# Effect of Addition Carbon and Glass Fibers on Bond Strength of Steel Reinforcement and Normal Concrete

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## ABSTRACT

The concept of composite materials using fibers as reinforcement is not new. The aim of composing materials is to improve some properties of the original materials. In civil engineering, fiber reinforced concrete was one of the topics of interest. Using fibrous concrete in reinforced concrete structures arises a question of how does it affect the bond strength between the concrete and reinforcing steel bars. Thus, the present experimental study are carried out to have a clear understanding of the bond strength between normal concrete with two selected types of fibers which were carbon and glass fiber and steel reinforcing bars. Forty five pullout cubic specimens of size 150mm were fabricated and tested to serve that purpose. They were divided into five groups to study the effect of some selected parameters such as, type of fiber (carbon and glass),reinforcing bar diameter(12mm,16mm and 20mm)and fiber to cement ratio(f/c) by weight(0.75% and 1% ). Also, three concrete cubes having the same size of the pullout specimens from each concrete mix were tested in compression to find their compressive strength. It was found that the addition of glass fiber with bar diameter=16mm has much effect in enhancing bond strength than that enhancement accrued by addition of carbon fiber, the bond strength increases by about 13.6 % and 4.5 % with the addition of 0.75% and 1% glass fiber. On the other hand, the bond strength increases as bar diameter decreases.The addition of the carbon or glass fibers increases the bond strength for specimens with smaller bar diameter and vice versa and the fiber(either glass or carbon) to cement ratio of 0.75% give higher bond strength than that of 1.0%.

**Keywords:** Bond strength, Carbon fiber, Glass fiber, Pull out test, Pullout Specimens, Slip

# تأثيراضافة الالياف الكاربونية والزجاجية على مقاومة الربط لحديد التسلح والخرسانة الاعتيادية

## الخلاصة

إن مفهوم المواد المركبة باستعمال الألياف كتسليح ليس حديثا. أن الهدف من المواد المركبة هو تحسين بعض خواص المواد الأصلية. الخرسانة المسلحة بالألياف واحدة من أهم المواضيع في الهندسة المدنية. ان استعمال الخرسانة المسلحة الحاوية على الألياف يثير تساؤل عن مدى تأثيرها



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على قوة الترابط بينها وبين قضبان حديد التسليح.أجريت الدراسة العملية الحالية للحصول على فهم واضح لقوة الترابط بين الخرسانة الاعتيادية ب ا س تعمال ن و ع ين مختارين من الألياف الزجاجية والكاربونية وقضبان حديد التسليح. تم تصنيع وفحص خمس وأربعون نموذج سحب مكعب بإبعاد ١٥٠ملم للوصول إلى ذلك الهدف. قسمت هذه النماذج إلى خمس مجاميع لدراسة تأثير بعض المتغيرات المختارة كنوع الألياف المستعملة(الكاربونية والزجاجية)وقطر قضبان التسليح (١٢ملم و١٦ملم و٢٠ملم) والنسبة الوزنية للألياف إلى الاسمنت (٠.٧٥%و١.٠%). فحصت ثلاث نماذج مكعبة بنفس حجم تلك المستعملة في فحص الربط من كل خلطة لإيجاد مقاومة الانضغاط لكل منها. وجد بان التحسن الحاصل في قوة الربط باستعمال الألياف الزجاجية مع استعمال قطر حديد تسليح =١٦ملم اكبر من ذلك الحاصل باستعمال الألياف الكاربونية حيث تزداد قوة الربط مع الألياف الزجاجية بنسبة تسليح ١٣,٦% و٤,٥% عند استعمال هذه الألياف بنسبة ٠,٧٥% و ١% .ان قوة الربط تزداد بنقصان قطر قضبان حديد التسليح. إن إضافة ألياف الكاربون والألياف الزجاجية يحسن قوة الربط بين الخرسانة وبين قضبان حديد التسليح الأصغر والعكس بالعكس.أعطت النسبة الوزنية للألياف (سواء كانت زجاجية أم كاربونية) ٠,٧٥% نتائج أفضل لقوة الانضغاط من تلك التي أعطتها النسبة الوزنية ١,٠%.

## INTRODUCTION

Bond stress between steel reinforcement and concrete is defined as the unit shearing stress acting parallel to the steel bar axis [1], 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)[1].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 stress changes, or there can be no change in bar stress without bond stress[2].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[1]. Moreover, the transfer of stress between concrete and steel has a great influence in limiting the space and the width of cracks [1,2]. 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[2]:-

**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 [3].

The concept of using fibers to improve the characteristics of construction materials is very old. Early applications include addition of straw to mud bricks, horse hair 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 it's 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[4].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. There are many types of fibers such as steel fiber, glass fiber, polypropylene fiber, carbon fiber…etc [4,5 and 6].Each type of these fibers has different shapes and sizes to serve the purpose for which is added.

