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EFFECT OF ADDITION OF CHOPPED CARBON FIBER ON THE BEHAVIOR OF REINFORCED CONCRETE BEAMS WITH VARIABLE (SHEAR DISTANCE TO EFFECTIVE DEPTH) RATIOS.

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Abstract: The main objective of this work is to evaluate strength and behavior of reinforced concrete beams reinforced with discrete carbon fiber. Six beams were cast and tested up to failure under two concentrated static loads. Four beams were strengthened with discrete carbon fiber (two of them reinforced with carbon fiber of length 12mm and the other two with 6mm carbon fiber). The remaining two were casted without using carbon fiber as a reference beams. Load-deflection response of all the beams was evaluated. The effect of shear span to effective depth ratio and carbon fiber pecies length on the behavior of beams was studied. The results revealed a good improvement provided b the usage of carbon fiber as compared with the references beams (without carbon fiber). The results also show that. The use of carbon fiber lead to a good improvement in the ultimate load value [(6mm) length carbon fiber increased (Pu) by 18.75% for (a/d = 4/3) and by 20% for (a/d = 4), while the (12mm) length carbon fiber increased (Pu) by 64.06% for (a/d = 4/3) and by 80% for (a/d = 4)].

KeyWords: *Reinforced concrete, Beam, chopped carbon fiber, strengthening.*

تأثير اضافة الياف الكربون المقطعه على سلوك الكمرات الخرسانية المسلحة بنسب (مسافة قص الى عمق فعال) مختلفة

الخلاصة: كان الهدف من هذا البحث هو تقييم قوة وسلوك الاعتاب الخرسانية المسلحة و المقواة بألياف الكربون المتقطعة. صبت ست أعتاب خرسانية بعدد كلي مقداره ستة و فحصت لحد الفشل تحت تأثير حملين سكونيين مركزين. أربعة من هذه الاعتاب تم تقويتها بإضافة الياف الكربون المتقطعةا لى خلطاتها الخرسانية بطول (12 ملم) لأثنين من تلك الاعتاب وبطول (6 ملم) للأثنين الآخرين. أما العتبتين المتبقيتين فقد تم صبهما بدون الياف الكربون فيهما كأعتاب مرجعية. تم تقييم استجابة جميع الأعتاب للأحمال عن طريق رسم منحني (الحمل-الهطول), مع بيان تأثير طول قطع اللألياف الكربونية (12و6 ملم) على تلك الاستجابة, ثم درس تأثير نسبة فضاء القص الى العمق و طول قطع الياف الكاربون على سلوك العتبة. لقد اظهرت النتائج التحسن الملحوظ الذي وفره استخدام قطع الألياف الكربونية داخل الخلطة الخرسانية مقارنة بالاعتاب الخالية منها, كما و أظهرت النتائج جليا ان قطع الألياف الكربونية ذات الطول (12 ملم) كانت أكثر كفاءة و تأثيرا على تقوية العتب مقارنة بتلك التي طولها (6ملم). ان استخدام الياف الكاربون المتقطعة اظهرت تحسن في حمل الفشل حيث كانت الزيادة 18.75% لنسبة فضاء القص الى العمق 4/3 وبطول 6ملم لالياف الكاربون المتقطعة

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و زيادة 20% لنسبة فضاء القص الى العمق 4 ولنفس طول لالياف الكاربون المتقطعة ,بينما كانت الزيادة الزيادة 64.06% لنسبة فضاء القص الى العمق 4/3 وبطول 12ملم لالياف الكاربون المتقطعة و زيادة 80% لنسبة فضاء القص الى العمق 4 ولنفس طول لالياف الكاربون المتقطعة.

1. Introduction And Literature Review

Fiber reinforced concrete is a concrete resulted from addition of fibers like steel, carbon, glass, nylon, aramid, polypropylene, polyester, jute, etc to concrete. Inherent interior micro cracks are the most reason to formed cracks in concrete which decrease the concrete resistance to tensile forces. To control these defects, extra materials are added to improve the performance of concrete [1].

These additives make concrete an isotropic material; they also change its brittle behavior to ductile one. Steel fibers resort to rust and glass fibers tumble in the high alkaline medium of cement, therefore carbon fibers are safer than steel fibers besides they have a good chemical stabilization as compared with glass fibers in the alkaline medium. However, carbon fibers are lower in density than the two. [2].

