EFFECT OF HYBRID MICRO STEEL-POLYPROPYLENE FIBERS ON HIGH STRENGTH CONCRETE WITH MICRO SILICA FUME

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Abstract

The present investigations consider the effect of hybrid micro steel- polypropylene fibers on high strength concrete. The fractions of steel and polypropylene fibers are 1% and 0.5% by volume respectively. Many mixes have been investigation by combination between steel fibers and polypropylene fibers with different percentages it is (0%S.F-100%P.P.F), (100%S.F-0%P.P.F), (25%S.F, 75%P.P.F), (50%S.F-50%P.P.F), (75%S.F-25%P.P.F) in addition to reference mix. Properties of high strength concrete such as compressive strength, splitting strength, flexural strength, static modulus of elasticity, and absorption have been studied. The results showed that, the compressive strength decrease by about 28% when adding (0%S.F-100%P.P.F), and there are a small increasing with adding (100%S.F-0%P.P.F). However the results showed that there are an inverse relationship between compressive strength and the amount of polypropylene fibers. Experimental work also showed that adding (0%S.F-100%P.P.F)decrease the splitting strength by about 16%, while using hybrid fibers increase the splitting strength but less than its increasing when adding (100%S.F-0%P.P.F). It can be concluded that, the maximum effect of hybrid fibers is on the flexural strength, it is reach to 128% more than reference mix. Furthermore absorption increases by using polypropylene fibers.

Keywords: steel fibers, polypropylene fibers, high strength concrete, compressive strength, splitting strength, flexural strength, modulus of elasticity.

تأثير هجين الياف الحديد الدقيقة-البولي بروبلين على الخرسانة عالية المقاومة الحاوية على غبار السلكا الدقيقة

الخلاصة

هذا البحث أخذ بنظر الاعتبار تأثير مزيج الألياف الحديدية وألياف البولي بروبلين على الخرسانة عالية المقاومة. إن نسبة ألياف الحديد والبولي بروبلين هي 1% و5,0% على التوالي. عدة خلطات تم الاستقصاء عنها وذلك بالمزج بين ألياف الحديد والبولي بروبلين بنسب مختلفة وهي)0% ألياف حديد-001% ألياف البولي بروبلين(,)001% ألياف حديد-0% ألياف البولي بروبلين(,)52% ألياف حديد-57% ألياف البولي بروبلين(,)05 % ألياف حديد-05% ألياف البولي بروبلين(,)57 % ألياف حديد-52% ألياف البولي بروبلين(بالإضافة إلى الخلطة المرجعية. مواصفات الخرسانة العالية المقاومة تم دراستها كمقاومة الانضغاط و مقاومة الانشطار ومعامل الإنحاء ومعامل المرونة ونسبة الامتصاص. النتائج أظهرت إن مقاومة الانضغاط تقل بنسبة 82% بإستخدام)0% ألياف حديد-001% ألياف البولي بروبلين(وعند استخدام)001% ألياف حديد-0% ألياف البولي بروبلين(تزداد مقاومة الانضغاط بنسبة صغيرة . لكن النتائج أظهرت إن هناك علاقة عكسية بين زيادة نسبة ألياف البولي بروبلين ومقاومة الانضغاط. النتائج العملية أظهرت أيظا إن إضافة)0 % ألياف حديد-001 % ألياف البولي بروبلين(تقلل من مقاومة الانشطار بنسبة 61% ولكن استخدام مزيج الألياف يزيد من مقاومة الانشطار ولكن هذه الزيادة أقل من الزيادة الناتجة من استخدام)001 % ألياف حديد-0% ألياف البولي بروبلين(. ويمكن الاستنتاج إن أكثر تأثير لمزيج الألياف هو على مقاومة الانحناء حيث تصل الزيادة إلى 821% أكثر من الخلطة المرجعية. بالإضافة إلى إن نسبة الامتصاص تزداد بإستخدام ألياف البولي بروبلين.

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Introduction

The term high-strength concrete (HSC) is generally used for concrete with compressive strength higher than 55 MPa [1]. The use of HSC has steadily increased over the past years, which leads to the design of smaller sections. This in turn reduces the dead weight, allowing longer spans and more usable area of buildings [2].