This paper presents tests results on the performance of carbon and glass fiber when used with concrete. The effect of type of fiber (carbon and glass), reinforcing bar diameter (12mm, 16mm and 20mm) and fiber to cement ratio (f/c) by weight (0.75% and 1%) on bond strength is intended to discuss.

## EXPERIMENTAL PROGRAM

The experimental program consists of casting and testing of 45 pullout cubic specimens having size of 150mm and 15 cubic control specimens having the same size of pullout one . The variables investigated using the pull-out specimens are: Type of fiber, bar diameter (12, 16 and 20mm) and fiber/ cement ratio by weight (f/c)

The pulls out specimens are divided into five groups. Each group consists of 9 different specimens with different steel reinforcement diameters (three for each bar diameter considered). **Table (1)** gives the details of these specimens. The notations used are as follows:

The specimen **CF-0.75-12**, the letters **CF** represents a specimen with carbon fiber, bar diameter of (**12** mm) and **0.75**% carbon fiber.

**Table (1) Pull Out Test Specimens Details.**

| Group | Sample Designation | No. Of Specimens | Bar Diameter | Bonded Length(mm) $L_b=3d_b$ | Type of Fiber | (f/c)% |
|---|---|---|---|---|---|---|
| A | C | 3 | - | - | - | - |
| | C-12 | 3 | 12 | 36 | - | - |
| | C-16 | 3 | 16 | 48 | - | - |
| | C-20 | 3 | 20 | 60 | - | - |
| B | CF-0.75 | 3 | - | - | Carbon | 0.75 |
| | CF-0.75-12 | 3 | 12 | 36 | Carbon | 0.75 |
| | CF-0.75-16 | 3 | 16 | 48 | Carbon | 0.75 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | CF-0.75-20 | 3 | 20 | 60 | Carbon | 0.75 |
| C | CF-1 | 3 | - | - | Carbon | 1 |
| | CF-1-12 | 3 | 12 | 36 | Carbon | 1 |
| | CF-1-16 | 3 | 16 | 48 | Carbon | 1 |
| | CF-1-20 | 3 | 20 | 60 | Carbon | 1 |
| D | GF-0.75 | 3 | - | - | Glass | 0.75 |
| | GF-0.75-12 | 3 | 12 | 36 | Glass | 0.75 |
| | GF-0.75-16 | 3 | 16 | 48 | Glass | 0.75 |
| | GF-0.75-20 | 3 | 20 | 60 | Glass | 0.75 |
| E | GF-1 | 3 | - | - | Glass | 1 |
| | GF-1-12 | 3 | 12 | 36 | Glass | 1 |
| | GF-1-16 | 3 | 16 | 48 | Glass | 1 |
| | GF-1-20 | 3 | 20 | 60 | Glass | 1 |

**X-0.75-12***
**X=C,CF,GF control , with carbon fiber, with glass fiber**
**0.75=(weight of fiber/weight of cement)%**
**12=bar diameter**

## MATERIALS

The properties and quantities of materials used are as follows:

### Cement

Ordinary Portland cement type I of Tas Luja Factory was used in the present study. Test results comply with the requirements of the Iraqi Standard Specification I.Q.S. No.5, 1984[7].

The coarse aggregate was a 14mm maximum size crushed gravel and the fine aggregate was natural river sand (AL-Ukhaider),zone (2) according to IQS:45 1984[8] with a 2.71 fineness modulus. .

### Reinforcing Steel

Deformed steel bars of (12,16,20) are used ,**Table (2)** shows the full properties of these reinforcing bars.

**Table (2) Properties of Reinforcing Bars**

| Nominal Diameter | Measured Diameter(mm) | Area (mm2) | Fy(MPa) | Fu(MPa) | Elongation (%) |
|---|---|---|---|---|---|
| 12 | 11.8 | 109.358 | 594 | 658 | 10 |
| 16 | 16.066 | 202.724 | 430.63 | 507.2 | 12 |
| 20 | 19.77 | 306.975 | 395.2 | 556.2 | 16 |

***The test was made in the Laboratory of Materials in the Engineering Collage of Al-Mustansiriya University**

**Fibers**
**A. Glass Fiber**

**Table (3) Properties of Glass Fiber.**

| Size mm | Tensile strength GPa | Specific Gravity | Modulus of Elasticity GPa | Aspect Ratio |
|---|---|---|---|---|
| 20-25 | 2.5 | 2.78 | 70 | 857:1 |

