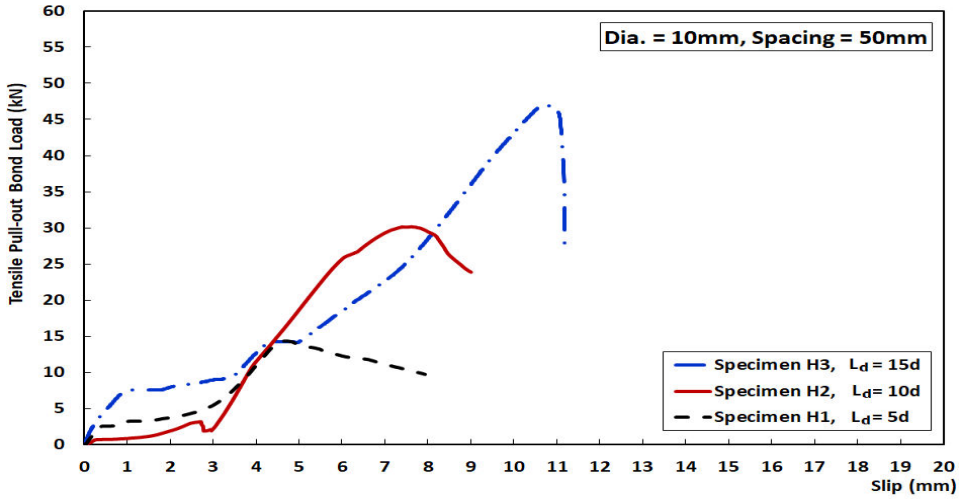

Figure-19. Bond load-slip relationships for deferent development lengths with diameter 10mm.

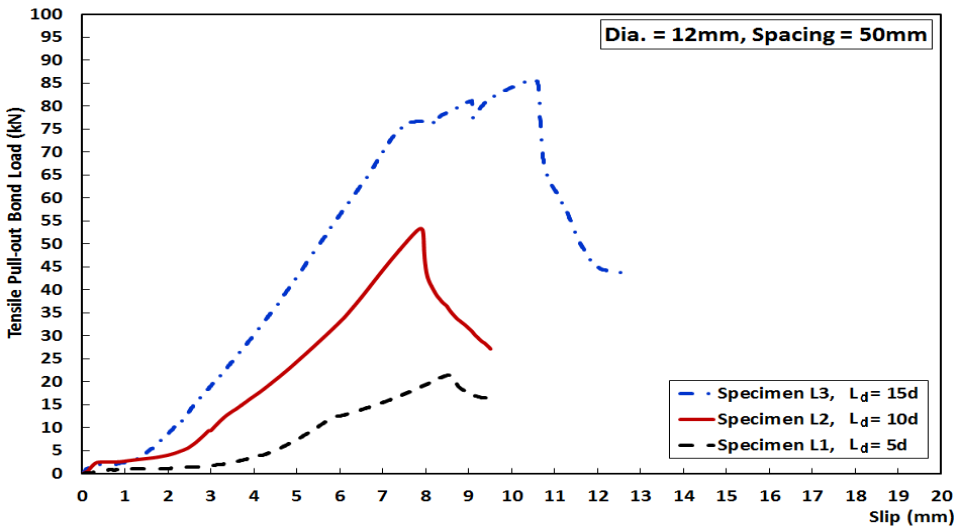

Figure-20. Bond load-slip relationships for deferent development lengths with diameter 12mm.

From the previous comparisons, the bond load-slip relationships can be divided into three stages: micro-slip stage, slip stage and descending stage.

a) **Micro-slip stage:** at the initial stage of loading and in this stage the value of slip was small. The value of bonding load in this stage was increased rapidly.

b) **Slip stage:** With the increase of pull-out bond force, the bond-slip relationship curve gradually deviates from the previous stage. The bond stress is primarily relied on the friction force, mechanical occlusion force and gradually reduced chemical bond force of reinforcing bars and fiber reinforced concrete (FRC). The relation in this stage was the non-linear rising stage. Thereafter, the value of slip increased faster when the bond load reached the ultimate bond load.

c) **Decline stage:** After the bond load reached to the peak value, the bond load did not disappeared completely, but decreased gradually with the increase of slip. In this stage, the mechanical occlusion force decreased, and the friction force weakened gradually due to the ribs of deformed bars, which leads to the rapid increase of slip.

As mentioned previously, as the embedded length increased, the bond load-slip distribution in the bonded section became increasingly non-uniform. The ultimate tensile bond load increased with the increase of embedded length, as shown in Figure-21.

