Influence of Steel Fibers on the Reinforcement Bond of Straight Steel Bars of High Strength Concrete

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***Abstract*— The present experimental study are carried out to have a clear understanding of the bond strength between high strength steel fiber concrete HSSFC with three selected shapes of fibers, which were straight steel fiber SS , hooked end steel fiber HS and waved steel fiber WS and steel reinforcing bars. Six groups which consisted from thirty-three pullout cubic specimens of size 100 mm were fabricated to study the effect of some selected parameters such as, shapes of fiber SS ,HS and WS, reinforcing bar diameter 10 mm ,12 mm and 16 mm , volume fraction of steel fibers Vf 0% , 1% and 2% and aspect ratio of steel fibers l/d 30 , 65 and 90. In addition, twenty seven cubes having the same size of the pullout specimens with average three concrete cubes from each concrete mix (nine mixing) were tested in compression to find their compressive strength. It was found that the addition of HS fiber has much effect in enhancing bond strength than that enhancement accrued by addition of SS or WS fibers, On the other hand, the bond strength increases as bar diameter decreases. The addition of steel fibers to concrete strengthens the bond between the reinforcing bar and the concrete.**

Keywords-component; High strength; steel fiber; bond strength.

I. INTRODUCTION

The concept of using fibers to improve the mechanical properties of concrete is known for many decades. It has been increasingly used in structural engineering applications. Adding fibers enhances the compressive, tensile and shear strengths, flexural toughness, durability and resistance to impact. The mechanical properties of fiber reinforced concrete depend on the type and the content of the added fibers [1].

Research and design of steel fiber reinforced concrete (SFRC) began to increase about 40 years ago. Various types of steel fibers have been developed. They differ in size; shape and surface structure (Fig. 1). These fibers have different mechanical properties such as tensile strength, grade of mechanical anchorage and capability of stress distribution and absorption. Hence, they have different influence on concrete properties [2] bond stress between steel reinforcement and concrete is defined as the unit shearing stress acting parallel to the steel bar axis, thus permitting the transfer of force from the concrete to the reinforcing bar and vice versa. This shear stress (bond stress) modifies the steel stress in the bar, either increasing or decreasing it. It has been customary to define bond stress as shear force per unit area of bar surface, using the nominal surface of the deformed bar (which ignores the extra surface created by the lugs and ribs)[3]. Bond stress could also be measured by the rate of change of the steel stress in the bar. Whether one chooses to think in this term or not, there can be no bond stress unless the bar stresses changes, or there can be no change in bar stress without bond stress [4]. Another definition of the Bond strength is that, it is the resistance to slipping of the steel bar, or separation (splitting) of concrete around the bar, which is embedded in concrete. This property is of a great significance in structural design of concrete members [3]. Moreover, the transfer of stress between concrete and steel has a great influence in limiting the space and the width of cracks [3, 4].

Effective bond strength creates the composite action of steel with concrete. Better performance of reinforced concrete members requires an adequate interaction between the steel bar and the surrounding concrete. This performance occurs only if an adequate bond is provided between the two materials. Resistance against slipping or Pull- out of the reinforcing bar depends upon the shape of its surface and is provided by the three components [4], 1-Chemical adhesion between the steel and surrounding concrete. 2- Friction resistance. 3- Bearing of lugs against the concrete (mechanical interlock).

The main methods of tests bond between steel and concrete are the pull-out test and beam test. The advantages of pull-out test are the easy setup and specimens simplicity, and the additional confinement provided by the compression induced into the specimen around the anchorage area [5].

The concept of using fibers to improve the characteristics construction materials is very old. Early applications include addition of straw to mud bricks, horsehair to reinforce plaster and asbestos to reinforce pottery. It has been known that concrete is weak in tension and has a brittle character. So, Concrete was reinforced with continuous reinforcement to increases its strength and ductility but that requires careful placement and labor skill. The introduction of fibers in discrete form in plain or reinforced concrete increases the strength and ductility[6]. Since it makes the concrete to be more homogeneous and isotropic so, when concrete cracks, the randomly oriented fibers start functioning, arrest crack formation and propagation. So, the use of fiber represents a better alternative to the continuous reinforcement. The failure modes of FRC are either bond failure between fiber and matrix or material failure.

II. Experimental Program

The experimental program included casting and testing sixty-three HSSFRC cubs. 33 pullout cubic specimens having size of 100 mm and 30 cubic control specimens having the same size of pullout one . An embedment or bonded length Lb of three times the bar diameter db (Lb=3db) was bounded by two unbounded.