Concrete has inherently brittle nature and has some dramatic disadvantages such as poor deformability and weak crack resistance in the practical usage. Also their tensile strength and flexural strength is relatively low compared to their compressive strength. It is found that, adding fibers in concrete enhancing its structural properties. Fiber–reinforced concrete is becoming an increasingly popular construction material due to its improved mechanical properties over unreinforced concrete and its ability to enhance the mechanical performance of conventionally reinforced concrete [3]. Hybrid Fiber Reinforced Concrete (HFRC) is formed from a combination of different types of fibers, which differ in material properties, remain bonded together when added in concrete and retain their identities and properties. Combining different kinds of fibers in the same mix enables a cementitious composite to achieve better properties and known that significant optimization is possible of Fiber Reinforced Composite (FRC) by rationally combining fibers to achieve different physical and mechanical improvements [3]. Hybrids based on fiber function- one type of fiber is intended to improve the fresh and early-age properties, such as ease of production and plastic shrinkage crack control, while the second fiber leads to improved mechanical properties. Some of these hybrids are commercially available with a low dosage of polypropylene fiber that is combined with a higher dosage of steel fiber. These hybrids include the combination of microsynthetic fibers with steel macrofibers, or microsynthetic fibers with macrosynthetic fibers [4].

Literature review

There are many researchers studied the behavior of high strength concrete with fibers:

Wei Sun, et al. in (2001) [5] investigated the high-performance concrete (HPC) incorporated with expansive agent and hybrid fibers, i.e., steel fibers, polyvinyl alcohol fiber (PVA fiber), and polypropylene fiber (PP fiber), was produced. The properties measured included shrinkage and water permeation of the concrete. Test results indicated that the hybrid fibers of different types and sizes could reduce the size and amount of crack source at different scales.

Salih, S. A., et al. in (2005) [6]investigated the effect of steel fibers content and the combined effect of rice husk ash (RHA) and high range water reducing agent (HRWRA) on the mechanical properties of high performance concrete (HPC). The percentages of steel fibers were (0.5%, 1% and 1.5%). The addition of steel fibers (0.5% and 1%) to HPC leads to increase the compressive strength of HPC, but it decreased at 1.5% steel fiber. The optimum volume fraction of steel fiber was 1%, 8% RHA and 6% superplasticizer were used to improve the compressive strength of concrete, the percentage increases were 0.89%, 11.57% and 21.6% at 7, 28, and 90 days, respectively. Furthermore the results showed significant increase in splitting and flexural strengths at all ages

Sarsam, K. & Al-Azzawi, Z. (2009) [7] studied the mechanical properties of high-strength concrete with and without fibers. Different types of steel fibers (straight, hooked, duoform, crimped) with a volume fraction ranging from 0 to 2 percent were studied. The concrete compressive strength ranged from 41 to 115 MPa Test results indicated that adding 1.5 percent by volume of straight steel fibers resulted in a small increase of 6% in compressive strength, and resulted in an increase of 24.5% in modulus of rupture and 32% in splitting tensile strength; compared to an increase of 17.5% in compressive strength, 77% in modulus of rupture, and 99% in splitting tensile strength; when using 1.5% volume fraction of hooked steel fiber.

Yew, M. K., et al. in (2011) [8] Investigated the strength properties of hybrid nylon-steel and polypropylene-steel fiber-reinforced high strength concrete at low volume fraction. The content of the high performance macro structure steel fibers is at 0.4% volume fraction, and the content of micro nylon and polypropylene-fibers is at 0.1% volume fraction. The experimental results showed that, the compressive strength and splitting tensile strengths and modulus of rupture (MOR) properties of the nylon-steel fiber concrete improved by 3.2, 8.3 and 10.2%, respectively.

Dawood and Ramli (2012) [2] investigated the mechanical properties of high strength flowing concrete with hybrid fiber (steel fibers, palm fibers, and synthetic fibers) as 2 vol.% fraction. The results demonstrated that the hybridizations of such fibers enhance the flexural toughness and tensile strength of the concrete. Increasing the content of hybrid fibers has led to the increase of impact load resistance and thus the first crack and the post-crack strength respectively.

