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Effect of Hybrid Fibers on the Mechanical Properties of High Strength Concrete

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ABSTRACT

In this study, high strength concrete of 75 MPa compressive strength was investigated. The experimental program was designed to study the effect of fibers and hybrid fibers (steel and polypropylene fibers) on the fresh (workability and wet density) and hardened properties (compressive strength, splitting strength, flexural strength and dry density) of high strength concrete. Results show that decreases in slump flow of all concrete mixtures containing steel, polypropylene and hybrid fibers compared with control mix (0% fiber). Hybrid high strength concrete with steel and polypropylene fibers showed superior compressive, splitting, flexural strengths over the others concrete without or with single fibers content. The test results indicate that the maximum increase in compressive and flexural strengths are obtains with the hybridization ratio (70%steel + 30% polypropylene) and were equal to 14.54% and 23.34% respectively, compared with the control mix. While, the maximum increase in splitting tensile strength with (100% steel fiber + 0 polypropylene) is 21.19%.

KEYWORDS: High strength concrete, Fibers, Hybrid fibers high strength concrete, Mechanical properties.

تأثير الألياف الهجينة على الخواص الميكانيكية للخرسانة عالية المقاومة

الخلاصة

في هذا البحث تم دراسة الخرسانة عالية المقاومة ذات مقاومة انضغاط (75 MPa). صمم البرنامج العملي لدراسة تأثير الألياف والألياف الهجينة (ألياف حديدية وألياف البولي بروبلين) على الخواص الطرية (قابلية التشغيل والكثافة الرطبة) والخواص المتصلبة (مقاومة الانضغاط، مقاومة الانشطار ، مقاومة الانحناء والكثافة الجافة) للخرسانة عالية المقاومة. نتائج الفحوصات بينت نقصان في الهطول لكل الخلطات الحاوية على ألياف الحديد، ألياف البولي بروبلين والألياف الهجينة مقارنة مع الخلطة المرجعية غير الحاوية على ألياف. الخرسانة العالية المقاومة الهجينة بألياف الحديد وألياف البولي بروبلين أظهرت مقاومة عالية في الانضغاط، مقاومة الانشطار ومقاومة الانحناء أكثر من الخرسانة غير الحاوية على ألياف أو الحاوية على ألياف من نوعية واحدة. أظهرت نتائج الفحوصات بان أعلى نسب زيادة في مقاومة الانضغاط ومقاومة الانحناء كانت في الخلطة الحاوية على ألياف هجينة (70% ألياف حديد + 30% ألياف بولي بروبلين) وكانت نسب الزيادة 14.54% و 23.34 % على التوالي، مقارنة مع الخلطة الخرسانية المرجعية الغير حاوية على ألياف. بينما أعلى نسبة زيادة في مقاومة الانشطار كانت في الخلطة الحاوية على (100% ألياف حديد + 0% ألياف بولي بروبلين) وكانت نسبة الزيادة 21.19%.

الكلمات الدالة: الخرسانة عالية المقاومة، الألياف، خرسانة الألياف الهجينة عالية المقاومة، الخواص الميكانيكية.

INTRODUCTION

High strength concrete (HSC) is generally accepted as a concrete having a compressive strength above 55 MPa according to ACI Committee 363[1].

Performance of conventional Concrete is enhanced by the addition of fibers in concrete. The brittleness in concrete is reduced and the adequate ductility of concrete is ensured by the addition of fibers in concrete. The fibers used are polyolefin and steel (crimped) fibers in various volume fractions. The main reasons for adding steel fibers to concrete matrix is to improve the post-cracking response of the concrete i,e., to improve its energy absorption capacity and apparent ductility, and to provide crack resistance and crack control. The base polyolefin is highly resistant to the majority of aggressive agents and will never oxidize when exposed to the conditions which cause steel to rust. The hybrid fibers of various proportions from 0.5%, 1%, 1.5% and 2% of volume of concrete were used in the concrete mixes. The workability of hybrid fiber reinforced concrete mix was increased by addition of superplasticizer Conplast SP 337. The test results show that use of Hybrid Fiber reinforced concrete improves flexural performance of the beams during loading [2].