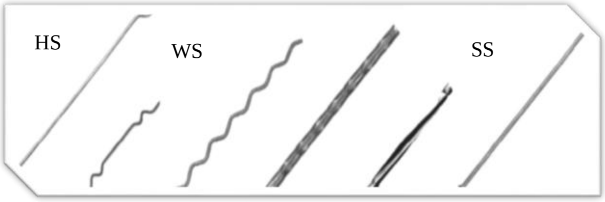

Figure 1 Different types of steel fibers

Zones (Lu), where Lu= ((L-Lb)/2) as shown in figure 2. The unbounded zones were performed by covering the reinforcing bar at these regions with a plastic tube and layer of an adhesive tape. All specimens are fabricated without using lateral reinforcing bar. The steel bars were screwed from the loaded end. At a distance 100mm from the bottom end of the bar, the bar was covered in this zone with adequate number of layers of an adhesive tape, so that the bar could stand vertical at the center of the cube. The upper screwed part of the bar is fabricated to fit the testing requirements. Plate 1 shows the reinforcing bar details

The main variables studied in the experimental program were

- ❖ Volume fraction of steel fibers(Vf)
- ❖ Aspect ratio of steel fiber (l/d)
- ❖ Dimension of steel reinforcement (db)
- ❖ Shapes of steel fiber (HS ,SS ,WS)

The pulls out specimens are divided into five groups. Each group consists of nine different specimens. Table 1 gives the details of these specimens. The notations used are as follows:

The specimen HS-1-10-65, the letters HS represents a shape of steel fiber, 1% steel fiber, bar diameter of (10 mm) and aspect ratio of 65.

III. Materials and Mix Design

The cement used in this research was Tasloja ordinary Portland cement (ASTM Type I) manufactured in Iraq. Densified silica fume from Sika Materials Company in Baghdad has been used as a mineral admixture added to the mixtures. The used percentage is 10% of cement weight (as an addition, not as replacement of cement) for HSSFRC.

Fine silica sand known as glass sand is used for the HSSFRC mix. This type of sand is by- produced in Al- Ramadi Glass factory. The fineness modulus is 2.32. Al-Ukhaidher fine sand grading and limits of ASTM C33[7] . The three types of steel fibers manufactured by Bekaert Corporation were used in SFRC (Plate2) mix with volume fraction (Vf) of 0%, 1% and 2%. The fibers have the properties described in Table 2.

The superplasticizer used in the mix was Flocrete PC 260[8], which is a polycarboxylic ether based superplasticizer. The mix design of HSSFRC using local constituent is 1:1: 0.1 (cement: sand: silica fume) with water cement ratio 0.2 plus 2.0% by weight of binder (Cement + Silica Fume) of Flocrete PC 260 admixture. In this study, deformed steel bars of (10, 12 and 16) are used, Table 3 shows the full properties of these reinforcing bars

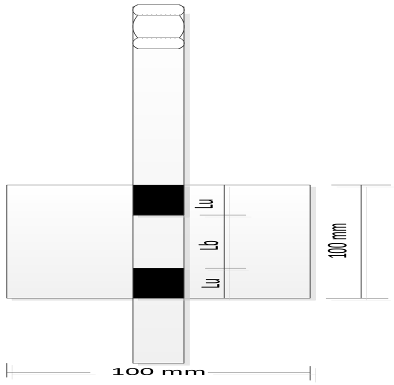

Figure 2 Testing specimen details.

Plate 1 Reinforcing bar details.

Table 1 Pull Out Test Specimens Details.

Group	Sample Designation	Shapes of steel fiber	Bar Diameter mm	Vf %	Aspect ratio l/d
(A)	HS-0-10-0	-	10	0	0
	HS-1-10-30	HS	10	1	30
	HS-2-10-30	HS	10	2	30
(B)	HS-0-10-0	-	10	0	0
	HS-1-10-65	HS	10	1	65
	HS-2-10-65	HS	10	2	65
(c)	HS-0-10-0	-	10	0	0
	HS-1-10-90	HS	10	1	90
	HS-2-10-90	HS	10	2	90
(D)	HS-1-10-65	HS	10	1	65
	HS-1-12-65	HS	12	1	65
	HS-1-16-65	HS	16	1	65
(E)	HS-1-10-65	HS	10	1	65
	SS -1-10-65	SS	10	1	65
	WS-1-10-65	WS	10	1	65