The effect of addition of carbon fiber on the performance of concrete increases with volume, fraction, unless the, volume fraction is too high that the air void content becomes extremely high. The air void content increases with carbon fiber content and air voids tend to have a bad effect on several properties, like compressive strength. In addition, the workability of the mix decreases with carbon fiber content [3]. A fiber content as low as 0.2% of volume is effective, even though fiber contents, exceeding 1 % of volume are more widely used [4].

Chen and Chung [5] notified that using chopped carbon fiber with length from 3.0 to 12.7mm of volume fraction 0.189% together with the presence of chemical agent such as silica fume in normal strength concrete resulted in:

- Increasing bending strength up to 85%,
- Rising flexural toughness up to 205%,
- Rising compressive strength up to 22 %,
- Reducing drying shrinkage 90%,
- Reducing slump from152mm to 102mm.

They decided that:0.1 volume fraction is the minimum carbon fiber fraction of concrete to be effective for raising the flexural strength. Below this fiber volume fraction, the fibers are still effective for raising the flexural toughness,

Khalil and Abdulrazq [6] studied the behavior of high performance concrete strengthened with different volume fractions of carbon fibers (0%, 0.2%, 0.3%, 0.4% and 0.5%).

The effect of chopped- carbon fibers on the mechanical properties (compressive and splitting tensile strengths, bending strengths, and elastic modulus) of high-performance concrete was examined. Mostly, the results revealed that adding carbon fibers developed the mechanical properties of high- performance concrete.

2. Experimental Work

The experimental program consisted of casting and testing of six reinforced concrete beams loaded up to failure. The experimental program is shown in figure.1

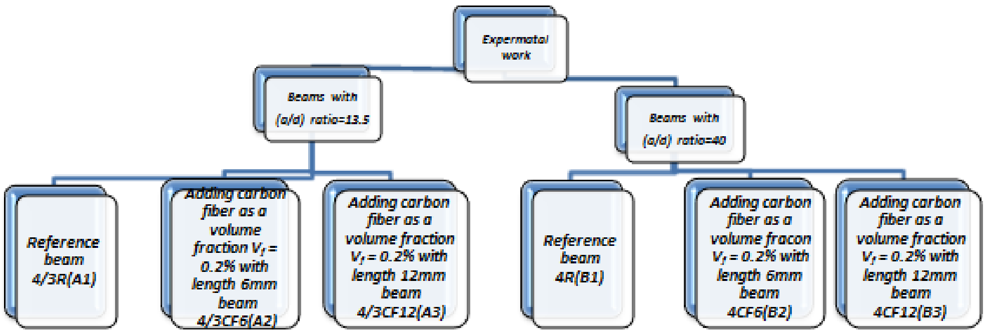


Figure. 1 Experimental Plan Chart

Table (1) Explaination of specimen's Designation

Designation	Symbol	Notations
4/3R	A1	shear span to effective depth ratio, Without carbon fiber
4/3CF6	A2	shear span to effective depth ratio, with6 mm carbon fiber length
4/3CF12	A3	shear span to effective depth ratio, with 12 mm carbon fiber length
4R	B1	shear span to effective depth ratio, without carbon fiber
4CF6	B2	shear span to effective depth ratio, with 6 mm carbon fiber length
4CF12	B3	shear span to effective depth ratio, with 12 mm carbon fiber length

3. Test Specimens

The six beam specimens used in this study is of rectangular reinforced cross section of (120mm x80mm) total length of (1100mm). The tested specimens were reinforced with two deformed wires of (10mm) diameter as a flexural reinforcement placed at 10mm distance from bottom of beam.

Figure. 2 Wooden molds for beam and cubes and plastic mold for cylinders

4. Materials

- **Cement:** ordinary Portland cement Type (I) manufactured in Slemania (Al Mass) is used.
- **Fine Aggregate:** AL-Ukhaidher natural sand is used was within the Iraqi specification No.45/1984[7]. In all concrete batches the sand was dried in air before being used.
- **Coarse Aggregate:** Gravel from AL-Nibaee region with maximum size of 10 mm) is used and was mostly of round shape The grading of coarse aggregate were within the Iraqi specification No. 45/1984 [7] .
- **Water:** Tap water is used for all concrete mixes.
- **Admixture:** To have good workability a super plasticizer (SP) was used, which is a chemical admixture that compensates for the associated reduction in workability happened by addition of carbon fiber. The (SP) used in this study, is commercially known as (Glenium 51) which complies with ASTM C 469-86[8].
- **Reinforcement:** two deformed bars of (10mm) diameter as flexural reinforcement at 10mm distance cover from bottom of beam .The average yield strength is (610 MPa) and the average ultimate strength is (720 MPa).
- **Carbon Fibers:** the typical of carbon fiber properties are listed in Table (2).

