Behavior and Strength of Steel-Carbon-Plastic Hybrid Fiber Reinforced Concrete Beams

Esraa Khudhair Mohsin Abuzaid
Highway and Transportation Engineering Department, College of Engineering
Al-Mustansiriya University, Baghdad, Iraq

Abstract: Fibers like steel, carbon, plastic; polyester, jute, etc. are add up to concrete known as fiber reinforced concrete. To obviate the deficiencies of concrete, fibers are added to concrete to reform the behavior of concrete. The fibers serve as not only the cracking control reinforcement, but also the vehicle to allow for significant internal plastic stress redistribution to increase the strength of the specimens after the first crack forms [1]. In this study hybrid reinforced concrete is made by adding steel, carbon and plastic fibers. (Steel + carbon and plastic + carbon) are used in order to combine the advantages of all of them and to make the mixture more economical by substituting half of the addition of carbon fiber with steel fiber and plastic fiber which cheaper carbon fiber; Addendum of steel fibers can increase compressive, tensile, and flexural strengths of concretes along with the post-cracking ductility while plastic fibers increase the resistance of concrete to cracking. Six beams were molded and tested over an effective span length 1000 mm up to failure under two concentrated loads. One beam molded without any strengthen (as a reference beam). Three beams were strengthened with three types of fibers (carbon fiber, steel fiber and plastic fiber) and 0.2% volume fraction. While the two last beams were strengthened with hybrid fibers(carbon fiber + steel fiber and carbon fiber + plastic fiber) (0.1%+0.1%) for each fiber . Estimation of load –deflection response to the six beams. The results show a good amelioration provided after using of fibers as matched with the reference beam (without fiber). The results also show that using of hybrid fiber lead to a good improvement in the ultimate load value [increased (Pu) by 58.5% for (S.F+C.F) and by 38.5% for (P.F+C.F), while when use only (S.F) alone ultimate load increased (Pu) by 55.4% and for (P.F) alone ultimate load increased (Pu) by 6.62% .

1. Objective of the Project
The objective is to investigate the flexural behaviour of hybrid fibre reinforced concrete beams by using a combination of steel, plastic and carbon fibers in order to combine the advantages of all of them and to make the mixture more economical by substituting half of the addition of carbon fiber with steel fiber and plastic fiber which cheaper carbon fiber.

2. Introduction and Literature Review
In general concrete has an upper brittleness with an increase in strength. This is a major drawback since brittleness can cause flash and catastrophic failure, especially in structures which are undergoing to earthquake, blast or suddenly exercised loads i.e., impact. This critical disadvantage of concrete can at least partially be obviated by adding fibers [2]. These additional materials change concrete to an isotropic material; they also increase its ductile behavior[3].

The effect of the addition of carbon fiber on the performance of concrete increases with volume, fraction [4], unless the, volume fraction is too high that the air void content becomes extremely high
A fiber content as down as 0.2% of volume is effective [6], even still fiber contents, exceeding 1% of volume are more excessively used [7,8].

Khalil and Abdulrazq [9] studied the behavior of high performance concrete strengthened with different Vf of carbon fibers (0%, 0.2%, 0.3%, 0.4% and, 0.5%). The effect of carbon fibers on the mechanical properties (compressive and tensile strengths, elastic modulus, and bending strengths) of high- performance concrete was evaluated. The results showed that adding chopped carbon fibers improved the mechanical properties of high- performance concrete.

3. Test Specimens
The six beam specimens used in this research are of the rectangular cross section (120mm x80mm) with length of (1100mm). The specimens were reinforced with two deformed bars of (10mm) diameter for flexural reinforcement and used 10mm cover from the bottom of beam.

Figure 1. Wooden and plastic molds were used in this study

4. Experimental Work

a. Concrete Mixes
Concrete reinforced with two fiber volume fractions of (Vf=0.0% &0.2%) is used. 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. The result of Six mixes were used in this work according to the type of fibers, as follows:
- With (0.0%) fiber-volume fraction (Vf) as reference.
- With (0.2%) carbon-fiber-volume fraction (Vf).
- With (0.2%) steel-fiber-volume fraction (Vf).
- With (0.2%) plastic-fiber-volume fraction (Vf).

b. Mixing Procedure
- Coarse and fine aggregate were mixed well in the electric muffler pan and finally cement was added.
- a. 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.
- b. For the mixes containing steel fiber, steel fiber was added at the end carefully to be sure that steel fiber bars dose not bended.
- c. For the mixes containing plastic fiber also was added finally.
- 75% 0f water was added first to the dry mix, and remixed.
Cautiously, the remaining (25%) of the mixing water ratio was added with the super plasticizer and added to the mix.

c. **Materials**

Cement: ordinary Portland cement Type (I) (Al Mass) is used to manufacture in Slemania.