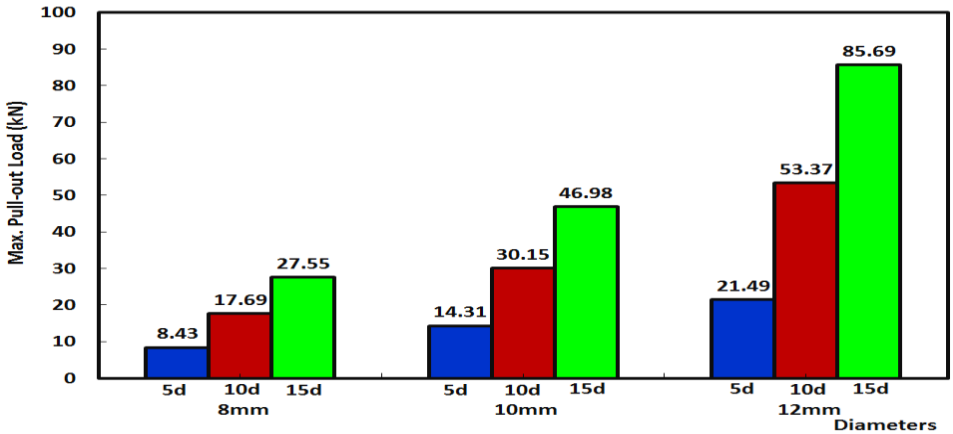

Figure-21. Effect of embedded length on ultimate tensile bond load.

It is seen from Figure-21 that the ultimate tensile bond load between the two- reinforcing bars and fiber reinforced concrete (FRC) increases with the increase of embedded length where in case of 8mm diameter, when increase the embedded length from 5d to 10d and from 10d to 15d, the increase ratio was 52.34% and 55.74%, respectively. For diameters 10mm and 12mm, in case of the changed of embedded length from 5d to 10d and from 10d to 15d, the ultimate tensile bond load was increased 52.53%, 55.82%, 59.73% and 60.55%, respectively. Thus, it is indicated that this increase in ultimate bond load is mainly due to the oblique pressure generated by the extrusion of the two deformed bars and FRC, and the force along the radial component is balanced by the concrete tensile load around the two bars. When the embedded length was large, the radial component force transmission path is increased, and the bonding load is increased.

Figure-22 shows that the relation between the bond stress and embedded length of diameters. From this comparison, it is shown that as the bond stress was directly proportional to the value of embedded length, as the increase in the embedded length increases the value of bonding stress due to the fact that the greater the bond length between two reinforcing bars and FRC concrete, the more serious non-uniformity of the bond stress occurred.

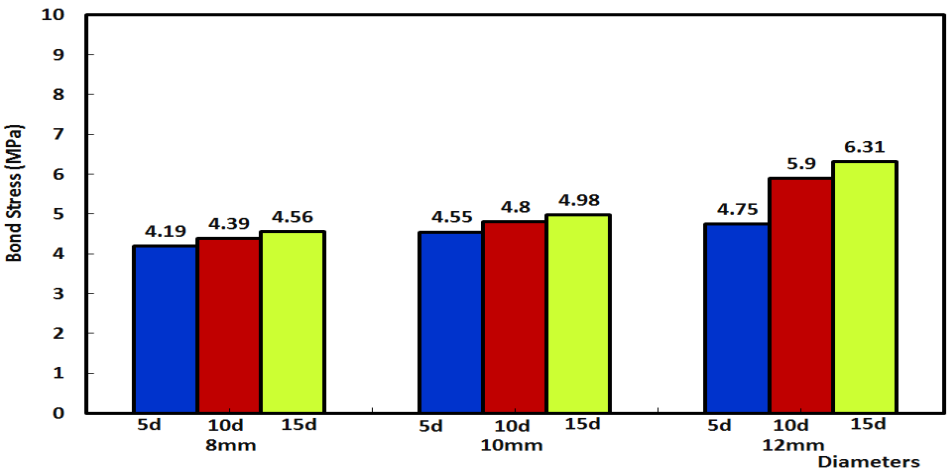

Figure-22. Effect of embedded length on ultimate tensile bond stress.

The bond strength increases obviously with the increase of embedded length. For diameter 8mm, the bond stress were 4.55% and 3.87%, when the increase of embedded length from 5d to 10d and from 10d to 15d, respectively. However, when the embedded length varied from 5d to 10d and from 10d to 15d, the bond stress increased with ratio 5.20% and 3.75%, respectively for diameter 10mm while in case of 12mm diameter, the increase in bond stress were 19.49% and 6.95% for the increase in the embedded length from 5d to 10d and from 10d to 15d, respectively.

It is worth to note that the area under the load-slip relationship up to failure is called toughness. Toughness is the ability of this system to withstand or absorb mechanical energy. Figure-23 represents relationship between toughness value and embedded lengths for all specimens having a spacing between two bars 50mm.

