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Experimental Behavior of Hybrid Steel and Polypropylene Fiber Reinforced Concrete Deep Beam Containing Openings

Abstract-*Twelve simple span reinforced concrete deep beams were tested under symmetrically two points top load to examine the effect of steel fiber and polypropylene fiber and influence of the transverse circular openings on their behavior. The variables investigated involve beams with and without openings, the volume fraction of fibers, shear span to effective ratio a/d, and inclined reinforcement around the openings. All the beams had the same overall dimensions, flexural reinforcement and opening size. Many mixes have been used by combination between steel fibers and polypropylene fibers with different percentages of (1%SF-0%PPF), (0.75%SF-0.25%PPF), (0.5%SF-0.5%PPF), (0.25%SF-0.75%PPF), (0%SF-1%PPF) in addition to mix without fibers. The test results showed that fibers greatly increase the diagonal cracking strength and shear strength of reinforced concrete deep beams, where the variation of the type of concrete from normal concrete to hybrid concrete for deep beam contains openings led to increase the ultimate strength by about 30%. In addition, it was found that the shear capacity of deep beams increased when the shear-span/effective depth ratio decreased. The inclined reinforcement around the opening was observed to be very efficient in improving the ultimate load capacity and deflection response.*

Keywords- *: Deep beams, hybrid concrete, openings, inclined reinforcement, ultimate load capacity.*

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1. Introduction

At present, reinforced concrete deep beams are more and more widely used in civil engineering with its features such as high stiffness, plausibility of mechanical characteristics and Formidable bearing capacity etc. For example, deep beams are applied to transfer beam in reinforced concrete high buildings, in every tall building construction is to achieve sufficient column free space in the lowermost storey either for parking or storage facility and deep beam considers the structural members in which most of the applied load transferred directly to the supports by tied arch [1]. In many cases, openings are required in deep beams to provide accessibility such as windows and doors or to facilitate essential services such as drainage pipes, water supply and air conditioning ducts. Hybrid fiber reinforced concrete receives interests of researchers at home and abroad because of its eminent mechanical performance, such as enhance tensile strength, flexural strength and the shear strength [2], in addition, these systems can lead to change in the cracking mechanisms [3], also improvement of mechanical properties of reinforced concrete beam under the influence of static and impact load [17]. Liu [2], studied the effect of hybrid fiber (steel and polypropylene) on the shear behavior of solid high performance concrete deep beams. Results show that hybrid fiber can increase notably the diagonal cracking load and the shear capacity of reinforced concrete deep beams. While Hasan [4], studied the influence of the transverse circular openings on the behavior of reinforced self-compacting concrete deep beams. Results show that when the opening interrupts the assumed load path, the ultimate shear was severely decreased, whereas the incorporation of the inclined reinforcement around openings was found very effective in improving the shear strength and the deflection of the tested beams. So it is necessary to study the shear behavior of hybrid fiber reinforced concrete deep beams with existence of the opening in shear span zone, especially when the opening positioned to interrupt the load path (that is: the line joining the load bearing edge and support bearing edge).

2. Experimental Program

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An experimental work was carried out to examine the behavior of hybrid steel-polypropylene fiber reinforced concrete deep beam containing openings. The study consisted of constructing and testing twelve simply supported deep beams under symmetrically two point loading. All deep beams had an overall height (h) of 400 mm, a width (b) of 150 mm, total length (L) of 1400 mm, clear span (L_n) of 1070 mm which gives Ln/h ratio equal to 2.675 which, is less than 4 that recommended by the provision of ACI 318M-14 code [5]. For each specimen, the main longitudinal tension reinforcement consisted of three deformed steel bars having a nominal diameter of 16 mm. Furthermore, vertical, horizontal web reinforcement made with 4 mm diameter deformed steel wires distributed at a spacing of 60 mm C/C which satisfy the minimum spacing recommended by ACI 318M-14 [5] as shown in Figure 1. For deep beams having inclined reinforcement, deformed steel wires of Ø 8 mm were placed as shown in Figure 2. According to the request of the relevant literature [4] on the open design, has been selected medium diameter of openings 110 mm. The specimens were classified into five groups GA, GB, GC, GD and GE according to selected parameters. Table 1 illustrates the details of the specimens. Deep beams notation consisted of three parts; the first part indicates the name of the group; the second part represents the type of the mix; and the third part represents to the number of deep beam. Thus, AN1refers that the name of the group is (A), the type of the mix is (N) for Normal, (H) for Hybrid fibers, (S) for only Steel fiber and (P) for only Polypropylene fiber, the number of deep beam is (1).