Fine Aggregate: AL-Ukhaidher sand is used according the Iraqi specification No.45/1984[10].

Coarse Aggregate: crushed gravel from AL-Nibaee with a maximum size of 10 mm) is used. The grading of coarse aggregate was used up to the Iraqi specification No. 45/1984 [10].

Water: Tap water is used in the concrete mixes.

Admixture: a super plasticizer (SP) was used for better workability, which is a chemical admixture that for the reduction in workability due to the addition of carbon fiber, steel fiber and plastic fiber. The (SP) used in this research, is known as (Glenium 51) which complies with ASTM C 469-86 [11].

Reinforcement: “two deformed wires of (10mm) diameter for flexural reinforcement and used 10mm cover from the bottom of the beam. The average ultimate strength is (720 MPa) and the average yield strength is (610 MPa).

Carbon Fibers: Chopped carbon fibers with length 12 mm were used. The properties are listed in Table 4.

Steel Fibers: steel fibers with length 13 mm and diameter 0.2 mm were used. The properties are listed in Table 5.

Plastic Fibers: nylon fibers with length 30 mm and diameter 0.8 mm were used. The properties are listed in Table 6.

![Figure 2](image)

**Figure 2.** chopped carbon fiber, plastic fiber and steel fiber were used in this study

| Sieve Size (mm) | % Fine Aggregate Passing | IOS 45/1984 Limits [12] |
|-----------------|--------------------------|--------------------------|
| 10              | 100                      | 100                      |
| 4.75            | 9.1.5                    | 90-100                   |
| 2.36            | 8.7.3                    | 75-100                   |
| 1.18            | 7.3.6                    | 55-90                    |
| 0.6             | 4.3.6                    | 35-59                    |
| 0.3             | 9.12                     | 8-30                     |
| 0.15            | 0.03                     | 0-10                     |
### Table 2. Grading of Coarse Aggregate

| Sieve Size (mm) | % coarse aggregate |
|-----------------|-------------------|
| 12.5            | 100               |
| 9.5             | 96                |
| 4.75            | 27                |
| 2.36            | 2.8               |
| 1.18            | 0.7               |

### Table 3. Typical Properties of Glenium 51

| Form          | Viscous liquid     |
|---------------|--------------------|
| Colour        | Light Brown        |
| Relative Density | 1.1 @ 20 0C |
| pH            | 6.6                |
| Viscosity     | 128+/-30 cps @ 20 0C |
| Transport     | Not. Classified as Dangerous |
| Labeling      | No. Hazard         |

### Table 4. Mechanical properties of chopped carbon fibers

| Property                     | Value             |
|------------------------------|-------------------|
| Elongation, %                | 1.5%              |
| Fiber Density                | 1.79 g/cm³        |
| Fabric Design Thickness      | 0.166 mm          |
| Areal Weight                 | 300 g/m² +        |
| Tensile strength, 3450 MPa   | 3900 N/mm²        |
| Tensile modulus of elasticity, 230 GPa | 230000 N/mm² |

### Table 5. Mechanical properties of plastic fibers

| Property                     | Value             |
|------------------------------|-------------------|
| Length of fiber              | 30mm              |
| Diameter                     | 0.8mm             |
| Tensile Strength             | 250-350 MPa       |
| Elastic Modulus              | 2500-3000 MPa     |
| Specific Gravity             | 1.14              |
| Aspect Ratio (l/d)           | 63                |
| Elongation                   | 16-20%            |
| Softening Point              | 160 C             |

### Table 6. Mechanical properties of steel fibers

| Property                     | Value             |
|------------------------------|-------------------|
| Length (mm)                  | 13                |
| Diameter (mm)                | 0.2               |
| Density (kg/m³)              | 7800              |
| Tensile Strength fu (MPa)    | 2600              |
| Aspect Ratio                 | 65                |
Testing of Hardened Concrete

a. Slump Test

The slump test made for six specimens (R, C.F, S.F, P.F, S.F+C.F and P.F+C.F) to determine the effect of fibers and hybrid fibers on the consistency to concrete. In general the slump decreases with adding fiber to concrete with respect to the reference beam (without fiber), but in hybrid specimens (S.F+C.F and P.F+C.F) can take advantage of adding carbon fiber to concrete with minimizing carbon fiber damage which increasing the slump losses.

| Specimens     | Slump Test |
|---------------|------------|
| R             | 100        |
| C.F           | 93         |
| S.F           | 97         |
| P.F           | 99         |
| S.F+C.F       | 95         |
| P.F+C.F       | 98         |

Figure 3. Slump test

b. Compressive Strength

18 cube specimens of size 100x100x100mm were casted and submerged in the curing tank for 28 days and they were tested according to BS 1881: part 116:1989 [12]. The specimens were tested at age of 3 months. The test was measured on 100 mm cubes using an electrical testing machine of capacity of 2000 kN. The results are shown table 8.
c. Splitting Tensile Strength  
18 cylindrical moulds of 200mm high and 100mm diameter were casted. After 24 hours moulds were opened and submerged in the curing tank for 28 days of curing and they were tested according to ASTM C 496-86 [13]. The specimens were tested at age of 3 months .