Materials

1. Cement

Ordinary Portland cement was used in this work type ALDOUH and the chemical analysis of cement are given in the Table (1), and the results compared with Iraqi specifications NO 5/1984[9]

Table (1): Chemical Analysis of Cement

Compound composition	CaO	SiO2	Al2O3	Fe2O3	SO3	MgO	L.O.I	L.S.F.	I.R.
Percentage by weight	63.2	18.9	3.8	4.6	1.5	1.7	1.9	0.9	0.4
Limits of Iraqi spec. No. 5/1984	----	----	----	----	≤ 2.5	≤ 5.0	≤ 4.00	0.66 -1.02	≤ 1.5

2. Fine aggregate

Natural washed sand with a 4.75-mm maximum size is used as fine aggregates from Ichlat region. The grading of the sand conformed to the requirement of Iraqi specifications NO 45/1984 [10]. Its sieve analysis results are given in Table (2).

Table (2): Grading of fine aggregate

Sieve size	Cumulative Passing %	Limit of Iraqi spec. NO 45/1984
10 mm	100.00	100
4.75 mm	95.08	90-100
2.36 mm	83.50	75-100
1.18 mm	70.03	55-90
600 µm	57.50	35-59
300 µm	16.40	8-30
150 µm	2.14	0-10

3. Coarse aggregate

The washed coarse aggregate used was crushed aggregate of 19-mm maximum size from Ichlat region. The sieve analysis of this aggregate is shown in Table (3). It conforms to the Iraqi specification No. 45/1984[10]

Table (3): Grading of Coarse aggregate

Sieve size	Cumulative Passing %	Limit of Iraqi spec. NO 45/1984
37.5 mm	100.00	100
20 mm	97	95-100
10 mm	47	30-60
5 mm	3.6	0-10

4. Steel fibers

The steel fibers used in this test program were straight steel fibers; Table (4) shows the properties of steel.

Table (4): Properties of steel fiber

Property	Specifications
Density	7800 kg/m³
Tensile strength	2850 MPa
Length	15 mm
Diameter	0.2 mm
Aspect ratio	75

******Manufacturer Properties***

5. Polypropylene fibers

Polypropylene used in this work has the following properties

Table (5): Properties of Polypropylene fiber

Property	Specifications
Specific gravity	0.91 g/cm³
Tensile strength	350 MPa
Length	12 mm
Diameter	18 µm
Young modulus	3700 MPa

****Manufacturer Properties***

Plate (1) polypropylene fibers (left) and steel fibers (right)

6. Silica Fume

Silica fume is a highly active pozzolanic material and is a by-product from the manufacture of Silicon or Ferro-silicon metal. It is collected from the flue gases from electric arc furnaces.

Silica fume is an extremely fine powder, with particles about 100 times smaller than an average cement grain. It is generally used as a partial replacement of cement for concrete structure that need high strength or significantly reduced permeability to water. The chemical composition and physical requirements are listed in Table (6); silica fume used in this investigation conforms to the chemical and physical requirements of ASTM C-1240 (2003) [11].

Table (6): Chemical and Physical Analysis of Silica Fume

Property	Specifications	ASTM C-1240 limitations
SiO_2	90.3	> %85
L.O.I.	3.8	≤ 6.0
Moisture content	0.8	≤ 3.0
Percent retained on 45µm (No.325) sieve, max, %	7	≤ 10
Accelerated Pozzolanic Strength Activity Index with Portland cement at 7 days, min. percent of control	125.6	≥ 105
Specific surface, min,(m^2/g)	21	≥ 15

***Manufacturer Properties**

7. High-Range Water Reducing Admixture (Superplasticizer)

Sika viscocrete-5930 complies with ASTM-C- 494 Types G and F is used as a High-Range Water Reducing Admixture HRWRA to get high flow ability with high water reduction up to 30 % with high early strength, is suitable for mixing with silica fume.

Experimental work

In this research, combination has been made between two types of fibers (steel and polypropylene). Different percentages of steel fibers that have total volume (1%) and polypropylene fibers that have total volume (0.5%) combined to form hybrid fibers in order to study the behavior of some properties of high strength concrete with silica fume (compressive strength, splitting, flexural, modulus of elasticity and absorption). six mixes have been investigated include reference mix as shown in Table (7). All experimental work has been made in Almuthana university/engineering collage

Table (7): Details of the experimental program, with Slump 200 mm

Mix	Percent of 1% S.F	Percent of 0.5% P.P.F	Cement (Kg/m^3)	Sand (Kg/m^3)	Aggregate (Kg/m^3)	W/C	S.P % of cement
A	0	0	500	700	1050	0.3	1
B	0	100	500	700	1050	0.3	2
C	100	0	500	700	1050	0.3	1.2
D	25	75	500	700	1050	0.3	1.8
E	50	50	500	700	1050	0.3	1.5
F	75	25	500	700	1050	0.3	1.3