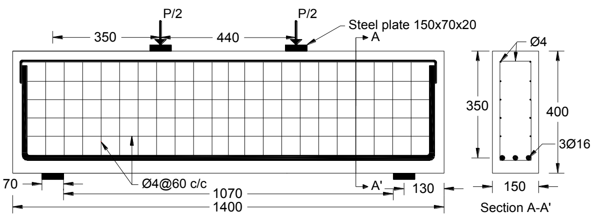

Figure 1: Specimens details and arrangement of reinforcement

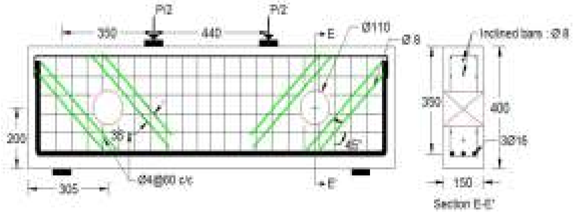

Figure 2: Specimens details and arrangement of reinforcement Note: All dimensions in mm

The parametric study was designed to cast deep beams into five series,

- Group A - This group consisted of two solid deep beams (AN1, AH2), one cast normal concrete and the other from hybrid steel-polypropylene fiber concrete.
- Group B - This group consisted of one deep beam (BN3), contains openings and cast using normal concrete without hybrid fibers.
- Group C - To study the effects of the fiber volumetric ratios. Five deep beams (CS4, CH5, CH6, CH7 and CP8), with SF percent of 1%, 0.75%, 0.50%, 0.25% and 0% were constructed, and for PPF, the percent were 0%, 0.25%, 0.50%, 0.75% and 1% respectively.
- Group D - The type of shear failure depends mainly on a/d ratio, so thus two deep beams (DH9, DH10) with 0.8, 1.2 of a/d ratios was used to study this behavior.
- Group E - The last group has two deep beams (EH11, EN12) having inclined reinforcement around their openings. But, one of them cast with normal concrete and the other from hybrid steel-polypropylene fiber concrete. Two bars of 8 mm diameter deformed steel wires were a position to make 45 degrees with the horizontal axis of the beams.

3. Materials

I. Cement

Ordinary Portland cement (Type I) was used throughout this study. Test results complying with the requirements of the Iraqi standard specifications IQS NO.5/1984 [6].

II. Fine sand

Natural sand from Al-Akhaidher region in Iraq was used in concrete mixes. The obtained results indicate that the fine aggregate grading and the sulfate content is within the limits of Iraqi specification No. 45/1984 [7].

III. Coarse Aggregate

Crushed gravel passing sieve 12mm from Al-Niba'ee region was used. The obtained results reveal that the coarse aggregate grading are within the requirements of Iraqi Standard IQS No.45/1984 [7].

VI. Additive

Super-plasticizer based on modified poly-carboxylic ether commercially named as Glenium 54 produced by BASF Company, Dubai-UAE was used with concrete mix, to increase its workability and reduce mixing water. Glenium 54 is free from chloride and complies with ASTM C494-05[8] types A and F.

IV. Fibers

a) Steel Fiber: Hooked end steel fibers manufactured by DRACO® Company were used throughout the experimental program as shown in plate 1. Table 2 shows the technical properties of steel fiber.

b) Polypropylene Fiber: High performance monofilament polypropylene fibers were used in this study as shown in plate 2. Table 3 illustrated the typical properties of the used polypropylene fibers.

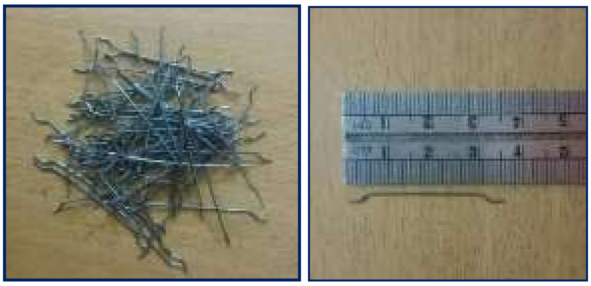

Plate 1: Hooked End Macro SF

Plate 2: Monofilament PPF

IV. Steel reinforcement

Deformed longitudinal steel bars were used in this study with nominal diameters of 16 mm while, deformed steel wires of diameter 4 mm were utilized for both vertical and horizontal shear reinforcement. Deformed steel wire of 8 mm in diameter was used as inclined reinforcement around openings. Tensile tests of the steel bars and wires were carried out according to ASTM A370-14[9] using three specimens for each diameter. Table 4 illustrates the properties of steel bars utilized.