High strength concrete is brittle material that has low tensile strength, low strain capacity and its tensile strength is typically only about one tenths of its compressive strength. These draw backs may be avoided by the addition of short discrete fibers randomly distributed in concrete[3]. The behavior of fiber reinforced concrete and its use depends upon many factors such as length of fiber, fiber volume fraction, fiber aspect ratio, orientation of fiber in composite, spacing between fiber and fiber matrix interfacial bond. Generally, as fiber volume increases, workability decreases for all aspect ratios. Also increasing fiber volume increases the wet density of fresh concrete slightly for all concrete series and compressive strength reduces. This could be attributed to difficulties coming from achieving good compaction [3]. The split tensile strength of hybrid fiber concrete was found to be higher compared to reference and mono steel fiber concrete. The hybrid fiber concretes containing steel and glass at all volume fractions show the best split tensile strength among all concretes at all dosages. Among other combinations, only the steel-polypropylene combination at a dosage of 0.5% (with 30% polypropylene fibers) gave strength higher than the mono-steel fiber concrete. Enhancement in split tensile strength is expected with fibers since the plane of failure is well defined (diametric). The higher the number of fibers bridges the diametric 'splitting' crack, the higher would be the split tensile strength. However, fiber availability is not the only parameter governing the strength; the stiffness of the fiber is also a major parameter affecting the strength [4].

Fiber reinforced concrete (FRC) is primarily made of hydraulic cement, fine and coarse aggregate and discontinuous discrete reinforcing fibers. High strength concrete with steel and polypropylene hybrid fiber (SPPFRC) showed the superior compressive strength, tensile strength, and flexural toughness over PC and all FRCs with single, double, or triple types of fiber [5].

The Increasing percentage of fiber volume in the mix reduces the workability. The concrete mix with 2% fibers of concrete weight shows that concrete was stiff and difficult to compact. Fiber combination of 70% long steel fiber and 30% short hooked end steel fiber at 1.5% volume fraction gives the most appropriate combination as regards to the highest flexural and split tensile strength. While the concrete mix containing of 70% short fiber and 30% long fiber at 1.5% volume fraction give the highest compressive strength. The results reveal that longer fiber performs better in flexural and tensile strength, whereas, concrete with short steel fiber performs better in compressive as compared to concrete with longer steel fiber [6].

A composite can be termed as hybrid, if two or more types of fibers are rationally combined in a common matrix to produce a composite that derives benefits from each of the individual fibers and exhibits a synergetic response. According to (Benthur and Mindess)[7] the advantages of hybrid fiber systems can be listed as follows:

1- To provide a system in which one type of fiber, which is stronger and stiffer, improves the first crack stress and the ultimate strength, and the second type of fiber, which is more flexible, and ductile, leads to improve toughness and strain in the post-cracking zone.
2- To provide a hybrid reinforcement in which one type of fiber is smaller, so that it bridges the micro cracks of which growth can be controlled. This leads to a higher tensile strength of the composite. The second type of fiber is larger, so that it arrests the propagating macro cracks and can substantially improve the toughness of the composite.
3- To provide a hybrid reinforcement, in which the durability of fiber types is different. The presence of the durable fiber can increase the strength and/or toughness relation after age while the other type is to guarantee the short-term performance during transportation and installation of the composite elements.

Increasing the percentage of steel fiber in Hybrid Combination reduces the slump value, to maintain the constant slump we have to increase the superplasticizers dose in concrete[8].

In the case of disperse hybrid fibers or long hybrid fibers reinforcement, the deformability of the concrete increases in tensile actions. From the performed study it can be noticed a better behaviors of the elements disperse reinforced with long fibers than the ones reinforced with hybrid fibers. Along with the increase of the volumetric percentage of fibers, the risk of fiber congestion appears, which leads to the non-homogeneity of the material [9].

Therefore, the objective of this study is to study the effect of fibers and hybrid fibers (steel and polypropylene fibers) on the fresh (workability and wet density) and hardened properties (compressive strength, splitting strength, flexural strength and dry density) of high strength concrete.

EXPERIMENTAL PROGRAM

Material

All test specimens were prepared using locally available materials. The properties of materials used in concrete mixtures are given below.