Table 2 Properties of the Steel Fibers

description	Length mm	Diameter mm	Density Kg/m3	Tensile strength MPa	Aspect Ratio
Straight fiber	13	0.20	7800	2600	65
Wavedfiber –MPS50	60	1	7800	1200	65
Hooked fiber	15	0.5	7800	1800	30
	30	0.5	7800	1800	60
	45	0.5	7800	1800	90

IV. Mixing, Curing and Fabrication

All the constituents were batched by an electronic balance and mixed in a horizontal rotary mixer of 0.19 m3 capacities mixer for about 10 minutes. Water and superplasticizer is added to the rotary mixer and the whole mix ingredients were mixed for a sufficient time. For the SFRC mix the fibers were uniformly distributed into the mix slowly in 3 minute during mixing process, and then the mixing process continued for an additional 1 minutes (Plate 3). Three 100 mm * 100 mm cubes were prepared from each batch and used for determining the compressive strength (f'u) of SFRC Steel mold with wood base was used to cast all the pull-out specimens. The mould was coated with oil before putting the reinforcing bar, and casting the concrete.

PLATE 2 TYPES OF STEEL FIBERS USED IN SFRC

TABLE 3 PROPERTIES OF THE STEEL BARS IN TENSION

Nominal diameter mm	Bar Area mm2	Yield Stress MPa	Yield Strain (mm/mm)	Ultimate Stress MPa	Modulus of Elasticity MPa
10	97	611	0.00305	710	200000
12	113.09	638	0.00322	691	198000
16	201	568	0.00269	649	211000

The specimens were heat cured at about 70o C for 48 hours in a water bath. After that, the samples were left to be cooled at room temperature, then placed in water and left until the end of water curing at 28 days.

PLATE 3 CASTING OF PULL- OUT SPECIMENS

V. LOADING SETUP AND MEASUREMENTS PULLOUT TEST

The pull-out specimens were tested by a specially fabricated testing frame (Fig. 3). The frame consisted of a fixed part made from steel sections, which consisted of two standing parts. The upper heads of the standing parts were fastened to a bearing plate by screws and welding. The bearing plate had a central hole which permits the prisms reinforcing bar to pass through. The two standing sections together with the bearing plate formed an inverted U shape, which was fastened to the steel base by the means of screws and welding.

Hydraulic jacks were fastened to the steel base by screw. The upper heads of the hydraulic jacks were also fastened by screw to stiffen the moving section, which had a central hole located exactly on the bearing plate hole. The hydraulic jacks were controlled by a hydraulic machine (plate 4), which enabled the jacks to supply the same loads. With this machine three types of jacks could be used, 1 Ton, 2 Ton and 3 Ton hydraulic jacks. For every type of jacks, there is a loaded gage. The pullout specimens are hold inside the inverted U section. The loaded top end of tested cube is pressed on the inside face of the bearing plate, figure 3. The reinforcing bar passes through the two holes and is screwed at the upper face of the moving head. The slip is measured at the unloaded end by a dial gage with an accuracy of 0.002 mm.

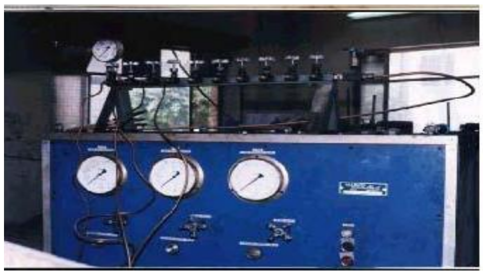

PLATE 4 HYDRAULIC LOADING.

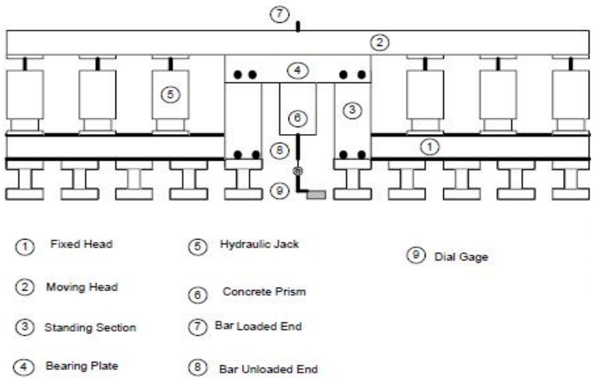

FIG. 3 TESTING FRAME DETAILS MACHINE.