Table (2) Mechanical properties for chopped carbon fibers

Properties	Results
Fiber Type	Carbon
Elongation, %	1.5%
Fiber Density	1.79 g/cm^3
Fabric Design Thickness	0.166 mm
Areal Weight	300 g/m^2 +
Tensile strength, 3450 MPa	3900 N/mm^2
Tensile modulus of elasticity, 230 GPa	230000 N/mm^2

5. Concrete Mixes

Concrete reinforced with two carbon fiber volume fractions of (V_f=0.0% &0.2%) is used with two lengths of (6mm) and (12mm).

The following mix proportions was used in this work [cement: sand: aggregate] was [1:2:2] by weight and the water/cement ratio was (0.45) with super plasticizer of (0.8 %) by weight of cement. This mix was the result of several trials mixes in order to obtain the most suitable mix.

Three mixes were used in this work according to the carbon fiber-volume fraction and length was used, as follows:

- With (0.0%) carbon-fiber-volume fraction (Vf).
- With (0.2%) carbon-fiber-volume fraction (Vf) and length of (6mm).
- With (0.2%) carbon-fiber-volume fraction (Vf) and length of (12mm).

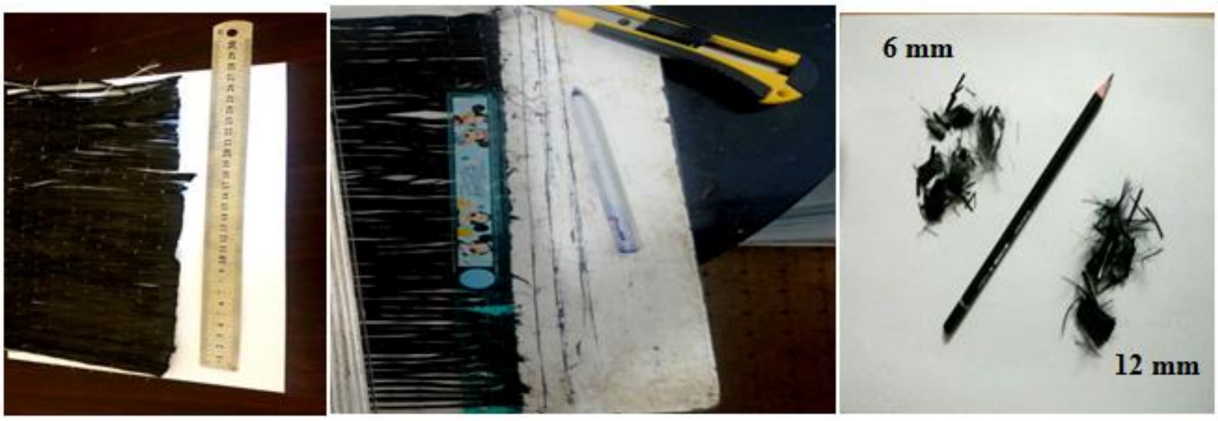


Figure.3 Chopped Carbon Fibers

6. Mixing Procedure

1. Fine and coarse aggregate were mixed well in the pan and then cement was added.
2. For the mixes containing carbon fiber, fine aggregate (sand) was mixed with chopped carbon fiber by hand very well until a good dispersion of fibers occurred and to avoid clumping or balling then coarse aggregate was added to the mix and remix the content, finally cement was added.
3. 75% 0f water was added first to the dry mix, and remixed.
4. Carefully, the remaining (25%) of the mixing water ratio was added with the super plasticizer and poured to the mix and remix again.

7. Testing Of Hardened Concrete

7.1 Compressive Strength

18 cube specimens of size 100x100x100mm were poured and submerged in the curing tank for 28 days of curing and they were tested according to BS 1881: part 116:1989[9]. The specimens were tested at age of 3 months.