Cement:

The cement used throughout this work was Ordinary Portland Cement produced by Badush Cement Factory. The content of cement for all mixes was 520 kg/m^3. The chemical and physical properties of the used cement are given in Tables (1) and (2) respectively. It conforms to the Iraqi specification No. 5/1984.

Table 1. Chemical Analysis of Cement

Compounds Composition	Percentage by Weight (%)	limits of Iraqi Spec. No. 5/1984 (%)
Al_2O_3	5.80	3-8
SiO_2	21.35	17-25
Fe_2O_3	2.60	0.5-6
CaO	62.30	60.0-67.0
SO_3	2.50	$\leq$2.8%
MgO	3.33	$\leq$5.0%

Table 2. Physical Properties of Cement

Physical properties	Test result	Limits of Iraqi spec. No. 5/1984
Specific surface area Blaine method, m2/kg	280	> 230 m^2/kg
Setting time, Vicat's method: Initial setting, hrs: min. Final setting, hrs: min.	137 165	> 45 min <600 min
Soundness (%)		< 0.8
Compressive strength of mortar, N/mm2: 3 days 7 days	23.8 26.6	> 16 N/mm^2 > 24 N/mm^2
Tensile strength of mortar, N/mm2: 3 days 7 days	1.63 2.48	≥1.6 N/mm^2 ≥2.4 N/mm^2

Fine Aggregate

Rounded natural sand of 4.75 mm maximum size, brought from Khazer region, Mosul, Iraq was used for concrete mixes. The sieve analysis of the used sand is given in Table (3). It conforms to the limits of B.S: 882:1992. The specific gravity and material finer than sieve No. 200 (75 µm) of the used fine aggregate were (2.68 and 0.8%) respectively.

Table 3. Sieve Analysis of Fine Aggregate

Sieve size (mm)	Accumulated percentage passing (%)	Accumulated percentage retained (%)	Limits of B.S: 882:1992 (Fine F) Specification
4.75	100.0	0.0	-
2.36	89.0	11.0	80-100
1.18	74.5	25.5	70-100
0.60	55.5	44.5	55-100
0.30	21.5	78.5	5-70
0.015	3.5	96.5	-

Coarse Aggregate

The washed rounded coarse aggregate of 12.5 mm maximum size, brought from Khazer region, Mosul, Iraq was used for concrete mixes. The sieve analysis of this aggregate is given in Table (4). It conforms to the B.S: 882:1992. The specific gravity and material finer than No. 200 (75 µm) sieve of the used coarse aggregate were (2.66 and 0.2%) respectively.

Table 4. Sieve Analysis of Coarse Aggregate

Sieve size (mm)	Accumulated percentage passing (%)	Accumulated percentage retained (%)	Limit of B.S: 882:1992 (5-14 mm) Specification
14	100	0.0	90-100
10	76.0	12.20	50-85
5	0.9	88.40	0-10
2.36	0.0	100	-

Fibers

Two different types of fiber were used in this study. The first type was steel fiber having a crimped shape. This fiber shape achieves a good bond between the matrix and the fiber depending on the fiber geometry. This fiber has 25mm length and 1mm diameter. The second type was polypropylene fiber having a crimped shape with 25 mm length and 1 mm diameter. In this investigation, one volume fraction of fiber (1%) was used with all mixes containing fibers.

In hybrid fibers, the used proportion of polypropylene to steel fibers were (100-0,70-30,30-70,0-100). Table (5) shows the properties of the used fibers.

Table 5. Details of Steel and Polypropylene Fiber.

Type of fiber	Steel	Polypropylene
Length(mm)	25	25
Diameter (mm)	1	1
Aspect ratio	25	25
Fraction volume (%)	1%	1%
Density(kg/m^3)	7890	910

Superplasticizer

Superplasticizer (ViscoCrete-SF 18) was used throughout this work as high range water reducing admixture and viscosity modifying agent. The dosage used was 1% by weight of cement. The properties of viscoCrete –SF 18, as provided by the manufacturer, are given in Table (6).