4. Concrete Mixes

Many trial mixes have been made to gain a suitable strength (about *fc*=35 MPa) while keeping the slump in appropriate range. The quantity of water and Superplasticizer were kept constant for all mixes in order to evaluate the effects of fibers on the workability of concrete. The later mixes adopted using different volume fractions of SF and/or PPF. The details of mixes which were used in this study are shown in Table

5. Mix-cast and Curing of Concrete Specimens

The mixing of concrete was carried out in an electric horizontal pan mixer of 0.10 m^3 capacity. Before casting, the PVC pipes were fixed on the lateral mold surface by using silicon and then cleaned and oiled to avoid the adhesion of hardened concrete to the internal surface of the molds or pipes, after that the steel reinforcement cages were placed in the proper location by using plastic spacers. In all mixes, the dry fine and coarse aggregates were poured and mixed for several minutes in the mixer and the cement was added. The materials were well mixed and 2/3 of the water was blended with 2/3 super plasticizer added to the mixer and then the materials were mixed for 1 minute. The remained amount of water added to the mixer. Afterward, if the mix contains the fibers, it is added and mixed for 2 minutes to achieve homogenous distribution. Then the remained amount of super plasticizer added gradually to the mixer and all components were remixed for 5 minutes and then the mix became ready to use. The concrete was placed in the molds in three layers. Each layer was compacted by using a common immersion type portable internal vibrator. Then, the top surface of the specimen was well finished using a steel trowel to give the top a smooth finish. All deep beams were cast in a vertical position. After 24 hours the molds were removed, and the deep beams were covered with burlap to prevent evaporation of water, and cured for 28 days. Then the deep beams were cured by water sprinkling until the end of wet curing. The control specimens for each different mix included 12 standard cylinders of 100 × 200 mm, 4 prisms 100×100×400 mm specimens were cast in order to determine the compressive strength of concrete, splitting tensile strength and Flexural strength.

Plate 3: Universal testing machine used for deep beams testing

Plate 4: Test setup for deep beam specimen

6. Experimental Results

Compressive Strength (f'_c): Compression test is the most common test conducted on hardened concrete. ASTM C39/C39M-03[12] procedure was followed in the performing of compressive strength test by using three concrete cylinders of 200 × 100 mm. The cylinders were loaded axially using digital ELE testing machine of 3000 kN capacity. Table 6. Show results of compressive strength tests.

Splitting tensile strength (f_t): Splitting tensile strength test was conducted on 200x100 mm concrete cylinders according to ASTM C496/C496M -11[13]. The test was performed with the same type of machine used for compressive test. The results are presented in Table7.

Flexural strength (f_r): A prism specimen with dimensions 100×100×400mm was used throughout this test. Prisms are tested using the two points loading with a simple span of 300 mm according to the ASTM C78- 10 [14] using the digital ELE testing machine. Flexural strength test results are presented in Table 8.