This test was measured on 100 mm cubes using electrical testing machine of capacity of 2000 kN.

7.2 Splitting Tensile Strength

18 cylindrical moulds of 100mm diameter and 200mm high were casted. The moulds were opened after 24 hours of casting and submerged in the curing tank for 28 days of curing and they were tested according to ASTM C 496-86[10]. The specimens were tested at age of 3 months. The results is shown table (3).

Table (3) Compressive strength and tensile strength test results

V_f %	Length of carbon Fiber (mm)	f_{cu} (average) MPa	Percentage of increase in compressiev strength	ft (average) MPa	Percentage of increase in tensial strength
0.0	Without fiber	25	-------	5.813	-------
0.2	6	27.9	11.6	8.313	43
0.2	12	30.75	23	9.813	68.811

8. Testing and Results

All the beams were tested over a simply supported span of 1000 mm, c/c of supports the load of which was monotonically increased under static loading. The vertical mid-span deflection was measured using mechanical dial gauge of 0.01 mm accuracy. The crack development and propagation were monitored and marked during the progress of the test.

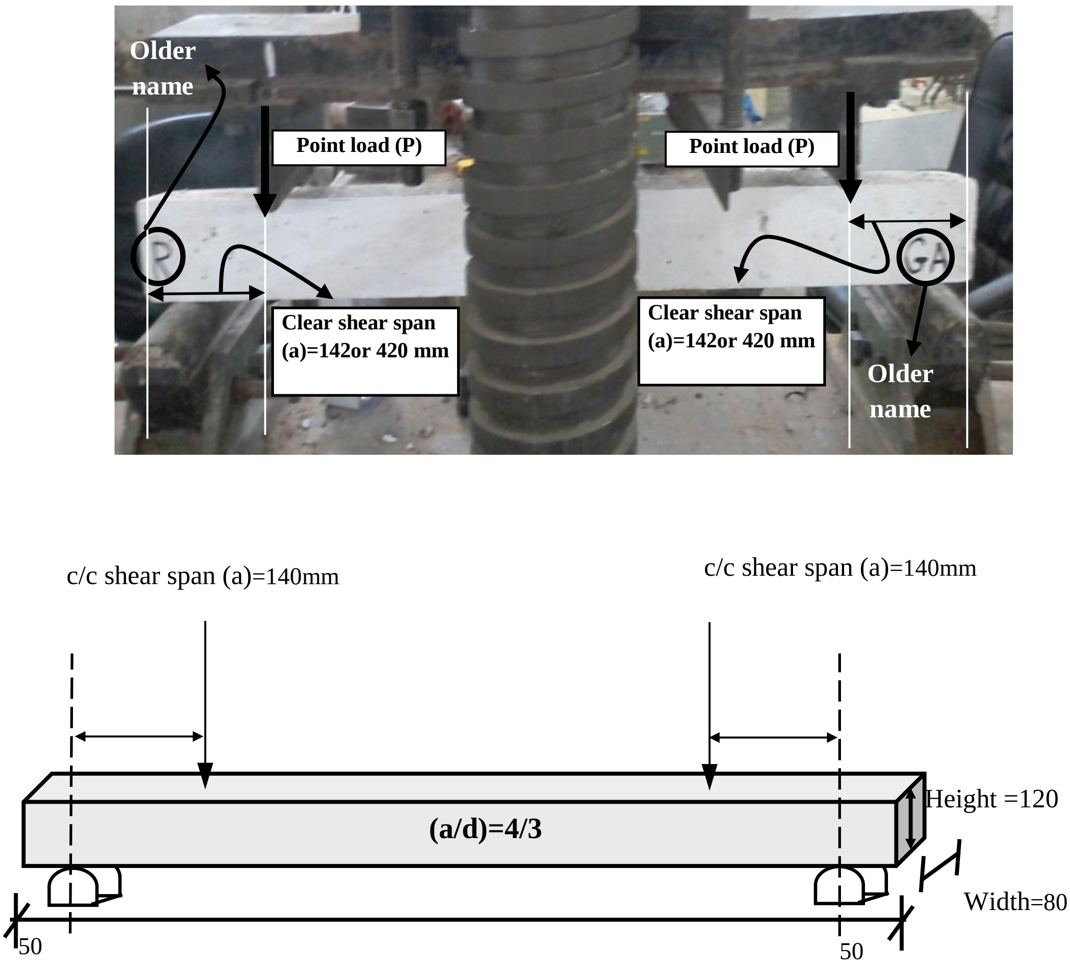


Figure.4 Preparation for loading test machine

9. Load –Deflection Response For Beams Specimens

As shown in Fig.5, which illustrate that when adding chopped carbon fiber (6 and 12mm) the ultimate load increased while the deflection decreased at the same load level.