Table 6. The physical properties of ViscoCrete –SF 18

Name	Sika ViscoCrete – SF 18
Chemical base	Modified polycarboxylates based polymer
Appearance / color	Light brownish liquid
pH value	3-7
Density	1.1 g/cm3 ±0.02, (at + 20 oc)
Dosage	1.0-2.0% by weight of cement

Fillers

One type of fillers, silica fume was used in this research. For all concrete mixes, the dosages of used silica fume were 10% by weight of cement. It is a concrete additive of a new generation in powder form with fineness 0.1µm.

The purpose behind using of silica fume is to improve the strength of concrete which may be ascribed to the pozzolanic reaction $Ca(OH)_2$ crystals located in the transition zone and as a result improving the bond between the cement particles and aggregate surface.

Mixing water

Ordinary potable water was used in this investigation for both mixing and curing purposes.

Mix Designed

The concrete mix was based up on the trail mixes to obtained high strength concrete. The reference concrete mix designed to have a 28 days, compressive strength of about (74) MPa and slump 110 + 5 mm. The content of cement for all mixes was 520 kg/m^3.The maximum size of the used aggregate was (12.5 mm). The volume fraction of fibers, percentage of silica fume and percentage of Visco Crete-SF 18 for all mixes were 1%, 10% and 1%, respectively. According to the mix design, concrete mix with a weight proportions of (1:1.6:1.4) and water/cement ratio of (0.24) was used as a reference concrete. Table (7) shows the details of all mixes used throughout this work.

Table 7. Details of the Experimental Program, Mix Proportions

Mix designation	Cement content (Kg/m^3)	(W/Cm)* to give slump 100 $\pm$ 5 (mm)	Steel fiber content (%)	Polypropylene fiber content (%)
Mix0	520	0.24	0	0
Mix1	520	0.27	100	0
Mix2	520	0.27	0	100
Mix3	520	0.27	70	30
Mix4	520	0.27	30	70

* W/C_m ratio: Water/ cementitious materials ratio

Mixing Procedure of Concrete

The mixing procedure of fiber reinforced concrete is achieved by putting the gravel and sand in a concrete mixer and dry mixed for 1 minutes then the cement and silica fume placed in concrete mixer and dry mixed for 1 minute too. About the half of the mixing water and the total amount of the superplasticizer are added and mixed for 2min. After that, the amount of fibers are distributed and mixed for 3min. The remaining water is then added and the mixing is done until good homogeneous mixture is obtained (as visually observed).

Casting and Curing of Specimens

The molds were lightly coated with mineral oil before use, according to ASTM C 192-88 [10], 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 with polyethylene sheet in the laboratory for about (24 ± 2) hrs. After that the specimens remolded carefully, marker and immersed in water until the test date. The age of specimens was 28 days for control tests. No micro cracks due to heat of hydration and shrinkage were observed during mixing and casting concrete, because the quantity of used cement was not very high and the experimental program was done during winter season.

Testing of Hardened Concrete

Compressive Strength Test

Based on BS 1881: part 5 [11], the compressive strength was carried out on 100x100x100 mm cube specimens. These specimens were tested under compression testing machine, Matest type, Italy manufacturing, with capacity 2000kN. The compressive strength was taken as the average value of three specimens.

Splitting Tensile Strength Test

The splitting tensile strength was conducted on cylinders of (100 x 200 mm). The average of three test specimens was taken. The test was carried out in accordance with ASTM C 496-86 [12]. These specimens were tested under compression testing machine, Matest type, Italy manufacturing, with capacity 2000kN.

Flexural Strength Test

A testing machine, Matest type, Italy manufacturing, with capacity 150 KN was used for testing the flexural strengths of 100x100x400-mm beam specimens. This test was done according to ASTM C 78-84, using Two-Point Loading with span length 270 mm [13]. The flexural strength was taken as the average value of three specimens.

Results And Discussion

The influence of fibers and hybrid fibers on the properties of high strength concrete (workability, density, compressive strength, splitting strength and flexural strength) are presented in Table (8) and Figs. (1) to (4).