***** *S.F: Steel Fibers***
***** *P.P.F: Polypropylene fibers***
***** *S.P: Superplasticizer***

Mixing, casting, curing

The procedures for mixing the fiber reinforced concrete involved the following. Firstly, the gravel and sand were placed in a concrete mixer and dry mixed for 1 min. Secondly, the cement and silica fume were spread and dry mixed for 1 min. After which, the specified amount of fibers were distributed and mixed for 3 min in the mix. This was followed by the addition of water and the Superplasticizer with a mixing time of 5 min. lastly, the freshly mixed fiber-reinforced concrete is fed into the molds, the molds were lightly coated with mineral oil before use, according to ASTM C 192-88 [12], concrete casting was carried out in different layer each layer of 50 mm. Each layer was compacted by using a vibrating table for (15-30) second until no air bubbles emerged from the surface of the concrete, and the concrete is leveled off smoothly to the top of the molds. Then the specimens were kept covered in the laboratory for about (24) hours. After that the specimens remolded carefully, marker and immersed in water until the age of test.

Testing of concrete

The testing was completed in compression machine with 2000 kN capacity

1. Compressive strength test

Based on BS 1881: part 5 [13], the compressive strength was carried out on 100x100x100 mm cube specimens. The compressive strength was taken as the average value of three specimens.

2. Splitting tensile strength test

The splitting tensile strength was conducted on cylinders of (100 * 200 mm). The average of three test specimens was taken. The test was carried out in accordance with ASTM C 496-86 [14].

3. Flexural strength test

This test was done according to ASTM C78 (2002) [15]. The flexural strength was carried on (100x100x400mm) prism. The flexural strength was taken as the average value of three specimens.

4. Water Absorption

Water absorption at 28 days of curing tests of three 100×100×100 mm concrete beams were conducted according to the requirements of ASTM C 642 [16].

5. Static Modulus of Elasticity

The modulus of elasticity was done according ASTM C 469 (2002) [17] with cylinder dimension (150 * 300 mm).

Results and Discussion

1. Compressive strength

Compressive strength in 7 and 28 days has been predicted, the results of compressive strength are shown in Table (8). It can be seen that for mix B that content 100% polypropylene fibers, the compressive strength decrease from that on mix A by about 25% and 28% for 7 and 28 days respectively. The reduction of compressive strength may be attributed to the nature of polypropylene that absorbs the water and the cement paste surrounds it so, the interaction between the aggregate and cement paste reduce. However adding 100% of steel fibers to the mix led to increasing the compressive strength by about 5% for 7 and 28 days. It can be

observed that, under axial loads, cracks that occur in microstructure of concrete and steel fiber limit the formation and growth of cracks by providing pinching forces at crack tips.
It can also seen that decreasing the percent of polypropylene fiber (mix D, E and F) and replace it by steel fiber let to increase the compressive strength as compare with mix B by about 11%, 34% and 40% respectively at 28 days as shown in Figure (1).

Table (8): Compressive strength at 7 and 28 days

Mix	Compressive strength MPa-7 days	Compressive strength MPa-28 days
A-0%S.F-0%P.P.F	45.3	59.4
B-0%S.F-100%P.P.F	34	42.8
C-100%S.F-0%P.P.F	47.7	62.5
D-25%S.F-75%P.P.F	37.6	47.6
E-50%S.F-50%P.P.F	42.1	57.3
F-75%S.F-25%P.P.F	44.2	60.1