7. Test response of individual groups of concrete deep beams

The cracking loads due to initiation of shear, flexural effects and ultimate load are shown in Table 9 and Plate 5. All beams tested failed in shear. Hybrid concrete beams showed better results in strength than the normal beams. In beams with openings, crack patterns characterized by formation of inclined cracks formed at the diagonal edges of the opening, then propagated toward load and support points. In all tested beams, first flexural cracks appeared after the formation of a first shear crack except beam AN1 that appeared before the formation of shear crack. The first crack in fibrous concrete beams appears at a load level higher than the load, which causes crack initiation in non-fibrous concrete beam. The failure occurred by splitting of the concrete along the line joining the edge of load plates and opening tangents opposite to the load points with the crushing of concrete at the edge bearings at the load positions for normal concrete deep beams, while the failure of hybrid concrete deep beams occurred in a same manner but without crushing of concrete. For GA beams, it was observed when inclusion fiber in concrete causing a delay in the appearance of the first cracks and the number of cracks is less than of non-fibrous concrete deep beam, especially flexural cracks. For beam with openings in GB, it was seen that the presence of the openings decreased the cracking and failure loads when compared with solid beam. From the test results of GC beams, it was concluded that the first crack in hybrid reinforced concrete deep beams appears at a load level appreciably higher than the load which causes cracking initiation in the normal concrete deep beam. Furthermore, the improvement in ultimate load by about 27.5%, 30%, 22.5%, 10% and 5% for beams CS4, CH5, CH6, CH7 and CP8 respectively. That improvement in ultimate load value because of hybridization, the presence of steel fiber, which is stronger and stiffer improves the first crack stress, and ability of polypropylene to enhance the load bearing capacity in the post-cracking zone [15]. For GD beams, it was observed that when a/d ratio increased, the shear capacity was decreased as a result of increasing the applied moment, also the shear cracks loads were decreased. For GE, It can be noted that the beams failed with load greatly larger than the failure load of beam BN3 by about 63% and 35% for beam EH11 and EN12 respectively. This increment was expected because that the inclined reinforcement was very efficient in improving the ultimate shear capacity of the pierced beams [16], on the other hand, due to the hybrid concrete.