Table 8. Workability (Slump and Ve-Be Time), Fresh Density, and Dry Density Test Results of concrete Mixes

Mix designation	(W/C_m) to give slump ± 5 (mm)	Slump (mm)	Ve-Be Time (sec)*	Fresh Density (kg/m^3)	Dry Density (kg/m^3)
Mix0	0.24	114	5.18	2420	2380
Mix1	0.27	112	7.32	2465	2420
Mix2	0.27	107	8.24	2395	2368
Mix3	0.27	110	7.52	2445	2400
Mix4	0.27	109	8.22	2410	2390

*Digital watch clock was used to measure Ve-Be Times

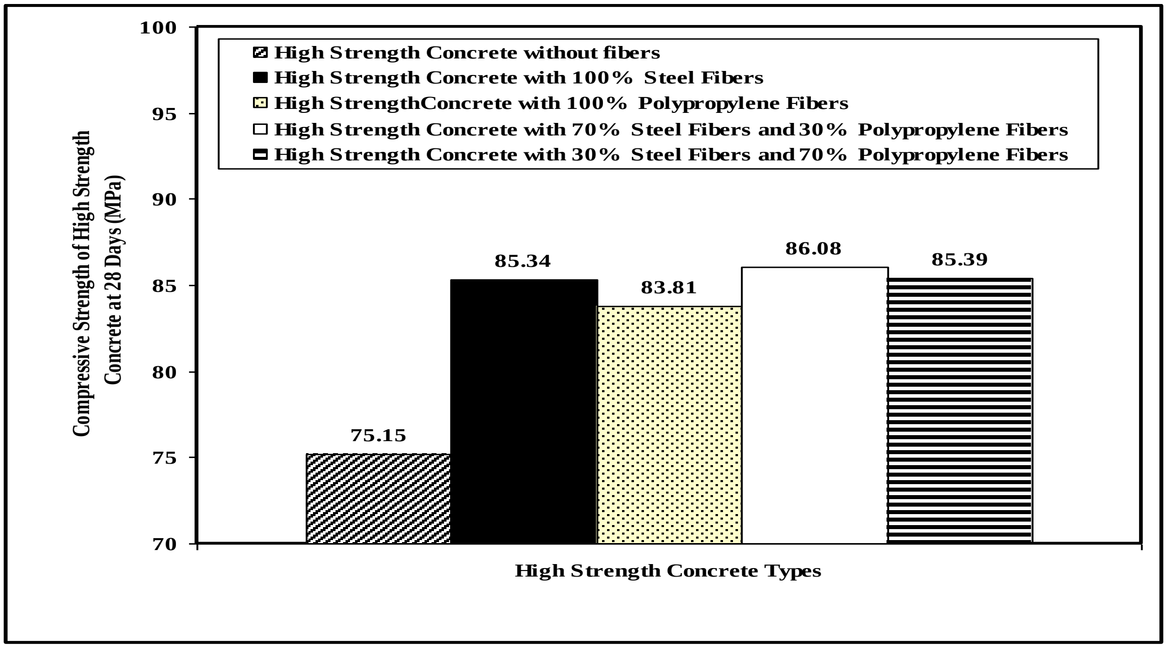

Fig. 1 The Effect of Fiber Types and Hybrid Fibers on the Compressive Strength of High Strength Concrete