**B. Product Chopped Carbon Fiber**

**Table (4) Properties of Glass Fiber.**

| Type | Size mm | Carbon Content % | Tensile Strength GPa | Young's Modulus GPa | Linear Density g/m | Density g/cm$^3$ |
|---|---|---|---|---|---|---|
| SY-DQCF-25 | 25 | 95 | ≥ 3 | 210 | 0.8 | 1.76 |

**Figure (1) Glass Fiber.**

**Figure (2) Carbon Fiber.**

**Super plasticizer(SP)**

Chloride free liquid admixture with **1.21** specific gravity was used, commercially named **Top Bond 603**. **Table (5)** shows the technical description of top bond 603.

**Table (5) Technical description of Top Bond 603.**

| **Form** | **Viscous liquid** |
|---|---|
| Color | Dark brown/Dark |
| Specific Gravity | 1.21@25±2ºC |
| Chloride Content | Nil |
| Flash Point | N/A |

**MIX PROPORTION**

The contents used from each mix material component were: **385** kg/m$^3$ as cement content,**578** kg/m$^3$ as sand content , **1156** kg/m$^3$as gravel content. The water and superplasticizer contents were **223** liter/ m$^3$and **5.0** liter/ m$^3$. These contents lead the mix proportion by weight to be **1:1.5:3** and W/C ratio=**0.58**.

**Table (6) Mix Proportions of Concrete**

| Mix | Cement $Kg/m^3$ | Sand $Kg/m^3$ | Gravel $Kg/m^3$ | Water $Liter/m^3$ | Glass Fiber $gm/m^3$ | Carbon Fiber $gm/m^3$ | S.P Liter/m |
|---|---|---|---|---|---|---|---|
| A | 385 | 578 | 1156 | 223 | - | - | 5 |
| B | 385 | 578 | 1156 | 223 | - | 2888 | 5 |
| C | 385 | 578 | 1156 | 223 | - | 3850 | 5 |
| D | 385 | 578 | 1156 | 223 | 2888 | - | 5 |
| E | 385 | 578 | 1156 | 223 | 3850 | - | 5 |

## FABRICATION AND DETAILS OF SPECIMEN

Cubic pullout specimens 150×150×150mm were chosen to fit the recommendation of American standards (ASTM C-234)[9].The embedment or bonded length of three times the bar diameter (**$L_b$=3$d_b$**) is bounded by two unbounded zones (**$L_u$**), where (**$L_u$=(L-$L_b$)/2** as shown in **Fig (3).** The embedment length or bonded length of three times the bar diameter is assumed to be short enough to produce approximately uniform bond stress distribution along the length, but long enough as compared with the maximum size of aggregate particles[10].The unbounded zones are performed by covering the reinforcing bar at these with a plastic tube and layer of an adhesive tape. All the specimens are fabricated without lateral reinforcing bar. The steel bars are screwed from the loaded end. At distance 100mm from the bottom end of the bar, the bar is 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. Figure (4) shows the reinforcing bar details

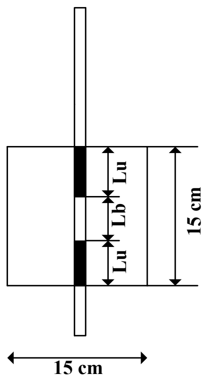



**Figure (3) Testing Specimen Details.**

Figure (4) Reinforcing Bar Details.

## MOLDING, CASTING AND CURING

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. Then the concrete was mixed for about three minutes by a horizontal rotary mixer of **0.19** $m^3$ capacities. The mix of FRC should have a uniform dispersion of the fibers in order to prevent segregation or balling of the fibers during mixing. External vibration is preferable to prevent fiber segregation. The specimens were then cast into three layers; each of which was compacted by a table vibrator. The pull-out specimens were cast in groups, each group is of 9 cubes with three cubes (150x150x150) mm to investigate the compressive strength of concrete **Figure (5).** After casting, the specimens were covered with a nylon cover to prevent evaporation of water for a period of 24 hours. After 24 hours, the molds were stripped from the specimens and placed in water containers in the laboratory for 28 days to be cured **Figure (6).** After curing the specimens were tested 24 hours after removing them from water according to **(ASTM C-234)[9].**

Figure (5) The Casting. Figure (6) The Curing.