VI. RESULTS AND DISCUSSIONS

A. Compressive Strength of Concrete

The results of this test are shown in Table 4. The test results show, the addition of SS, HS and WS fiber increases the compressive strength of concrete about 29.8% , 20.8% and 12.7% respectively compared with nonfiberous concrete . Also, It is observed that for addition of 1% and 2% Fiber have aspect ratio 90 gives slightly more compressive strength than 65 at same volume fraction. In mixes, have straight steel fiber SS show increases the compressive strength about 7.4% and 15.2% from mixes have HS and WS.

Table 5 shows the results from experimental tests to investigate the pull-out bond strength of steel-fiber reinforced concrete in contrast to the control specimens. By dividing the load needed to induce a precise amount of slip caused by the surface area of the bar in contact with the concrete, a bond force per unit area of rebar surface is attained. From the test results, it can be seen that the failure values of the pull-out bond loads were found to increase with increasing values of steel-fiber volumes (Vf), the aspect ratios of the fibers (L/D) increase as well.

TABLE 4 COMPRESSIVE STRENGTH AT 28 DAYS ACCORDING TO BS 1881 OF INVESTIGATED CONCRETE COMPRESSIVE PULLOUT SPECIMENS

Group	Sample Designation	Shapes of steel fiber	Compressive Strength fus (MPa)	Vf %	Aspect ratio l/d
(A)	HS-0-10-0	-	101.2	0	0
	HS-1-10-30	HS	118.7	1	30
	HS-2-10-30	HS	136	2	30
(B)	HS-0-10-0	-	101.2	0	0
	HS-1-10-65	HS	122.3	1	65
	HS-2-10-65	HS	137.7	2	65
(c)	HS-0-10-0	-	101.2	0	0
	HS-1-10-90	HS	123.3	1	90
	HS-2-10-90	HS	138	2	90
(D)	HS-1-10-65	HS	122.3	1	65
	HS-1-12-65	HS	122.3	1	65
	HS-1-16-65	HS	122.3	1	65
(E)	HS-1-10-65	HS	122.3	1	65
	SS -1-10-65	SS	131.4	1	65
	WS-1-10-65	WS	114.1	1	65

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TABLE 5 TEST RESULT DETAILS

Group	Sample Designation	Shapes of Steel Fiber	Max Slip mm	Failure Force (KN)	Bond Strength (Mpa)	l/d
(A)	HS-0-10-0	-	3.5	65.4	69	0
	HS-1-10-30	HS	6.83	115	122	30
	HS-2-10-30	HS	7.03	127	135	30
(B)	HS-0-10-0	-	3.5	65.4	69	0
	HS-1-10-65	HS	6.92	125	133	65
	HS-2-10-65	HS	7.11	132	140	65
(c)	HS-0-10-0	-	3.5	65.4	69	0
	HS-1-10-90	HS	7.10	133	141	90
	HS-2-10-90	HS	7.41	142	151	90
(D)	HS-1-10-65	HS	6.92	125	133	65
	HS-1-12-65	HS	5.27	95	70	65
	HS-1-16-65	HS	6.26	87	36	65
(E)	HS-1-10-65	HS	6.92	125	133	65
	SS -1-10-65	SS	9.21	125	133	65
	WS-1-10-65	WS	7.25	124	132	65

AS THE VOLUME OF STEEL FIBERS INCREASED, THE failure values of the pullout bond loads were found to increase for the same value of aspect ratio. For an aspect ratio of 30, the increase ranged from 75.8% to 94.2%, for a ratio of 65, it ranged from 91.1% to 101.8% and for a ratio of 90, it ranged from 103.4% and 117.1%. It can clearly be seen from these results that the rate of pullout bond strength is increasing as the aspect ratio increases. In addition, the failure pull-out bond loads were detected to increase for the same volume of steel fibers as the aspect ratio increased. The increase ranged from 8.7% to 15.7% for a steel fiber volume of 1.0% , from 3.9% to 11.8% for a volume of 2% .

Also, It is observed that the bond strength for pull out specimens with bar 10 mm decreased about 47.33% and 72.87% from bar diameters 12 mm and 16 mm respectively. In concrete with fiber, the bond strength increases and the maximum increasing recorded when the ratio of fiber 2%. Specimens with bar 10 mm the bond strength decreases with adding WS, this decrease ranges from about 0.8% for concrete with WS fiber.

The test results which reveal the effect of pre mentioned parameters on the bond-slip response are discussed in this section.