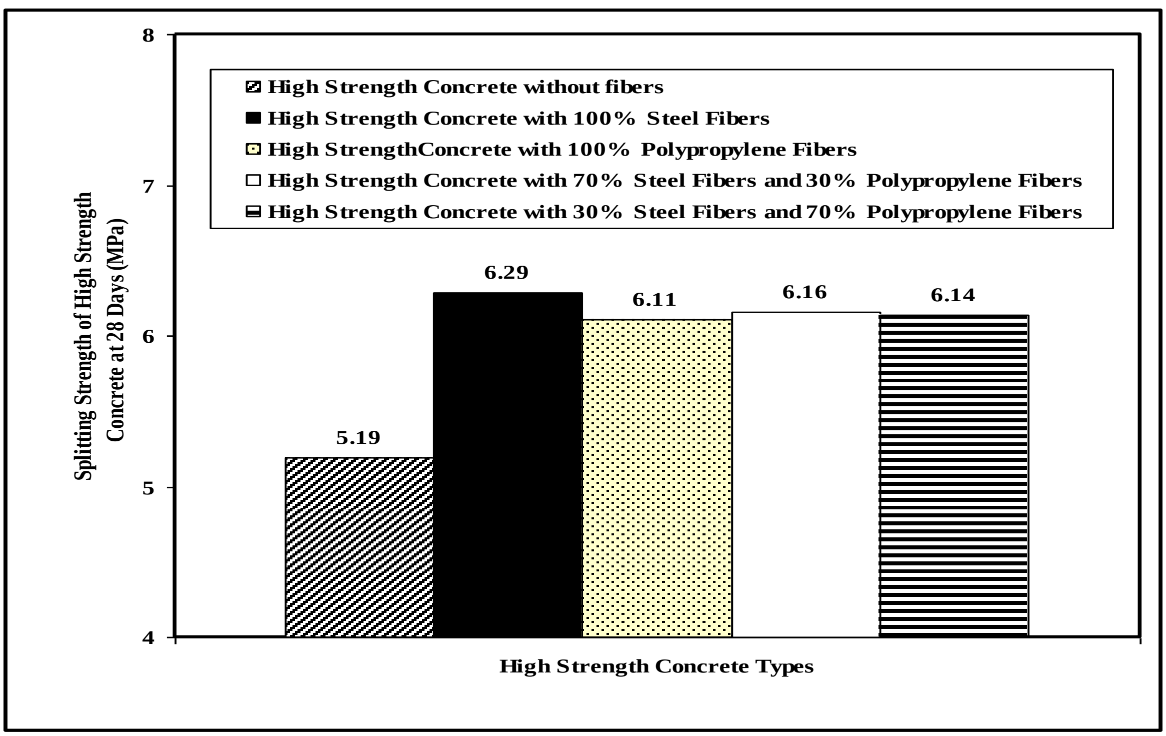

Fig. 2 The Effect of Fiber Types and Hybrid Fibers on the Splitting Strength of High Strength Concrete