## TESTS SETUP AND INSTRUMENTATION

### Pullout Test

The pull-out specimens were tested by a specially fabricated testing frame as shown in Figure (7). 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. Six (3 Ton) capacity 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 as shown in Figure (8), 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, as shown in Figure (7) The pull-out specimens are hold inside the inverted U section. The loaded end (top end) of tested cube is pressed on the inside face of the bearing plate. 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 0.002mm.

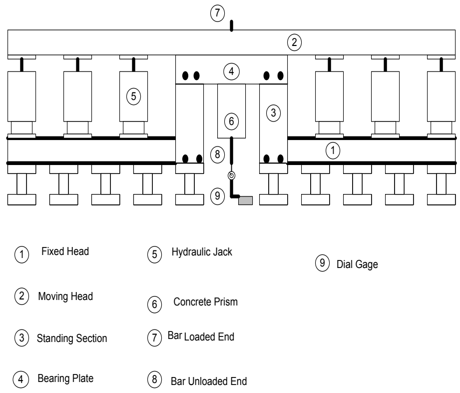



**Figure (7): Testing Frame Details** **Figure(8): Hydraulic Loading. Machine.**

### Compressive Strength Test for Control Concrete Specimens

Universal testing machine were used to test the five groups of control specimens cast.

## RESULTS AND DISCUSSIONS

### Compressive Strength of Concrete

150 mm cubes were cast and tested in accordance with BS 1881(part 116: 1983) standard to determine the compressive strength of the concrete mixes at the age of testing (28 day). Three cubes, cast from each concrete batch, were tested. The results of this test are shown in **Table (7)**.

The test results show, the addition of carbon fiber in group B and C increases the compressive strength of concrete about **9.5%** and **10.8** %respectively. In group D and E glass fiber decreases the compressive strength about **5.7%** and **2.4%**.

**Table (7): Compressive Strength at 28 Days According to BS 1881 (Part 116:1983) of Investigated Concrete Compressive Pullout Specimens.**

| Group | $f_{cu}$ at 28 days (MPa) | Average $f_{cu}$ at 28 days | % of Difference* |
|---|---|---|---|
| A | 34.66 | 33.7 | - |
| | 33.33 | | |
| | 33.11 | | |
| B | 37.55 | 36.88 | 9.5 |
| | 37.77 | | |
| | 35.33 | | |
| C | 35.33 | 37.33 | 10.8 |
| | 36 | | |
| | 40.66 | | |
| D | 29.11 | 31.77 | -5.7** |
| | 33.11 | | |
| | 33.11 | | |
| E | 33.77 | 32.88 | -2.4 |
| | 33.55 | | |
| | 31.33 | | |

*The percent of difference is measured with respect to group A.
**The negative sign refers decreasing.

## Failure Load

The test results for the pull out specimens for the different studied groups are summarized in Table (11). It is observed that the bond strength for pull out specimens with bar 12 the addition of fiber doesn't affect on the bond strength. For specimens with bar16 the bond strength increases when adding carbon fiber with weight of fiber /weight of cement=**0.75** while it decreases when this ratio become **1**. In concrete with glass fiber , the bond strength increases and the maximum increasing recorded when the ratio of fiber weight to cement weight =**0.75**. specimens with bar 20mm the bond strength decreases with adding carbon or glass fiber , this decrease ranges from about **11%** and **17%** for concrete with carbon and glass fiber respectively (weight of fiber/weight of cement =**0.75**) to **28%** and **22%** for concrete with carbon and glass fiber (weight of fiber/ weight of cement=**1**).

**Table (8) Average Test Results of Pullout Specimens of Group A,B, C,D and E.**

| Group | Specimen Identification | Maximum Slip* (mm) | Failure Force* (kN) | Failure Mode |
|---|---|---|---|---|
| A | C-12 | 3.5 | 62.5 | Pull out |
| A | C-16 | 2.37 | 55 | Pull out |
| A | C-20 | 4.77 | 45 | Pull out |
| B | CF-0.75-12 | 5.87 | 62.5 | Pull out |
| B | CF-0.75-16 | 4.155 | 57.5 | Pull out |
| B | CF-0.75-20 | 4.49 | 40 | Pull out |
| C | CF-1.0-12 | 4.5 | 62.5 | Splitting |
| C | CF-1.0-16 | 2.36 | 42.5 | Pull out |
| C | CF-1.0-20 | 5.44 | 32.5 | Pull out |
| D | GF-0.75-12 | 3.64 | 62.5 | Splitting |
| D | GF-0.75-16 | 3.31 | 62.5 | Splitting |
| D | GF-0.75-20 | 3.31 | 37.5 | Pull out |
| E | GF-1-12 | 2.94 | 62.5 | Pull out |
| E | GF-1-16 | 3.38 | 57.5 | Pull out |
| E | GF-1-20 | 3.38 | 35 | Pull out |

***Average of 3 Specimens**

## Failure Mode

In pull out specimens presented in this study, when one of the following occurs, failure is considered to be reached:

**1**- Splitting of the concrete cube. The load at which the cube spilt is considered as the maximum or the ultimate load.