Figure 4. Compressive Strength MPa at 28th days

Figure 5. Split Tensile Strength MPa at 28th days
6. Testing and Results
All the beams specimens were tested on a simply supported span of 1000 mm, c/c of supports the static load of which was monotonically increased. The vertical deflection was measured at mid-span using mechanical dial gauge of 0.01 mm accuracy. The crack generation and propagation were monitored during the test.
a. **Load–Deflection Response for Beams Specimens**

The response for all beams specimens was the same. At the beginning of the test contact between the support and beam was developed until a load of 2.5 kN where a small bump can be found. First crack for the specimens is approximately between 7.5-9 kN. In general, the effect of fibers used (in most cases), increase the first cracking load with respect to reference beam (R).

From Fig.8 have been found that when adding chopped carbon fiber) the ultimate load increased by 61.5%, while the ultimate load increased by 55.4% for specimen of steel fiber and 6.62% for specimen of plastic fiber with respect R specimen and the deflection decreased at the same load level.

Two different mixes of hybrid fiber have been used, (S.F+C.F)) and (P.F+C.F)). As shown in Fig.9 and Fig.10 respectively, and Table 8, it was found that the usage of hybrid fiber increasing ultimate load (Pu) by 58.5% form specimen (S.F+C.F) and by 38.5% form specimen (P.F+C.F), this means that there is a good improvements even after replacing half of the addition of carbon fiber with steel fiber and plastic fiber which cheaper carbon fiber.

![Figure 8. Load–Deflection Curve for Beams Specimens](image-url)
Figure 9. Load –Deflection Curve for Beams Specimens

Figure 10. Load –Deflection Curve for Beams Specimens
Figure 11. Load –Deflection Curve for Beams Specimens

Table 8. Compressive strength, split tensile strength and ultimate load test results

| specimens | $f_{cu}$ (MPa) | $f_s$ (MPa) | shear distance(a) (mm) | $V_r$ (%) | ultimate load (Pu) (kN) | Percentage of increase in ultimate load (%) |
|-----------|---------------|-------------|------------------------|-----------|-------------------------|---------------------------------------------|
| R         | 25.4          | 6.25        | 150                    | 0.0       | 32.5                    | ------                                      |
| C.F       | 31.4          | 9.77        | 150                    | 0.2       | 52.5                    | 61.5                                        |
| S.F       | 28.8          | 8.5         | 150                    | 0.2       | 50.5                    | 55.4                                        |
| P.F       | 25.7          | 8.13        | 150                    | 0.2       | 34                      | 6.62                                        |
| S.F+C.F   | 31            | 9.97        | 150                    | 0.2       | 51.5                    | 58.5                                        |
| P.F+C.F   | 27            | 8.85        | 150                    | 0.2       | 45                      | 38.5                                        |
**Figure 12.** Ultimate load capacities at failure at 3 month

### b. Nominal Shear Strength

\[ \Phi V_c = \Phi \sqrt{f_c b d} \]

Where:
- \( \Phi \) = Strength reduction factor
- \( f_c \) = compressive strength of concrete
- \( b \) = the beam width, mm
- \( d \) = Effective depth, mm
- \( V_c \) = Shear strength

As shown in Table 9 increasing in shear strength is made by considering from improving in compressive strength.

**Table 9.** Shear strength values for the beams specimens

| Specimens | \( f'_{cu} \) (MPa) | \( V_t \) (%) | Shear strength (Vc) (kN) | Percentage of increase in Shear strength (%) |
|-----------|---------------------|---------------|--------------------------|------------------------------------------|
| R         | 25.4                | 0.0           | 40.32                    | ---                                      |
| C.F       | 31.4                | 0.2           | 44.82                    | 11.16                                    |
| S.F       | 28.8                | 0.2           | 42.93                    | 6.47                                     |
| P.F       | 25.7                | 0.2           | 40.48                    | 0.387                                    |
| S.F+C.F   | 31                  | 0.2           | 44.48                    | 10.32                                    |
| P.F+C.F   | 27                  | 0.2           | 41.52                    | 2.98                                     |