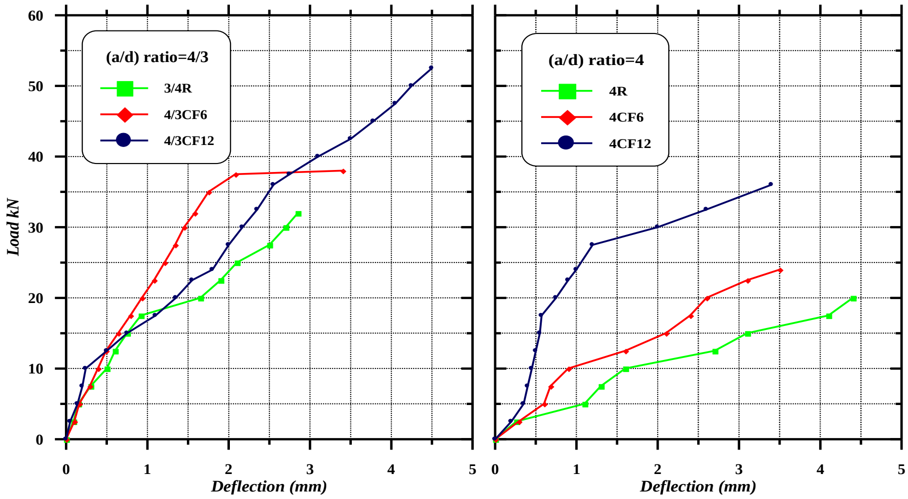


Figure 5 Load –Deflection Curve for Beams Specimens

10. Parametric Study

10.1 Effect Of The Using Of Carbon Fiber

Six tests have been carried out in order to investigate the effect of carbon fiber on ultimate load, using (0.2%) V_f for specimens (A2, A3) and (B2, B3) as compared with the originally designed (0.0%) V_f specimens (A1, B1). It was found that adding (6mm) length carbon fiber increase (Pu) by 18.75% for (a/d = 4/3) and by 20% for (a/d = 4), while the (12mm) length carbon fiber increased (Pu) by 64.06% for (a/d = 4/3) and by 80% for (a/d = 4), as illustrated in Table 4 and Fig.6. These results show the good response of specimens having carbon fiber especially the (12mm length) ones compared with those which have not. The interpretation behind these results is that the carbon fiber played a noticeable role in preventing potential cracks from initiation.

10.2 Effect Of Carbon Fiber Length

Two deferent lengths of carbon fiber have been used, (6mm) and (12mm) in specimens (A2,B2) and (A3,B3) respectively. As shown in Table 5 and Fig.7 and Fig.8, it was found that the effect of increasing carbon fiber length from (6mm to 12mm) on ultimate load (Pu) increased by 38.1% form specimen A2 to specimen A3 (for a/d=4/3) and by 50% form specimen B2 to specimen B3 (for a/d=4), this means that the effect of increasing carbon fiber length increases with increasing (a/d) ratio.

The physical interpretation of this result is that the 12mm length carbon fiber has more ability to prevent potential cracks in the tension zone to initiate than that of the 6mm length, perhaps because of the better anchorgement that the 12mm length provide with respect to that provided by the 6mm length.

Table (4) Effect of Carbon Fibers on Ultimatade Lo

Designation	symbol	f_{cu} (MPa)	f_t (MPa)	(a) (mm)	Length of carbon Fiber (mm)	V_f (%)	ultimate load (Pu) (kN)	Percentage of increase in ultimate load (%)	Ratio
4/3R	A1	25.5	6.25	142	-------	0.0	32	-------	a/d=4/3
4/3CF6	A2	28.8	8.125	142	6	0.2	38	18.75	
4/3CF12	A3	31	9.875	142	12	0.2	52.5	64.0625	
4R	B1	24.5	5.375	420	-------	0.0	20	-------	a/d=4
4CF6	B2	27	8.5	420	6	0.2	24	20	
4CF12	B3	30.5	9.75	420	12	0.2	36	80	