**2**-The bar pulled out from the surrounding concrete media without causing any splitting cracks.

**3**-Stress in the steel bar reached yield point.

Pull out failure is likely to occur when the concrete in between the reinforcing steel bar ribs (concrete key) is weak and surrounding concrete is strong. In case of splitting type of failure large compressive stresses occur on the contact point in front of the rib. These stresses are inclined from outwards towards the rib and the rib exerts equal and opposite stresses. The component of these stresses perpendicular to the bars exerts internal pressure on the surrounding concrete developing hoop tensile stresses [10].

**Table (8)** indicates the type of failure associated with each group of specimens.

It is noticed that the pull out failure was the common type of failure observed in this study, where all the specimens failed by pull out failure except the specimens **CF-1.0-12**, **GF-0.75-12** and **GF-0.75-16** in groups C and D. **Figure (9)** and **(10)** Show the two types of Failure

Figure (9) Pull out Failure.

Figure (10) Splitting Failure.

### Effects of The Investigated Parameters on Bond –Slip Response

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

### Effects of Fiber Type

The effect of fiber type on the bond behavior is shown in **Fig(11) to (16).** The bond strength for concrete with glass fiber is more than that with carbon fiber except specimens **Gf-0.75-20**.

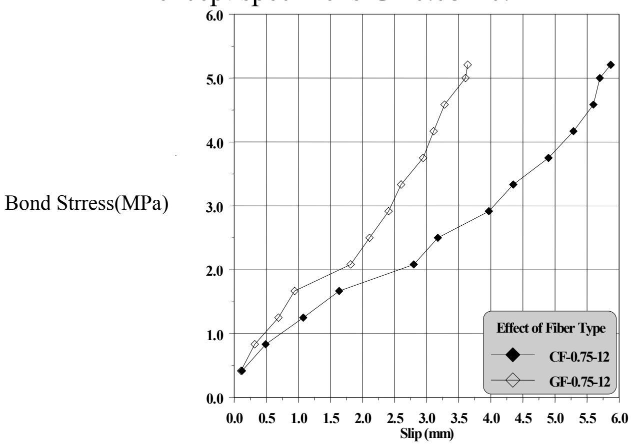



**Figure (11) Effect of Fiber Type with f/c=0.75 %on Bond Slip Response for Bar Diameter=12mm.**

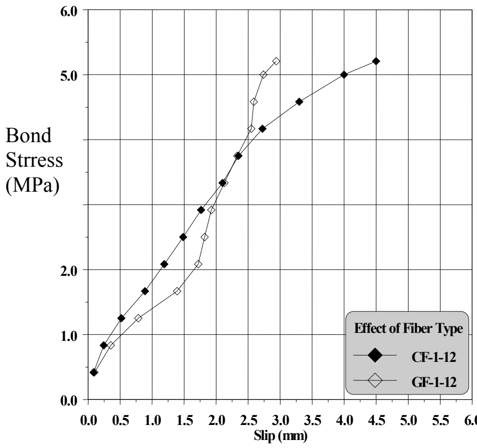



**Figure (12) Effect of Fiber Type with f/c=1 %on Bond Slip Response for Bar Diameter=12mm.**

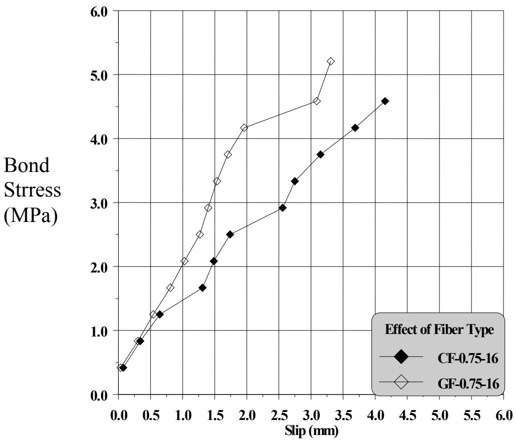



**Figure (13) Effect of Fiber Type with f/c=0.75 %on Bond Slip Response for Bar Diameter=16mm.**

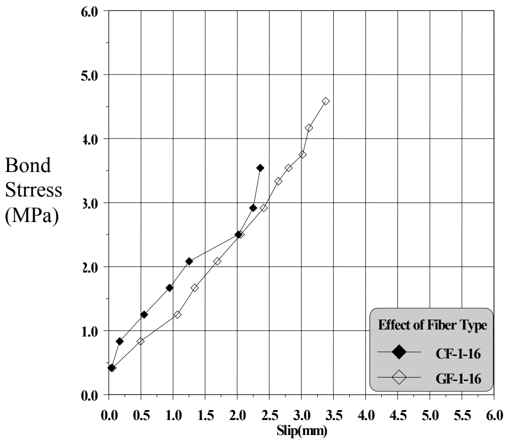



**Figure (14) Effect of Fiber Type with f/c=1 %on Bond Slip Response for Bar Diameter=16mm.**

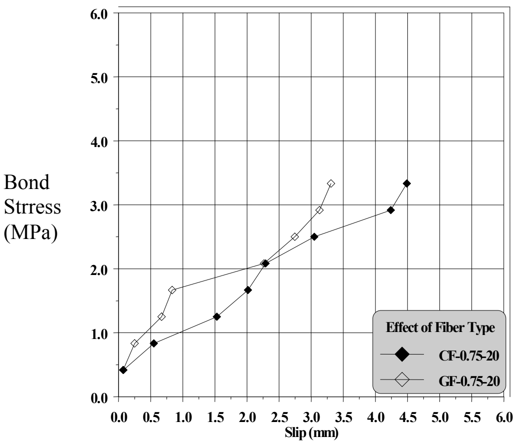



**Figure (15) Effect of Fiber Type with f/c=0.75 %on Bond Slip Response for Bar Diameter=20mm.**

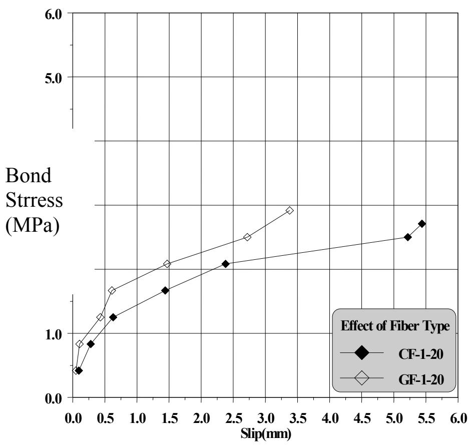



**Figure (16) Effect of Fiber Type with f/c=1 %on Bond Slip Response for Bar Diameter=20mm.**

## Effects of Bar Diameter

Many investigators[10,11,12,13,14,15,16 and 17] , 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 12mm, 16mm and 20mm . Figure (17) to (21) show the bond stress-slip curves for all groups . 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.