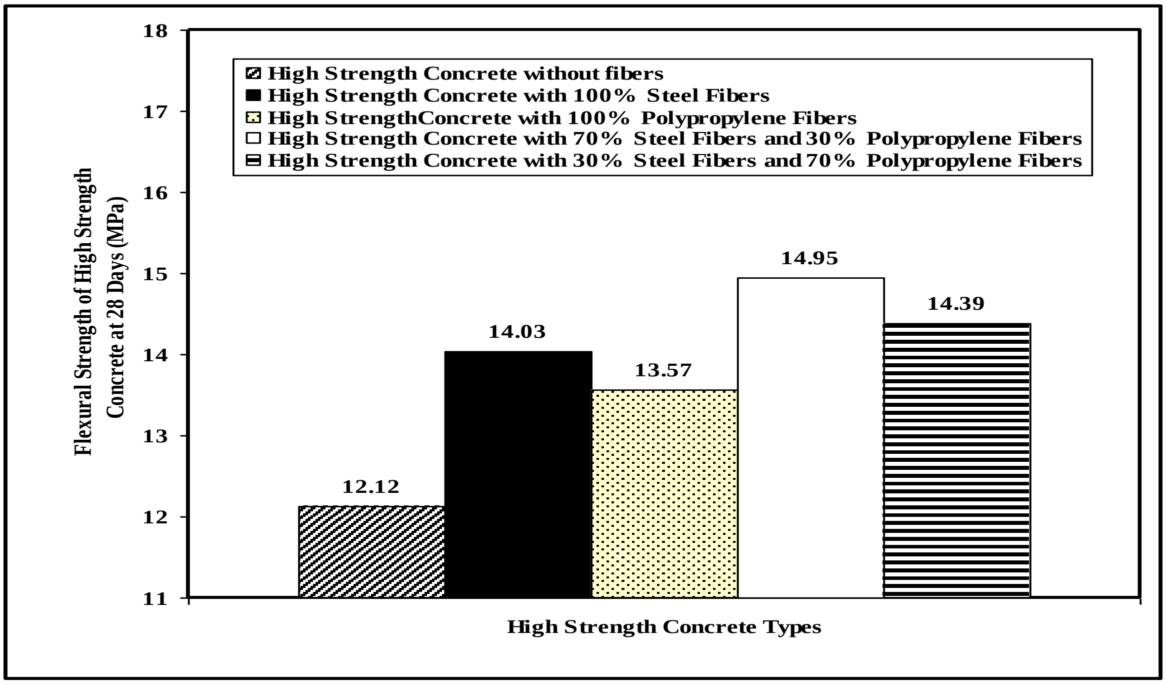

Fig. 3 The Effect of Fiber Types and Hybrid Fibers on the Flexural Strength of High Strength Concrete

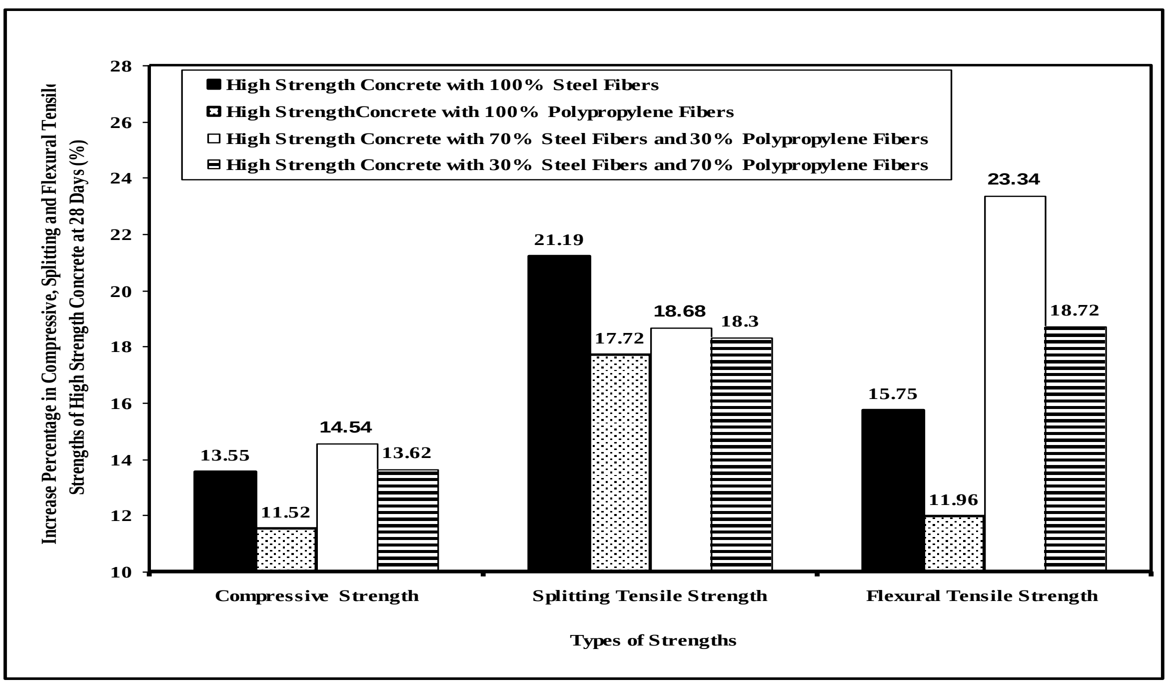

Fig.4 Increase Percentages in Compressive, Splitting and Flexural Tensile Strengths of High Strength Concrete at 28 Days (%)

Table (8) shows that slump flow decreases in all concrete mixtures containing steel, polypropylene and hybrid fibers compared to the control mix (0% fiber). This can be attributed to the fact that the incorporation fiber increases the internal resistance to flow.

The fiber and hybrid high strength concretes demonstrate increased in fresh and dry densities compared to their corresponding reference mix. The increase percents in fresh density for the fiber hybrid high strength concretes relative to the reference concrete were 1.85%, 1.03%, and 0.41% for Mix1, Mix3 and Mix4, respectively. The corresponding in increase in dry density for the fiber and hybrid high strength concrete relative to the reference concrete were 1.68%, 0.84%, and 0.42% for Mix1, Mix3 and Mix4, respectively. Using and increasing the percentage of steel fiber in fiber and hybrid fiber Concretes increase the wet and dry densities of concrete. Because the density of steel fiber more than density of concrete. On the other hand, the density of concrete more than density of polypropylene fiber.