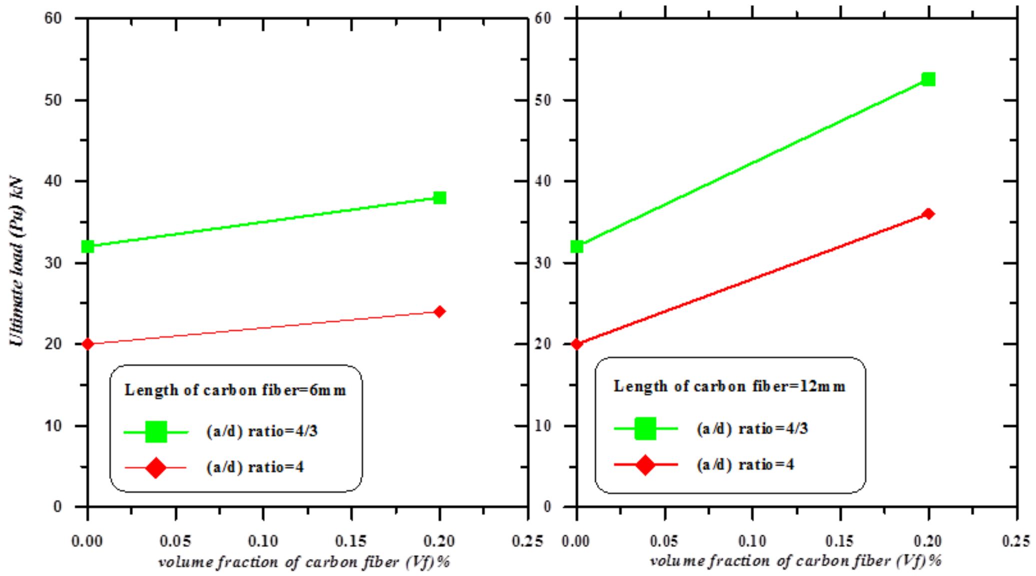
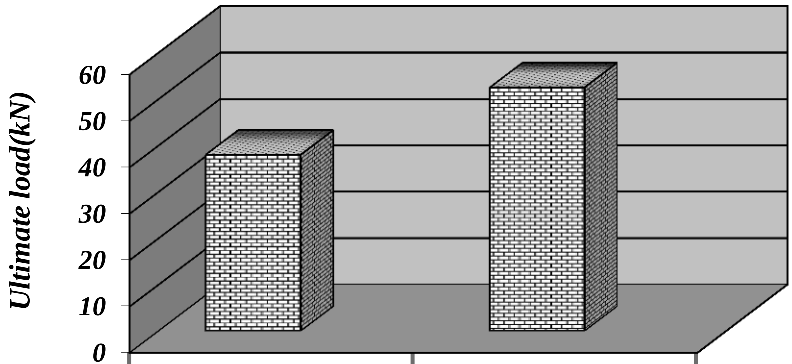


Figure 6 Effect of Carbon Fibers of Vf=o.2 on Ultimate Load

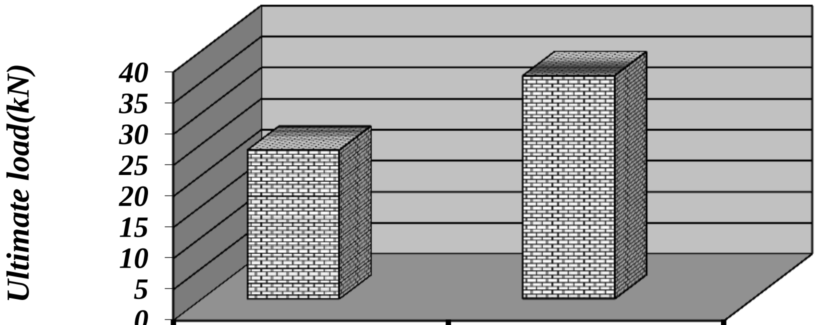
Table(5) Effect of increasing length of carbon fiber on ultimate Load with increasing (a/d) ratio.