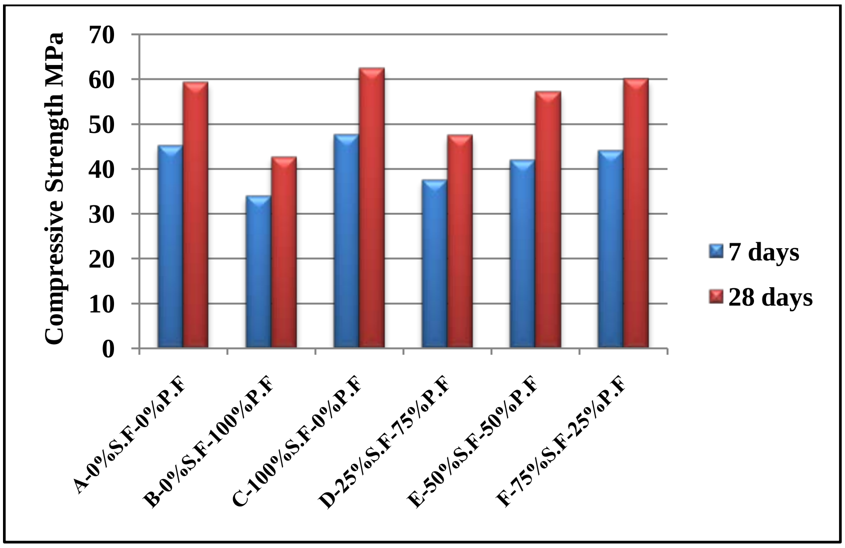

Fig. (1): Compressive strength at 7 and 28 days

2. Splitting tensile strength

The effect of steel and polypropylene fibers on splitting strength can be shown in Table (9) and Figure (2). It can be seen that the maximum effect on splitting strength is for mix C (adding 100% steel fiber and 0% polypropylene) and equal to 52% than that of the unreinforced control concrete (mix A). The substantial increase in splitting-tensile strength can contribute to the bridging action of the fibers. Once the splitting occurred and continues, the fibers bridging across the split portions of the matrix acted through the stress transfer from the matrix to the fibers and, thus, gradually supported the entire load. The stress transfer improved the tensile strain capacity of the two fiber-reinforced concretes and, therefore, increased the splitting tensile strength of the reinforced concretes over the unreinforced control counterpart [8]. Adding polypropylene fibers without steel fibers led to decrease the splitting strength by about 16.3%. However decreasing the percent of polypropylene fibers and adding steel fibers in the same time has the significant effect on splitting strength it's about 27.4%, 34.8%, and 39.8% for mixes D, E, and F respectively.

Table (9): Splitting tensile strength at 28 days

Mix	Splitting strength MPa-28 days	% Increase or decrease in splitting strength
A-0%S.F-0%P.P.F	4.60	---------
B-0%S.F-100%P.P.F	3.85	Dec. 16.3
C-100%S.F-0%P.P.F	7.00	Incre. 52
D-25%S.F-75%P.P.F	5.86	Incre. 27.4
E-50%S.F-50%P.P.F	6.20	Incre. 34.8
F-75%S.F-25%P.P.F	6.43	Incre. 39.8