B. *Effect of Volume Fraction (Vf) and aspect ratio (l/d) of Steel Fibers*

The bond- slip response for specimens of groups A, B and C are shown in figures 5 ,6 and7. It was show that as the percentage of fiber content increased from 0.0% to 2.0% the bond stress was increased as well as aspect ratio. For a given stress level, group C specimens have the lowest slip values followed by group B specimens and then group A specimens. Show fig. 8 and Fig.9.

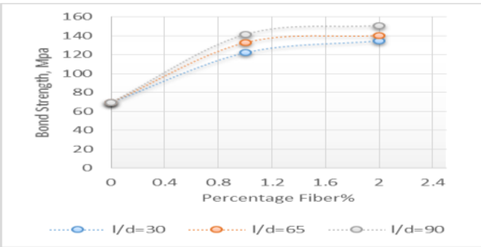

FIG. 4 EFFECT OF FIBER CONTENT ON BOND STRENGTH.

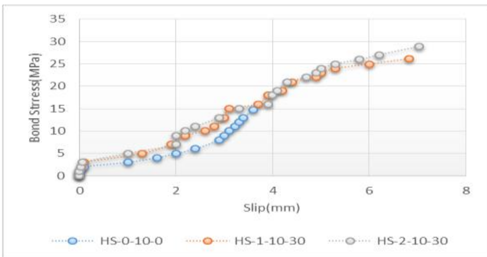

FIG. 5 EFFECT OF FIBER CONTENT VF ON BOND SLIP RESPONSE FOR GROUP A WITH AN ASPECT RATIO (L/D) =30

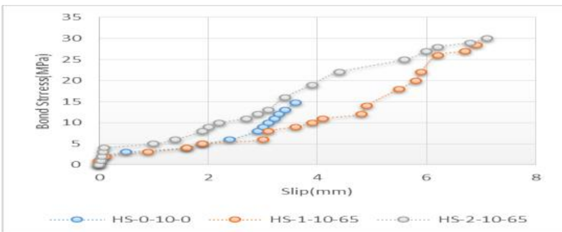

FIG.6 EFFECT OF FIBER CONTENT VF ON BOND SLIP RESPONSE FOR GROUP B WITH AN ASPECT RATIO (L/D) =65

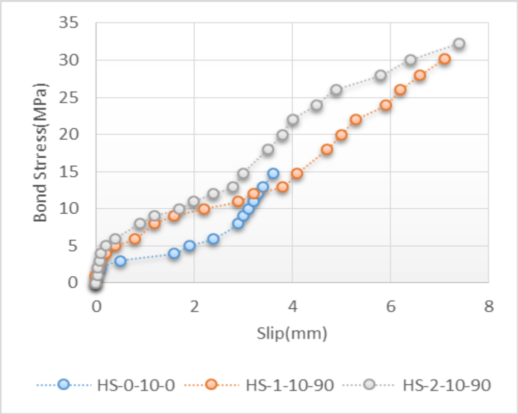

FIG.7 EFFECT OF FIBER CONTENT VF ON BOND SLIP RESPONSE FOR GROUP C WITH AN ASPECT RATIO (L/D) =90

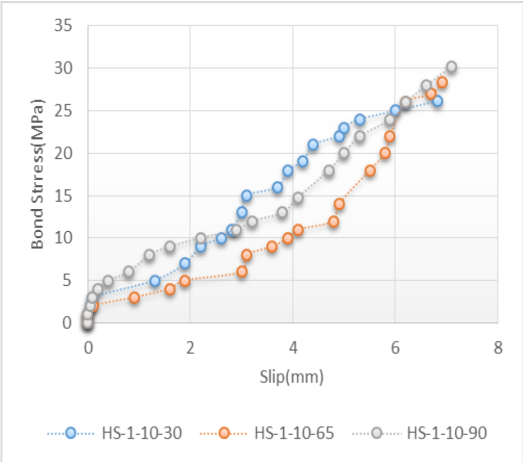

FIG. 8 EFFECT OF AN ASPECT RATIO(L/D) ON BOND SLIP RESPONSE FOR CONCRETE WITH FIBER CONTENT VF =1%

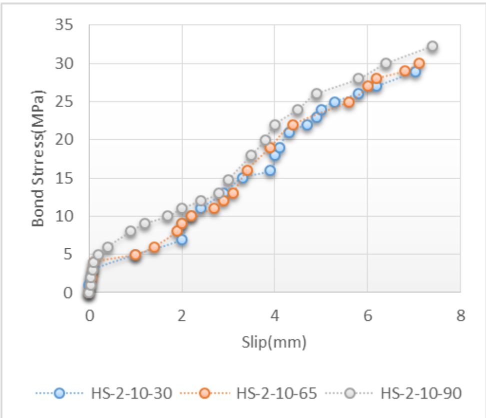

FIG. 9 EFFECT OF AN ASPECT RATIO (L/D) ON BOND SLIP RESPONSE FOR CONCRETE WITH FIBER CONTENT VF =2%

C. *Effects of Fiber Shape*

The effect of fiber shape on the bond behavior is shown in Figure 10. It was observed that hooked fibers HS and wave fibers WS have higher resistance to pullout than straight fibers because of the mechanical contribution. They also observed that the bond strength increases as the strength of the matrix increases.