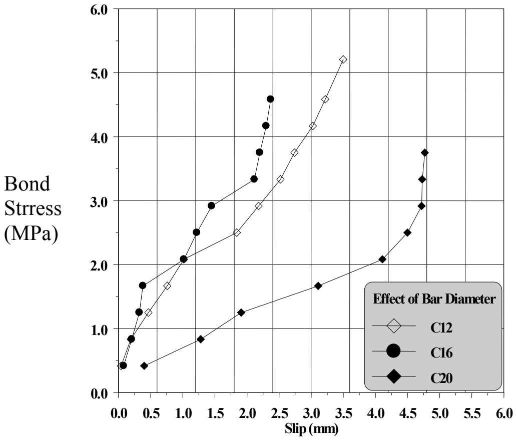



**Figure (17) Effect of Bar Diameter on Bond Slip Response for Group A.**

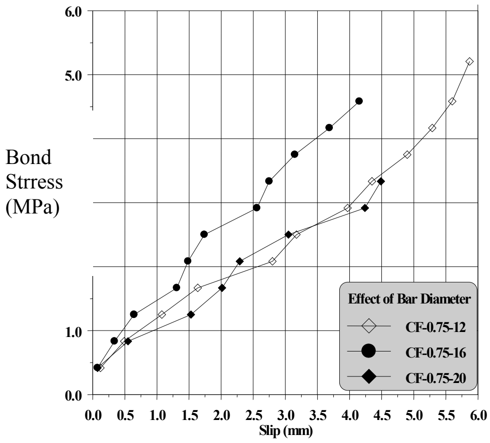



**Figure (18) Effect of Bar Diameter on Bond Slip Response for Group B.**

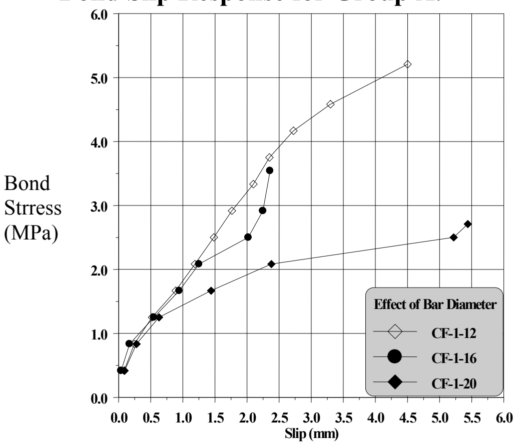



**Figure (19) Effect of Bar Diameter on Bond Slip Response for Group C.**

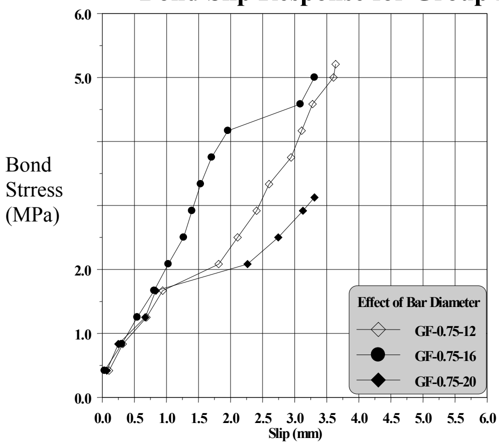



**Figure (20) Effect of Bar Diameter on Bond Slip Response for Group D.**

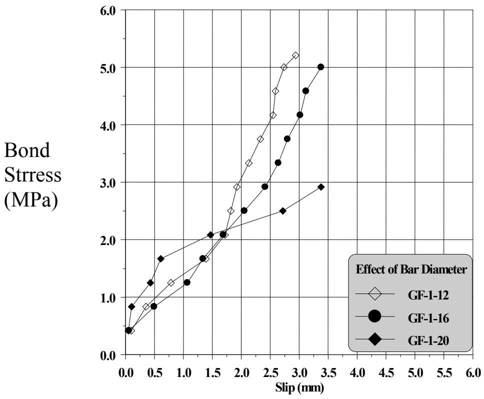
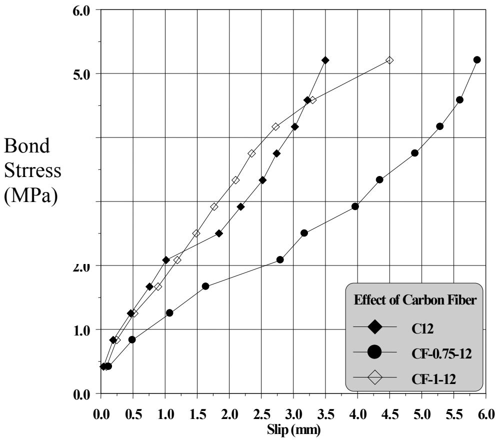


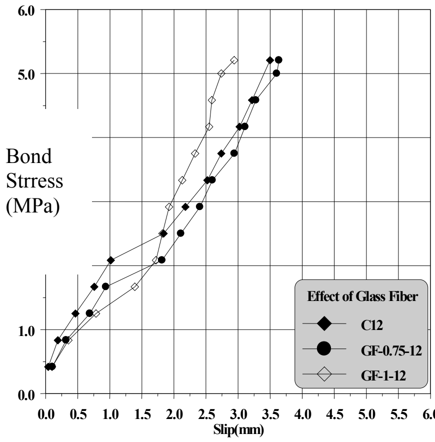

**Figure (21) Effect of Bar Diameter on Bond Slip Response for Group E**

## Effect of (fiber/cement) Ratio.

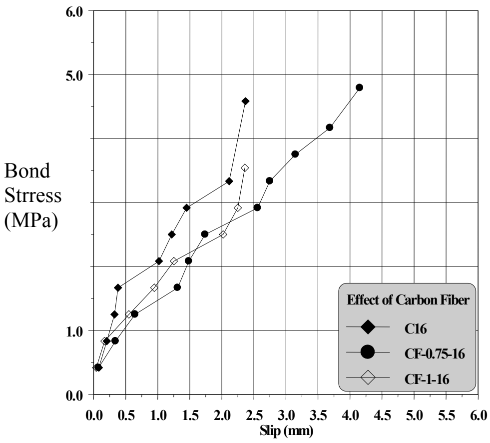
The relationship between the amount of fiber for both type and the bond strength is shown in figure (22)to (27). It is clear from the test results that the increase in the amount of fiber decreases the bond strength because this increase affects on the cohesiveness between the concrete and the steel bar .For carbon fiber this decrease about **26%** and **19%** for concrete reinforced with bar 16 and 20 respectively. The decrease in concrete with glass fiber is less than that for carbon fiber, its about **8%** and **7%** for concrete reinforced with bar 16 and 20 respectively. For both type the amount of fiber doesn't affect on the bond strength in concrete reinforced with bar 12.