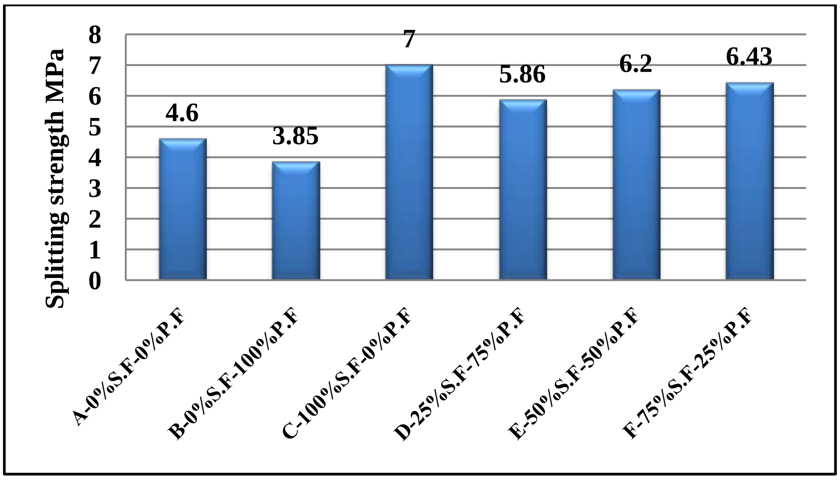

Fig. (2): Splitting tensile strength at 28 days

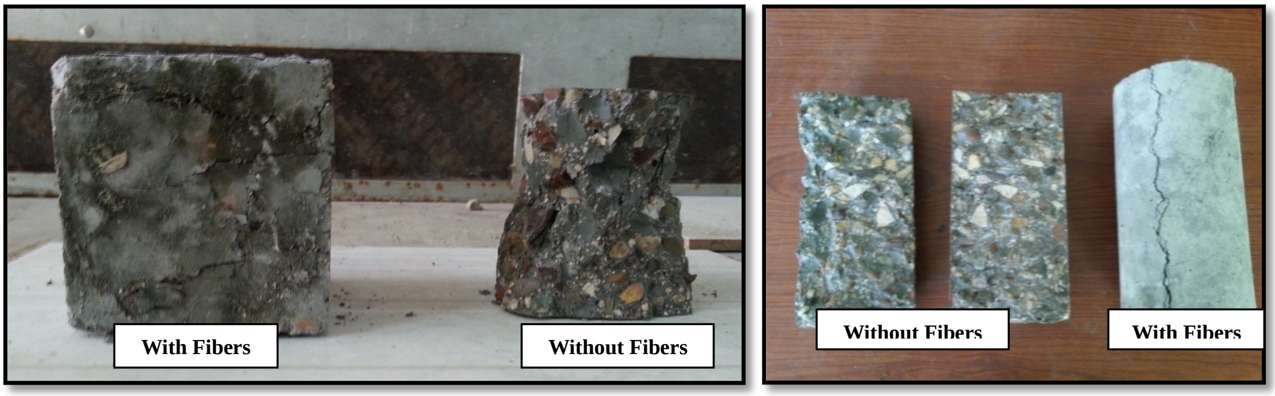

Plate (2): Mode failure of concrete with and without fibers

3. Flexural strength

Flexural strength test results are presented in Table (10) and Figure (3). The results demonstrate that using steel fibers and hybrid steel and polypropylene fibers causes a considerable increase in flexural strength in comparison with the non-fibrous concrete and the flexural strength increases with decrease the polypropylene fibers by about 73.7%, 95.2%, and 112% for mix D, E and F respectively. Generally it can be seen that the flexural strength for mix F (75% steel fiber and 25% polypropylene) have higher flexural strength than that for other mixes it's about 128.6% more than reference mix. While adding polypropylene without steel causes decrease in flexural strength by about 28.6%. It can be noticed from the experimental work that non-fibered specimen suddenly failed in a brittle manner and separated into two parts, while fiber concrete specimens have many cracks before the failure.

Table (10): Flexural strength at 28 days

Mix	Flexural strength MPa-28 days	% Increase or decrease in flexural strength
A-0%S.F-0%P.P.F	7.77	---------
B-0%S.F-100%P.P.F	5.55	Dec. 28.6
C-100%S.F-0%P.P.F	13.50	Incre. 73.7
D-25%S.F-75%P.P.F	15.17	Incre. 95.2
E-50%S.F-50%P.P.F	16.47	Incre. 112
F-75%S.F-25%P.P.F	17.76	Incre. 128.6

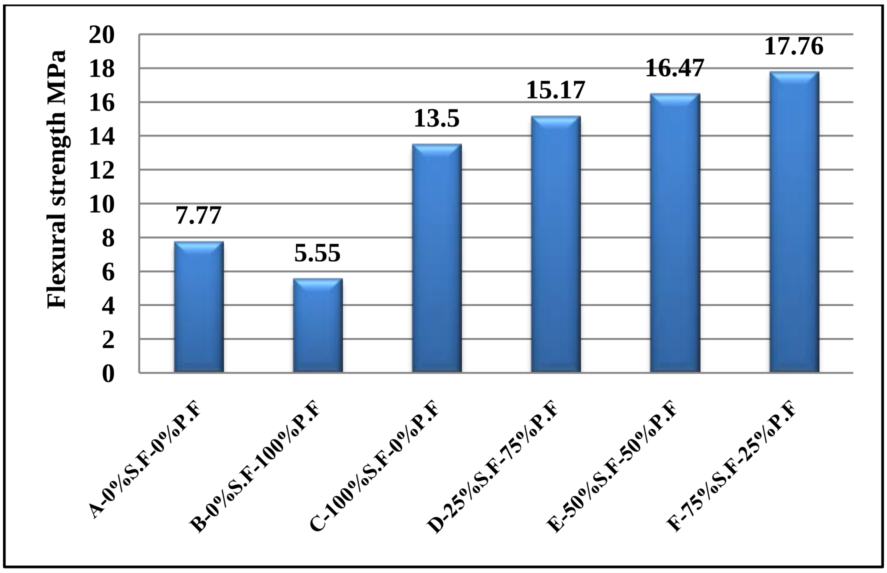

Fig. (3): Flexural strength at 28 days

Plate (3): Flexural strength of high strength concrete

4. Static modulus of elasticity

The static modulus of elasticity results for all mixes are presented in Table (11) and Figure (4), which show slight increases in the static modulus of elasticity at 100% steel fiber with respect to non-fiber concrete. In the other hand replacing steel fiber by polypropylenes fiber let to reduce the static modulus of elasticity and the maximum decreasing for 100% polypropylene fiber it is about 19.51%. There are an effective relationship between compressive strength and modulus of elasticity and the decreasing of static modulus related to decreasing of compressive strength as shown in Figure (5).