The high strength concrete showed a significant increases in compressive, splitting and flexural strengths compared to the plain reference concrete (Mix0).

From Figs 1 and 4, it can be observed that the increase percents in compressive strength of high strength concretes cured at 28 day compared to their referenced concretes mixes. The maximum increase in compressive strength in Mix3 contain (70 % steel fiber-30 % polypropylene) was 14.54%.

The increase in compressive strength resulted from increasing in control to the crack formation and development under axial load because these mixes were contain fibers. Thus, the increase in compressive strength occurred for the all mixes containing fibers, the maximum increase is obtained for the hybridization ratio (70 % steel - 30% polypropylene) in Mix3 and was equal to 14.54% compared with the control mix (Mix0).

From Figs. (2 and 4), the increase percents in splitting strength of high strength concretes cured at 28 day compared to their referenced concrete mixes, were 21.19%, 17.72%, 18.68% and 18.30% for concrete mixes with 100% steel,100% polypropylene, 70% steel +30% polypropylene and 30% steel +70% polypropylene fibers, respectively.

The results of splitting tensile test are demonstrated in Fig. (2). From Fig.(4), it can be observed that all mixes containing fibers have splitting tensile strength greater than the control mix. The maximum increase in splitting tensile strength in Mix1 contains (100 % steel fiber - 0% polypropylene) was 21.19%. The increasing of tensile strength in mix containing steel fiber (Mix1) because the steel fiber has tensile strength more than polypropylene fiber. Fibers, especially steel fibers, make the concrete less brittle and more ductile.

The average results of the flexural test results are given in Fig.(3). From Fig.(4) ,it can be observed that the percentage increases in flexural strength of high strength concretes cured at 28 day compared to their referenced concretes were 15.75% ,11.96 %,23.34% and 18.72% for concretes with 100% steel,100% polypropylene, 70% steel +30% polypropylene and 30% steel +70% polypropylene fibers, respectively.

Increased fiber availability in the hybrid fiber systems (due to the lower density of polypropylene fiber), in addition to the ability of polypropylene fibers of bridging smaller micro and macro cracks, could be the reasons for the enhancement in flexural properties.

The results shows that all mixes with steel fibers have flexural strength more than concrete mixes containing polypropylene fiber. The maximum increase in flexural strength achieved in Mix3 with hybridization fibers (70% steel +30% polypropylene fibers) was 23.35% in compare with the concrete mix without fibers (Mix0).

High-bonding of fiber with the matrix, is very effective in controlling the micro-cracking mechanism, which results in an improved behaviors in terms of smaller crack openings at peak resistance. On the other hand, high-modulus of steel fiber is effective in controlling macro-cracks over a wide range and at high stress level. As a result, the toughness of the material is significantly increased. It should also be noted that these fibers also have very different properties in terms of fiber geometry and tensile strength. These variables are also effective on flexural and splitting performances of beam samples at different loading levels.

CONCLUSIONS

From the obtained results in this study, the following conclusions can be drawn:

1- The concrete mix with fibers shows that concrete was stiff and difficult to compact. In addition to this, concrete with steel fiber has better workability as compared to concrete with polypropylene fiber.
2- It is possible to produce hybrid fiber concretes using polypropylene fibers in combination with steel fibers, with an enhanced strengths compared to controlled concrete without fibers.
3- High strength concrete with steel and polypropylene hybrid fiber showed the high mechanical properties (compressive strength, splitting strength and flexural strengths) over reference concrete (Mix0) or single fibers concrete mixes (Mix1 and mix2).
4- Fiber combination of 70% steel fiber and 30% polypropylene fiber at 1.0% volume fraction gives the most appropriate combination as regards to the highest in the flexural tensile and compressive strengths. While the concrete mix containing of 100% steel fiber at 1.0% volume fraction give the highest split tensile strength as compare with the control mix (Mix0).

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