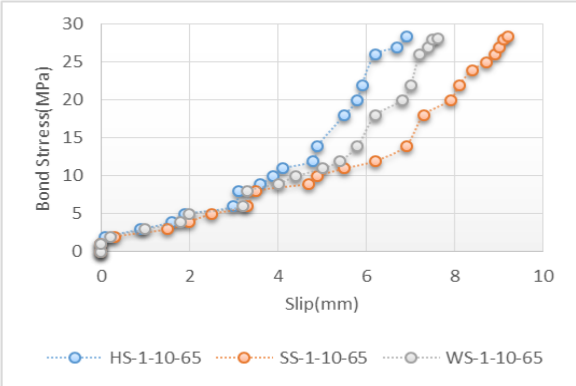

FIG. 10 EFFECTS OF FIBER SHAPES ON BOND SLIP RESPONSE FOR CONCRETE.

D. *Effects of Bar Diameter*

Many investigators [9, 10, 11, 12,13,14,15 and 16], noticed that the bond strength increases with the decrease of bar diameter. The test results of this study confirm this observation. The effect of bar diameter on the bond behavior was investigated in this study by the comparison between three different bar diameter pull out cube series .The bar diameters were 10 mm, 12 mm and 16 mm. Fig.11 show the bond stress-slip curves. It is obvious that the specimens with the smaller bar diameter have greater bond strength than the specimens with larger diameter bars the reason is that the bond stress is composed of two components, at initial stages of loading; the main parts of the bond are generated from the chemical adhesion between the concrete and the steel reinforcement. At this stage, the generation of bond stress is not accompanied by a significant slip between the reinforcing steel and the surrounding concrete. At the increase of the applied tensile force to the reinforcing bar, the second component of the bond will start developing. This part is generated from the mechanical interlock between the ribs of the reinforcing bar and the surrounding concrete. The role of the chemical bond is more pronounced in the small diameter bars and its effect decreases or diminishes as the reinforcing bar diameter increases.

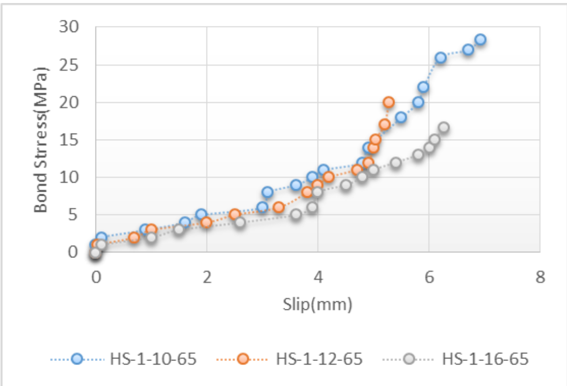

FIG 11 EFFECT OF BAR DIAMETER ON BOND SLIP RESPONSE

VII. CONCLUSIONS

There are some conclusions conducted from the present study as follows:

1. Mechanical properties of concrete such as compressive strength is Found that the addition of SS, HS and WS fiber increases the compressive strength of concrete about 29.8% , 20.8% and 12.7% respectively compared with nonfiberous concrete. Also, found to increase with straight steel fiber content greater than hooked and waved steel fiber.
2. It is noticed that the pull out failure is the predominant type of failure observed in this study.
3. The addition of steel fibers to concrete strengthens the bond between the reinforcing bar and the concrete.
4. Increasing the volume of steel fibers increases the bond strength between the concrete and the reinforcing bar.
5. Increasing the aspect ratio of fibers for a given volume of fibers increases the bond strength of steel-fiber reinforced concrete
6. The pull out specimens with the smaller bar diameter, produce greater bond strength than the greater bar diameter.
7. The ultimate bond strength of steel bar and concrete matrix with hooked steel fibers have higher resistance to pullout than straight fibers SS hooked fibers HS and wave fibers WS have higher resistance to pullout than straight fibers SS.

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