### c. 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.13 shows that the crack prorogation begins from supports to word the points of application of the concentrated loads. It has been found that the failure mode of all beams specimens was shear mode type as expected.
7. Conclusions:
From experimental study, the following conclusions may be stated, such as:
1. In general, the slump decreases with adding fiber to concrete with respect to the reference beam (without fiber), but in hybrid specimens (S.F+C.F and P.F+C.F) can take advantage of adding carbon fiber to concrete with minimizing carbon fiber damage which increases the slump losses.
2. At any given load level, the deflections are reduced considerably by improving the tension zone of the specimens with fibers[14].
3. In fiber reinforced concrete beams, the steel reinforcement improved the beam stiffness, ductility and load resistance after cracking[15].
4. The addition of fibers and hybrid fibers result to a good improvement in ultimate load [ (S.F+C.F) increased (Pu) by 58.5%), while the (P.F+C.F) increased (Pu) by 38.5%].
5. From the examined specimens, it is clear that (P.F+C.F) is further efficient in use than (P.F), due to that hybrid fibers has more ability to control potential cracks in the tension area to initiate than that of plastic fiber .
6. Compressive strength increase 22.1 % for (S.F+C.F), while compressive strength increase only 13.4% for S.F and 6.3% for (P.F+C.F) while compressive strength increase only 1.18% for P.F.it observed that the compressive strength of all hybrid fiber reinforced concrete mixes is more than compressive strength R, due to high strength stiffness and modulus of elasticity of S.F and C.F which are more capable to stopping the macro cracks.
7. Splitting tensile strength increase 59.5% for (S.F+C.F), while splitting tensile strength increase only 30.1% for S.F and 41.6% for (P.F+C.F) while splitting tensile strength increase only 30% for P.F. Hybrid fiber reinforced concrete increasing in tensile strength for mixed (S.F+C.F) and (P.F+C.F), when the first crack happened, the S.F and P.F would limits growth of crack, when stress continuously damaged the specimen, birding effect P.F and S.F would transfer to the C.F to make the concrete further resistance to the stress, more increasing the splitting tensile strength .
8. The crack pattern showed that, there was no propagation of cracks throughout the depth of the beam. If fiber comes across in line of crack further crack generation was in another direction. And the width of generated cracks was very less[16].
References:

[1] Kaize Ma, Ting Qi, Huijie Liu, and Hongbing Wang 2018 Shear Behavior of Hybrid Fiber Reinforced Concrete Deep Beams, Material (Basel), Vol. 11, Oct. 2018.

[2] R. Kandasamy1 and R. Murugesan 2011 Fiber Reinforced Concrete Using Domestic Waste Plastic As Fibers Journal of Engineering and Applied Sciences Vol. 6, No. 3.

[3] Shetty M.S., 1982 Concrete Technology-Theory and Practice, S. Chand and Company, New Delhi, PP 526& 528.

[4] Park SB, Lee BI. 1993 Cem Concr Composites 15(3), 153.

[5] Chen P, Fu X, Chung DDL. 1997 ACI Mater J 94(2), 147.

[6] Chen P, Chung DDL. 1993 Composites 24 (1), 33.

[7] Brandt AM, Kucharska L. 1996 Materials for the new millennium. In Proceedings of Material Engineering Conference, vol. 1, ASCE, New York, NY.;:271.

[8] Akihama S, Suenaga T, Banno T. 1984 Int J Cem Composites Lightweight Concrete 6(3):159.

[9] Wasan I. Khalil & Akar Abdulrazaq, 2011 Mechanical Properties of High Performance Carbon Fiber Concrete, Eng. & Tech. Journal, 29(5).

[10] Iraqi specification No. 45 of 1984, the ruins of the natural resources used in the concrete and construction of Baghdad in 1984, pp. 5-20.

[11] ASTM Designation C494-86, “Chemical Admixtures for Concrete”, Annual Book of ASTM Standards 1989, V. 04-02, PP. 248-255.

[12] BS 1881, Part 116, 1989, "Method for Determination of Compressive Strength of Concrete Cubes", British Standards Institution, pp. 3.

[13] ASTM C 496-86, "Standard Test Method for Splitting Tensile of Cylindrical Concrete Specimens", Annual Book of ASTM Standards, Vol.04.02, 1989, pp.259-262.

[14] S.Syed Ibrahim, Eswaris & Sundararajan Thirumalai, 2018 Behaviour of hybrid fibre reinforced concrete beams strengthened with GFRP laminates, Structural Engineering & Mechanics, PP.631-636.

[15] Suzan A.A. Mustafa & Hilal A. Hassan 2017 Behavior of oncrete beams reinforced with hybrid steel and FRP composites, HBRC Journal 14(3), pp. 300-308.

[16] H S Jadhav1 and M D Koli1 2013 Flexural Behavior Of Hybrid Fiberreinforced Concrete Beams, International Journal of Structural and Civil Engineering Research 2(3).