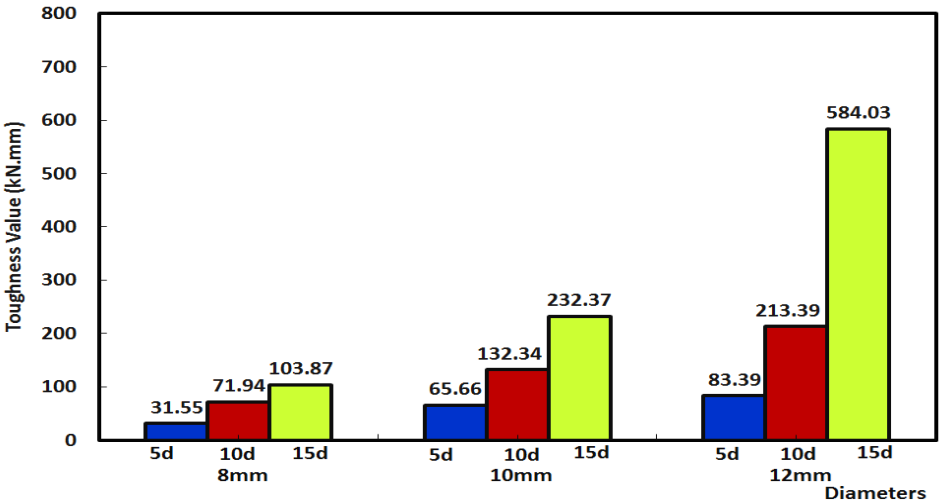

Figure-23. Effect of embedded length on toughness values.

From the previous toughness results, with increase in embedded lengths for diameters 8mm, 10mm and 12mm, the value of toughness increased. It seems that the increase of the depth of embedded length plays an important role in the resistance of bonding between reinforcing two-bars and FRC concrete. This indicates the significant contribution of the added steel fibers to maintain the tensile cracks in concrete due to the pull-out loading and hence increased the bond strength and toughness values. For diameter 8mm, the increase in the toughness 56.14% and 44.38% for increase embedded length from 5d to 10d and from 10d to 15d, respectively while in case of diameter 10mm, the increase in toughness was 50.38% and 75.58%, respectively for change the embedded length from 5d to 10d and from 10d to 15d and these ratio were 60.92% and 173.60%, respectively for diameter 12mm.

4.4 Bond Failure Mode for Specimens Having a Spacing Between Two Bars 50mm

In this group, cylindrical specimens failed by the following two-modes of failure, pull-out failure (PO) and splitting failure (SP). For two-deformed bars, the pull-out failure was observed in cases of all embedded lengths for diameter 8mm, 5d and 10d embedded lengths for diameter 10mm and 5d for diameter 12mm and was characterized by cracks on the top loaded face of concrete cylinder. For this failure type, it was noticeable during this test of specimens that at the beginning of loading, one of the deformed bars slipped before the other where cracks appeared around the other reinforcing bar that did not slip. As the loading rate increased, the other reinforcing slipped, as cracks occurred in FRC around the two reinforcing bars, especially in the region between the two bars. The bars slippage was due to extensive cracks on the surface of fiber reinforced concrete cylindrical specimens indicate that the bond loss failure mode is occurred.

For the remaining specimens from this group; splitting failure mode was the predominant type of failure of the remaining tested specimens. At the starting of the slip, one of the reinforcing bar was behaved without the other and with an increase in the tensile pull load rate, two reinforcing bars were behaved together. It was characterized by splitting of the fiber reinforced concrete specimen in a brittle mode of failure. Both transverse and longitudinal cracks were observed at failure where crush of the fiber reinforced concrete surrounding to deformed bars. These cracks were extended on the entire surface of FRC cylinder and also appeared on the outer perimeter along the entire embedded lengths. Modes of failure of for specimens having a spacing between two bars 50mm were seen in Figures 24 to 26.

L_d= 5d = 40mm L_d= 10d = 80mm L_d= 15d = 120mm

Figure-24. Specimens with diameter 8mm after testing with pull-out failure mode.

L_d= 5d = 50mm L_d= 10d = 100mm L_d= 15d = 150mm

Figure-25. Specimens with diameter 10mm after testing.

L_d= 5d = 60mm L_d= 10d = 120mm L_d= 15d = 180mm

Figure-26. Specimens with diameter 12mm after testing.

5. CONCLUSIONS

The following conclusions have been extracted from the experimental test results:

a) The bond stress and the value of slip for the specimens that have spacing between two reinforcing bars 25mm were higher than the specimens that have spacing between two reinforcing bars 50mm.

b) With the increase in the depth of embedded length, the ultimate load and the value of slip increased.

c) The use of biggest bar diameter with the same embedded length increase both bond strength and toughness values.

d) By increasing the embedded length increases the toughness values for the same diameter.

e) Pull-out failure was very common in all experimental specimens with shorter embedded lengths while splitting pull-out failure usually occurred in the pull-out test of high tensile steel bars with longest embedded lengths.

f) Mode of failure in case of specimens having a spacing between two-bars =25mm occurred by pulling the two-reinforcing bars simultaneously while for Specimens having a spacing between two bars =50mm, at the beginning of loading, one of the deformed bars slipped before the other and with the loading rate increased, the other reinforcing slipped. The bars slippage were due to extensive cracks on the surface of fiber reinforced concrete cylindrical specimens indicate that the bond loss failure mode is occurred.

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