Table (11): Modulus of elasticity at 28 days

Mix	Modulus of elasticity GPa-28 days	% Increase or decrease in Modulus of elasticity
A-0%S.F-0%P.P.F	38.34	----------
B-0%S.F-100%P.P.F	30.86	Dec. 19.51
C-100%S.F-0%P.P.F	39.10	Inc. 2.00
D-25%S.F-75%P.P.F	34.61	Dec. 9.73
E-50%S.F-50%P.P.F	36.24	Dec. 5.50
F-75%S.F-25%P.P.F	37.22	Dec. 2.90

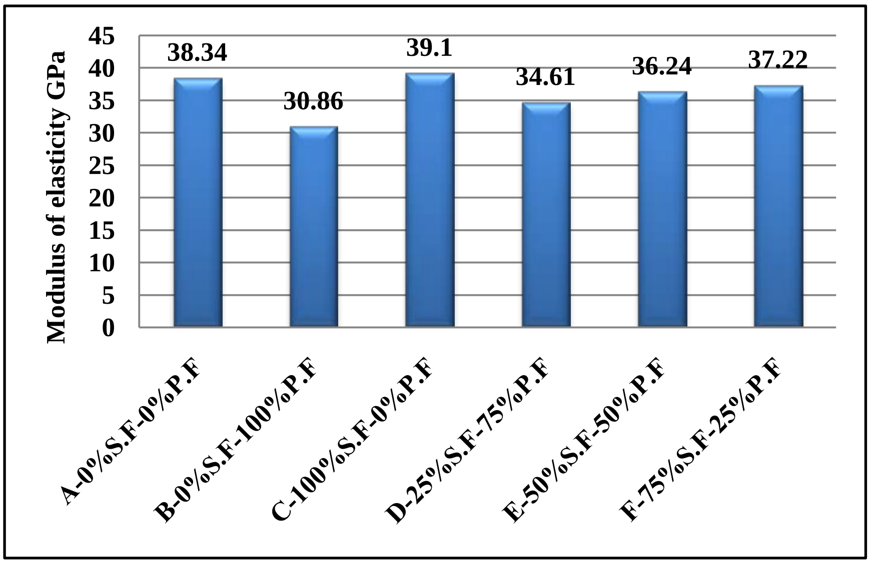

Fig. (4): Modulus of elasticity at 28 days

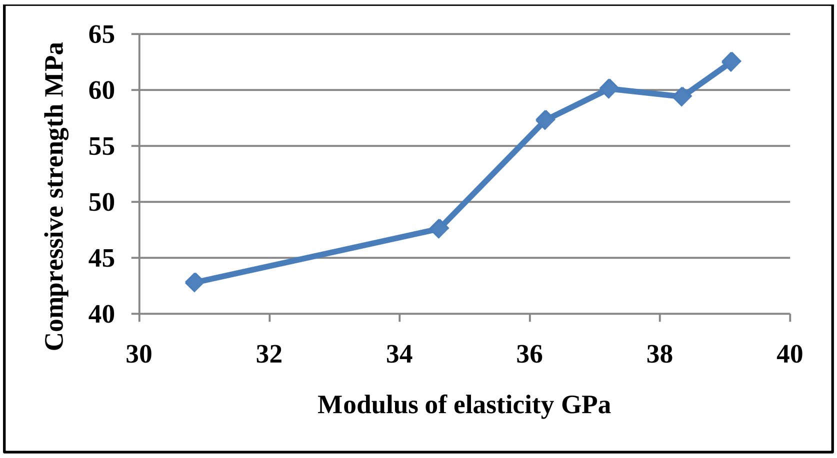

Fig. (5): Effect of compressive strength on modulus of elasticity

5. Water Absorption

Results of water absorption of concrete specimens are shown in Figure (6) and Table (12). It is clearly shown that introducing fibers to the concrete have direct effect on the water absorption behavior of concrete. The water absorption of all specimens increases by adding polypropylene fibers although increase in water absorption for polypropylene fibers is relatively higher than steel fibers. It may be concluded that increase in water absorption is due to entrapment of air during the mixing and thereby generating voids in concrete.