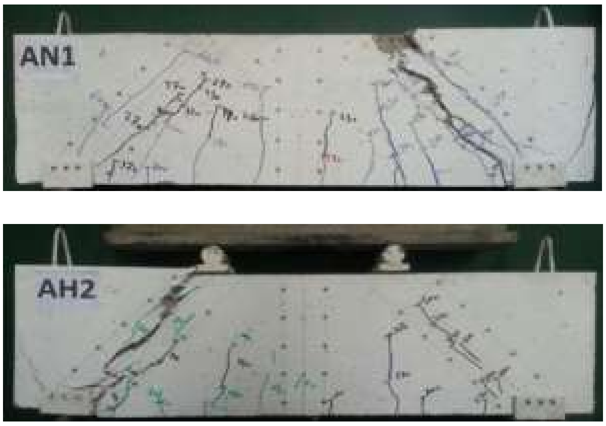

Plate 5: Deep beams after failure

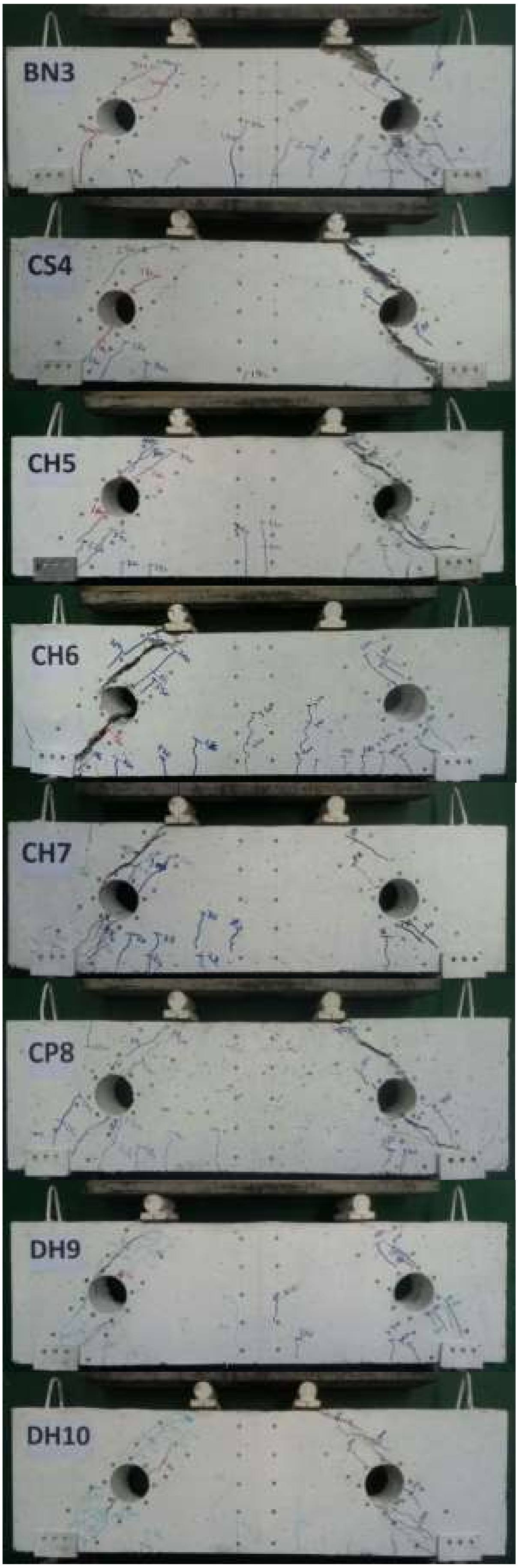

Plate 5: (continued) Deep beams after failure

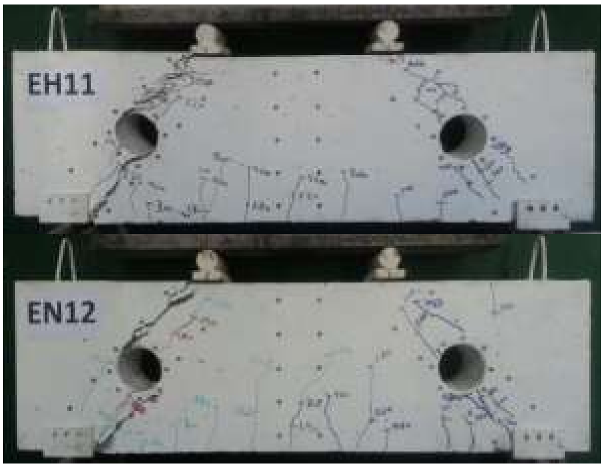

Plate 5: (continued) Deep beams after failure

8. Load-deflection Response

Figures 3 to 7 explains the load-deflection relationship of the beams tested. Clearly shows, the presence of fiber in concrete deep beam decreased the deflection of the hybrid concrete deep beam when compared with corresponding normal concrete deep beam due to increase the stiffness of hybrid concrete. Also, the presence of opening increased the deflection of the pierced beam when compared with corresponding solid one due to the decreased moment of inertia. For GD, It can be easy to observe that when a/d ratio increased the midspan deflection also increased. For GE, It can be noted that, for beam EN12 the deflection values decreased when added inclined reinforcement with increasing load as a result of arresting the crack width in the shear span, beside that the improving in deflection increasing for beam EH11, where the behavior is close to solid one AH2. Observed a clear decrease in the deflection values of the beam EH11 from the beam EN12 this because of the presence of fibers in concrete.