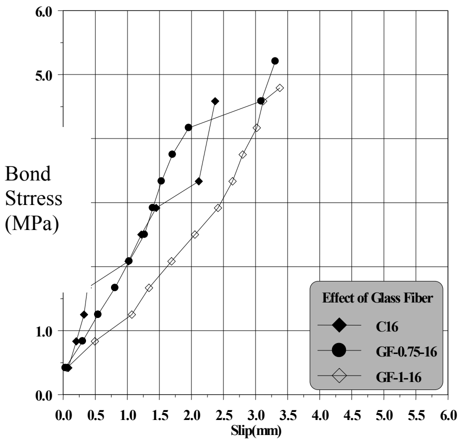

**Figure(22) Effect of f/c % on Bond Slip Response for Concrete with Carbon Fiber and Bar Diameter =12mm.**



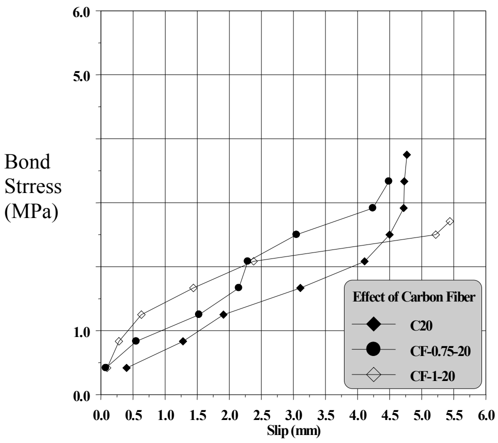

**Figure(23) Effect of f/c % on Bond Slip Response for Concrete with Glass Fiber and Bar Diameter =12mm.**



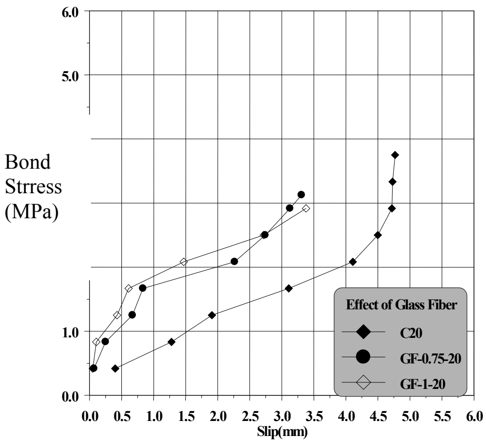

**Figure(24) Effect of f/c % on Bond Slip Response for Concrete with Carbon Fiber and Bar Diameter =16mm.**




**Figure(25) Effect of f/c % on Bond Slip Response for Concrete with Glass Fiber and Bar Diameter =16mm.**




**Figure(26) Effect of f/c % on Bond Slip Response for Concrete with Carbon Fiber and Bar Diameter =20mm.**




**Figure(27) Effect of f/c % on Bond Slip Response for Concrete with Glass Fiber and Bar Diameter =20mm.**

## CONCLUSIONS

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

**1-.** Mechanical properties of concrete such as compressive strength is found to increase with carbon fiber content. In the present study the average increase in the compressive strength when added **0.75 %** and **1%** is about **9.5%** and **11%** from traditional concrete. For concrete with glass fiber the compressive strength decreases about **6%** and **2.5%** when added **0.75%** and **1%** respectively.

**2-** It is noticed that the pull out failure is the predominant type of failure observed in this study, and 36 specimens failed by pull out, nine specimens failed by splitting, three with **1%** carbon fiber and had bar diameter =12mm, six with **0.75%** glass fiber, three had bar diameter=12mm and the other had bar diameter=16mm.

**3-** The pull out specimens with the smaller bar diameter, produce greater bond strength than the greater bar diameter.

**4-** The results show that the adding of carbon fiber or glass fiber increases the bond strength for specimens with small bar diameter and decreases for specimens with larger bar diameter. The best results obtained when the amount of carbon or glass fiber=**0.75%.**

**5-** Glass Fiber enhanced the bond strength for small bar diameter better than that of carbon fiber. the bond strength increases by about **13.6 %** and **4.5 %** with the addition of **0.75%** and **1%** glass fiber for concrete reinforced with bar 16mm .

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