Table (12): Water absorption at 28 days

Mix	Water absorption -28 days (%)
A-0%S.F-0%P.P.F	1.72
B-0%S.F-100%P.P.F	6.2
C-100%S.F-0%P.P.F	2.44
D-25%S.F-75%P.P.F	5.7
E-50%S.F-50%P.P.F	5.1
F-75%S.F-25%P.P.F	4.7

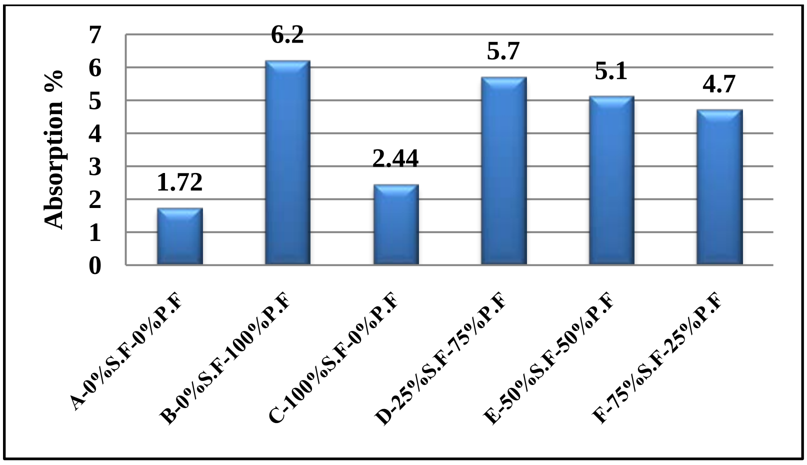

Fig. (6): Water absorption at 28 days

6. Effect of Fibers on Workability

From Table (13), it can be concluded that, increasing the amount of the polypropylene fibers in the mixes led to decrease in the workability, that is related to Polypropylene fibers absorb the water in the mix so that to obtain the same slump for all mixes it must be increase the proportion of S.P to offset the shortage of water in the mix.

Table (13): Proportions of super plasticizer in the mixes

Mix	S.P % of cement
A-0%S.F-0%P.P.F	1
B-0%S.F-100%P.P.F	2
C-100%S.F-0%P.P.F	1.2
D-25%S.F-75%P.P.F	1.8
E-50%S.F-50%P.P.F	1.5
F-75%S.F-25%P.P.F	1.3

Conclusions

Based on the tests results, the following conclusions can be drawn:

1- Compressive strength decrease with adding polypropylene alone, that decreasing about 28%. However using hybrid fibers leads to a considerable increase in compressive strength as compare with concrete with polypropylene fibers that increase about 11.2%, 33.9%, and 40.4% for (D-25%S.F-75%P.P.F), (E-50%S.F-50%P.P.F), and (F-75%S.F-25%P.P.F) respectively, while the increase in compressive strength is relatively lower when adding steel fibers as compare with non-fibrous concrete.

2- Fibers effect on the failure mode of high strength concrete specimens, where concrete without fibers has an explosive collapse under loading while with fibers, these fibers showed an arresting or confining effect in preventing specimen from sudden failure.

3- Splitting tensile strength increased by about 52% by adding 1% steel fibers without polypropylene fibers. In the other hand, adding 0.5% polypropylene fibers without steel fibers lead to decrease splitting strength by about 16% as compare with reference mix. When the hybrid fibers is added the splitting strength increase but less than when using 100% steel fiber without polypropylene and still achieves higher strength compared to the reference concrete mixture.

4- The modulus of rupture can be improved when the hybrid polypropylene-steel fibers is used and the maximum increasing with the combination of 75% of (1%) by volume SF and 25% of (0.5%) by volume PPF (F-75%S.F-25%P.P.F) it is about 128% as compared with reference mix. While adding polypropylene fibers decrease the modulus of rupture by about 28.6%.

5- The modulus of elasticity decrease with the addition of hybrid fibers. The decreasing of static modulus related to decreasing of compressive strength.

6- Water absorption increase with adding fibers and maximum increasing with using polypropylene without steel it is about 6.2% compared with reference mix.

7- There are an inverse relationship between slump and the percentage of polypropylene

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