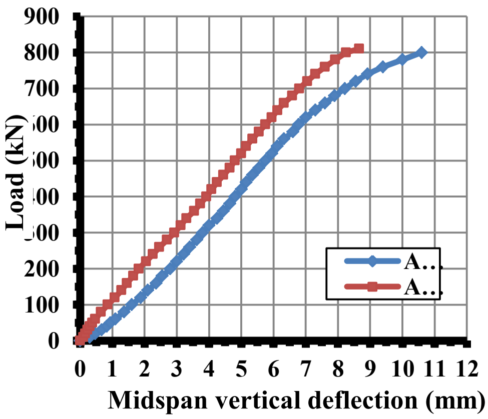

Figure 3: Load-deflection plot of GA deep beams

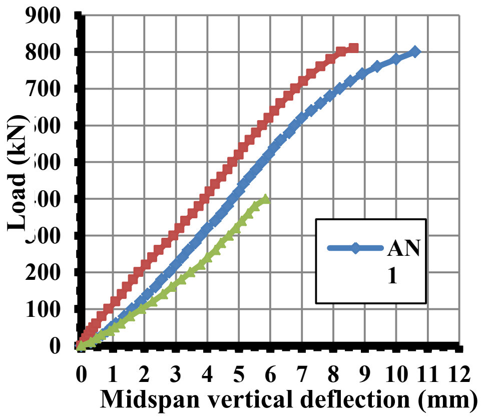

Figure 4: Load-deflection plot to comparsion between GA and GB

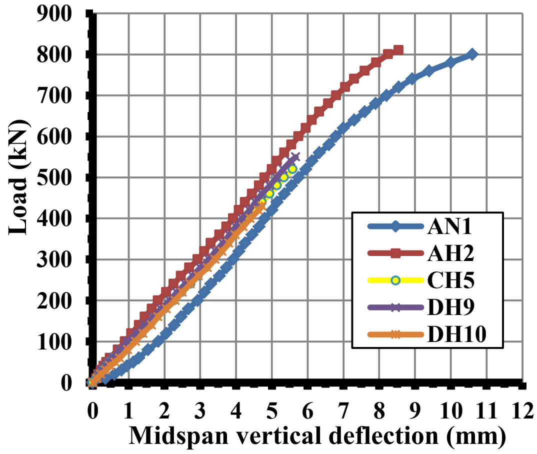

Figure 6: Load-deflection plot to comparsion between GA and GD

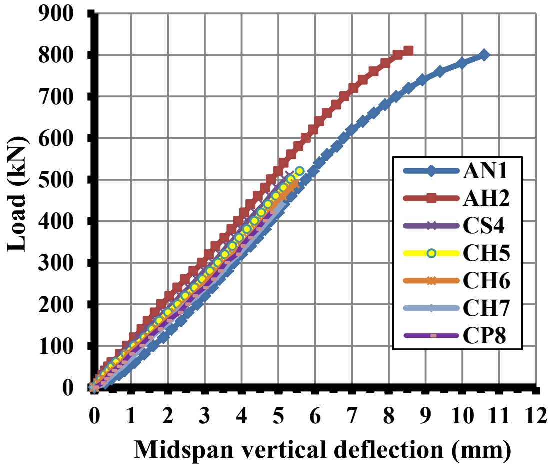

Figure 5: Load-deflection plot to comparsion between GA and GC

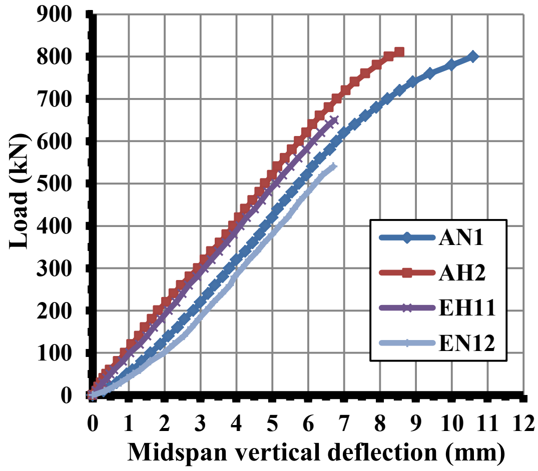

Figure 7: Load-deflection plot to comparsion between GA and GE

Table 1: Deep beam specimens' details

Group no.	Deep beam No.	Hybridization ratio		(a/d) Ratio	Distance from side edge to opening center (mm)	Inclined reinforcement
		SF%	PPF%			
A	AN1	0	0	1	—	—
	AH2	0.75	0.25	1	—	—
B	BN3	0	0	1	305	—
C	CS4	1	0	1	305	—
	CH5	0.75	0.25	1	305	—
	CH6	0.5	0.5	1	305	—
	CH7	0.25	0.75	1	305	—
	CP8	0	1	1	305	—
D	DH9	0.75	0.25	0.8	270	—
	DH10	0.75	0.25	1.2	340	—
E	EH11	0.75	0.25	1	305	2Ø8
	EN12	0	0	1	305	2Ø8

Table 2: The technical properties of SF

Properties	Result
Length L (mm)	35
Diameter D (mm)	0.55
Aspect ratio (L/D)	64
Wire tensile strength (MPa)	~ 1100
Wire bending strength (MPa)	~ 800
Elongation at break	<2%

Table 3: Properties of the used PPF

Properties	Result
Length L (mm)	12
Diameter D (mm)	0.15
Aspect ratio (L/D)	80
Tensile strength (MPa)	350
Density (kg/m^3)	900
Cross Sectional area	Circular

Table 4: Tensile test results of steel reinforcement

Bar diameter mm	Actual diameter mm	Area mm2	Yield strength MPa	Tensile strength MPa	Elongation %
16	15.95	199.706	595	680	18
8	7.85	48.43	556	632	7.8
4	4.5	15.9	548	629	6.7

Note: Tested steel bars reinforcement conformed to the requirements of ASTM A615/615M-14 [10] for grade 60 bars of minimum yield strength fy = 420 MPa, tensile strength fu = 620 MPa and elongation = 9%. Also the deformed wire reinforcement conforms to the requirements of A1064/A1064M-14[11] of minimum fy=515MPa and tensile strength fu= 585 MPa.