Designation	symbol	f_{cu} (MPa)	f_t (MPa)	(a) (mm)	Length of carbon Fiber (mm)	V_f (%)	ultimate load (Pu) (kN)	Percentage of increase in ultimate load (%)	Ratio
4/3CF6	A2	28.8	8.125	142	6	0.2	38	-------	a/d=4/3
4/3CF12	A3	31	9.875	142	12	0.2	52.5	38.1	
4CF6	B2	27	8.5	420	6	0.2	24	-------	a/d=4
4CF12	B3	30.5	9.75	420	12	0.2	36	50	



	4/3CF6	4/3CF12
Ultimate load(kN)	38	52.5
Length of carbon fiber(mm)	6	12

Figure 7. Effect of carbon fiber length on ultimate strength with carbon fiber volume fraction (Vf) =0.2% with a/d=4/3



	4CF6	4CF12
Ultimate load(kN)	24	36
Length of carbon fiber (mm)	6	12

Figure 8 .Effect of carbon fiber length on ultimate strength with carbon fiber volume fraction (Vf) =0.2% with a/d=4

10.3 Effect of a/d (Shear Span/ Effective Depth)

In order to inspect the effect of a/d on the behavior of beams, two ratios of a/d have been carried out, (4/3) and (4) in beams (A1, A2, A3) and (B1, B2, B3) respectively. As shown in Fig.9 and Table6, it has been found that before using carbon fiber as in specimens A1, B1,when the ratio of (a/d) has been changed from (4) at B1 to (4/3) at A1, the value of ultimate load Pu increased by 60%.

When carbon fiber (6mm length) has been used, we noticed that the percentage of increasing Pu decreased by 3.3% from 60% (for specimens A1, B1) to 58% (for specimens A2, B2), but when (12mm length) carbon fiber, has been used a large amount of decreasing occurred 25% in percentage of increasing of Pu i.e. from (60% for specimens A1, B1) to(45% for specimens A3, B3), which concludes that the (12mm length) carbon fiber was more efficient than the (6mm length) carbon fiber i.e. it decrees the damaging effect of the large (a/d) ratio.

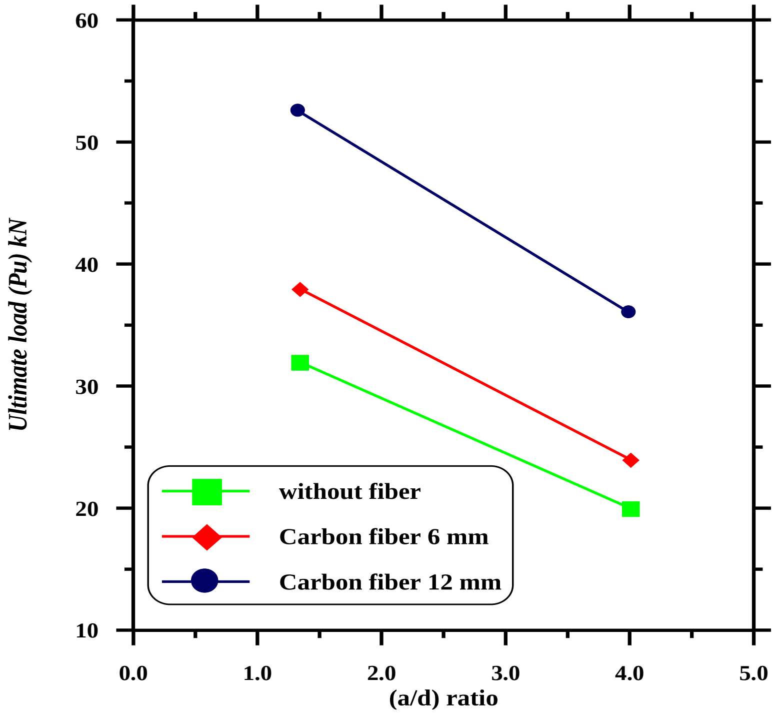


Figure 9 Effect of variable (a/d) ratio with various length of carbon fiber on ultimate load

Table(6) Effect of decreasing (a/d) ratio on Ultimate load with Increased Length of Carbon Fiber

Designation	symbol	f_{cu} (MPa)	f_t (MPa)	shear distance(a) (mm)	(a/d) ratio	V_f (%)	ultimate load (Pu) (kN)	Percentage of increase in ultimate load (%)	Length of Carbon Fiber (mm)
4/3R	A1	25.5	6.25	140	4/3	0.0	32	60	Without fiber
4R	B1	24.5	5.375	420	4	0.0	20	-------	
4/3CF6	A2	28.8	8.125	140	4/3	0.2	38	58	6
4CF6	B2	27	8.5	420	4	0.2	24	-------	
4/3CF12	A3	31	9.875	140	4/3	0.2	52.5	45	12
4CF12	B3	30.5	9.75	420	4	0.2	36	-------	

11. Crack Pattern

Crack pattern with the related load values were marked by a suitable marker pen on all beams specimens for all loading stages. Fig.10 shows that the crack prorogation begins from supports to word the points of application of the concentrated loads.