Table 5: Fiber reinforced concrete mix details

Mix	Cement kg/m^3	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	Water kg/m^3	Super plasticizer L/m^3	VF SF %	Vf PPF %
M1	400	745	990	185	0.4*	0	0
M2	400	745	990	185	0.4	1	0
M3	400	745	990	185	0.4	0.75	0.25
M4	400	745	990	185	0.4	0.5	0.5
M5	400	745	990	185	0.4	0.25	0.75
M6	400	745	990	185	0.4	0	1

* 1.6 liter/400 kg cement

Table 6: Compressive strength results

Mix	Hybridization Ratio		f'_c MPa-28 Days	f'_c MPa- at deep beams test time
	SF%	**PPF%**		
M1	0	0	37.3	39.8
M2	1	0	38.2	41.3
M3	0.75	0.25	36.6	38.7
M4	0.50	0.50	33.4	35.6
M5	0.25	0.75	31.5	33.5
M6	0	1	28.4	30.7

Table 7: Splitting tensile strength results

Mix	Hybridization Ratio		f_t	f_t
	SF%	PPF%	MPa-28 days	MPa- at deep beams test time
M1	0	0	2.75	3.5
M2	1	0	3.9	5.4
M3	0.75	0.25	3.75	5.2
M4	0.50	0.50	3.5	4.2
M5	0.25	0.75	3.3	4.1
M6	0	1	2.9	4.0

Table 8: Flexural strength results

Mix	Hybridization Ratio		f_r	f_r
	SF%	PPF%	MPa-28 days	MPa- at deep beams test time
M1	0	0	3.55	4.7
M2	1	0	7.0	9.1
M3	0.75	0.25	6.7	8.0
M4	0.50	0.50	6.4	7.7
M5	0.25	0.75	4.3	5.6
M6	0	1	4.0	5.2

Table 9: Experimental results of the tested deep beams

Group No.	Deep beam No.	Hybridization ratio		First shear cracking load $P_{cr(s)}$ (kN)	First flexural cracking load $P_{cr(f)}$ (kN)	Ultimate load capacity P_u (kN)
		SF %	PPF %			
A	AN1	0	0	200	140	800
	AH2	0.75	0.25	170	270	810
B	BN3	0	0	100	150	400
C	CS4	1	0	130	170	510
	CH5	0.75	0.25	160	220	520
	CH6	0.50	0.50	130	200	490
	CH7	0.25	0.75	100	220	440
	CP8	0	1	120	160	420
D	DH9	0.75	0.25	140	350	550
	DH10	0.75	0.25	110	220	430
E	EH11	0.75	0.25	140	220	650
	EN12	0	0	100	140	540

9. Conclusion

1. All tested beams failed in shear. The shear failure was characterized by a diagonal splitting mode that occurred in mid-depth of the strut between the load and support in the solid deep beams. While, it occurred by splitting along the diagonal crack joining the load and support bearing edges with opening tangents opposite to them in beams with openings.

2. At that final stage of loading, crushing of concrete occurred under the load positions for normal concrete deep beams due to over-stressing of concrete, while such failure did not appear in hybrid concrete deep beams .

3. The presence of the openings had a significant effect on the ultimate load capacity of the concrete deep beams. For the normal concrete deep beam BN3 the ultimate load capacity was decreased by about 50% when compared with corresponding solid AN1. Such difference in ultimate load decreased to reach 36% when the ultimate load of hybrid concrete deep beam CH5 compared with the ultimate load of hybrid concrete deep beam AH2.

4. Hybrid fiber can increase notably the ultimate load capacity and the diagonal cracking strength of reinforced concrete deep beams. The best improvement in ultimate load was obtained in beam CH5 (0.75% SF + 0.25% PPF) by about 30%, while the less one was obtained in beam CP8 (1%PPF) by about 5%.

5. The shear strength of deep beams was increased as the shear-span/effective depth ratio decreased. When the ratios decreased from 1.2 to 0.8 the shear strength increased by about 28%. The load-deflection relationship was linear prior to failure with convergent deflection values at the same stages of loading while the shear cracking loads decreased slightly when the a/d ratio was equal to 1.2.

6. The incorporation of the inclined reinforcement around openings was found very effective in improving the shear strength and the deflection of the tested beams. It was witnessed that, when using the inclined reinforcement around openings in hybrid concrete deep beam, the ultimate load capacity increased by about 25%, while using it in normal concrete deep beam increased the ultimate load by about 35%. Furthermore, the load-deflection relationship became similar to that of a solid beams.

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