It has been founded that the failure mode of all beams specimens was shear mode type as expected.

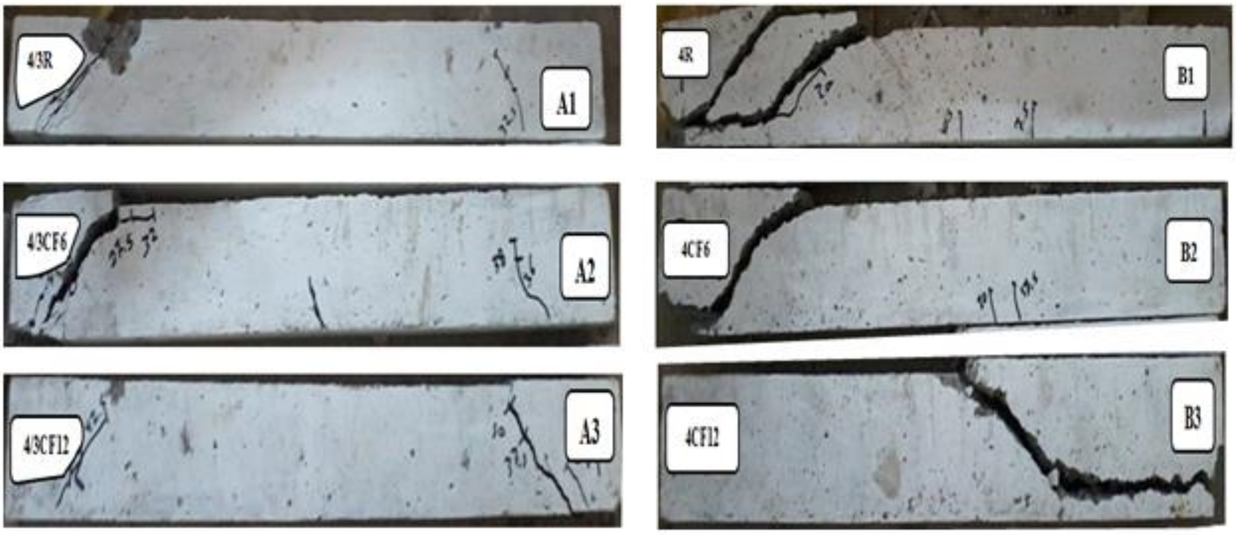


Figure 10. Crack patterns of Specimens beams[A1, A2,A3,B1,B2,B3]

12. Conclusions

From the examined specimens several conclusions may be stated, such as:

1. At any specific load level, the deflections are reduced considerably by improving the tension zone of the beams with carbon fiber.
2. The use of carbon fiber lead to a good improvement in the ultimate load value [(6mm) length carbon fiber increased (Pu) by 18.75% for (a/d = 4/3) and by 20% for (a/d = 4), while the (12mm) length carbon fiber increased (Pu) by 64.06% for (a/d = 4/3) and by 80% for (a/d = 4)].
3. From the experimental data, it is clear that (12mm length carbon fiber) is more efficient in use than (6mm length carbon fiber), because the 12mm length carbon fiber has more ability to prevent potential cracks in the tension zone to initiate than that of the 6mm length .
4. The (6mm) length carbon fiber decreases the bad effect of the large (a/d=4) by 3.3% compared with reference state whereas the (12mm) length carbon fiber decreases the bad effect of the large (a/d=4) by 25% compared with reference state.
5. Compressive strength increase 11.6 % for 6 mm carbon fiber length and 23% for 12 mm carbon fiber length.
6. Splitting tensile strength increase 43% for 6 mm carbon fiber length and 68.811% for 12 mm carbon fiber length.

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