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The Effect of Steel and Polypropylene Fibers on Properties of High Strength Concrete

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***Abstract*—This research work investigates the effect of the addition of steel and polypropylene fibers on the mechanical properties of high-strength concrete (HSC). Straight steel fibers (ST) with a 63mm length and 0.9 mm diameter, and Polypropylene fibers (PP) with a 12-mm length and 0.018 mm diameter were used. Each type separate and three mixtures were produced with the combination of steel and polypropylene fibers at (0.25% ST +0.75PP), (0. 5% ST +0. 5 PP) and (0.75% ST +0.25 PP). Slump, Compressive strength, split tensile strength, and flexural strength tests were performed and results were analyzed to associate with above fiber combinations. Based on experimental studies, the paper identifies fiber combinations that demonstrate maximum compressive, split tensile and flexural strength of concrete. Relationship between compressive strength and split tensile strength, compressive strength and flexural strength is presented. Among different combinations of steel and polypropylene fibers investigated, the best performance was attained by a mixture that contained 0.75% ST and 0.25% PP. Finally, the results show that introducing fibers to concrete resulted in increase in Compressive strength, split tensile strength, and flexural strength and depending on the fibers ratio used, compared to the mixture of plain concrete.**

Keywords*— Steel Fiber; Polypropylene Fiber; Mixture; Strength.

I. INTRODUCTION

Cement mortar and concrete made with Portland cement is a kind of most commonly used construction material in the world. These materials have inherently brittle nature and have 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. Fiber Reinforced Concrete is concrete containing fibrous material which increases its structural integrity. It contains short discrete fibers that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers each of which lend varying properties to the concrete. In addition, the character of fiber reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities. Fibers can be divided into following two groups (I) Fibers whose moduli is lower than the cement matrix such as cellulose, nylon, polypropylene (ii) Fibers with higher moduli than the cement such as asbestos, glass, steel etc. Fibers having lower modulus of elasticity are expected to enhance strain performance whereas fibers having higher modulus of elasticity are expected to enhance the strength performance. Moreover, the addition of hybrid fibers makes the concrete more homogeneous and isotropic and therefore it is transformed from brittle to more ductile material. [1-4].

Concrete is the most widely used construction material, because of the several well-known advantages it offers, such as low cost, general availability, and wide applicability. However, concrete is a quasi-brittle material, and its brittleness increases with its strength. Relatively low tensile strength and poor resistance to crack opening and propagation are the main disadvantages of conventional concrete [5–8]. Development of modern civil engineering construction has generated an essential demand for new types of concretes which should possess improved qualities such as high-strength, toughness, and durability [9,10]. Examples of new types of concretes include high-strength concrete (HSC), high performance concrete (HPC) and high performance fiber-reinforced concrete (HPFRC). The properties of such concretes show a substantial improvement over those of conventional concrete [11,12]. However, HSC is more brittle than normal-strength concrete (NSC) and this limits the utilization of HSC. Additionally, it is well understood that the use of supplementary cementitious materials such as silica fume (SF), ground granulated blast-furnace slag (GGBS), and fly ash (FA) as part of binders is required for production of high strength concretes [13,14].

II. MATERAILS USED

In this experimental study cement, fine aggregate, coarse aggregate, steel fibers, and polypropylene fibers were used. Properties of materials used are shown in table (1) and table (2). The properties of Superplasticizer is shown in table (3).

Table(1): Properties of Coarse Aggregate (Basalt) and Properties of Sand

Property	Basalt	Sand
Specific Gravity	2.67	2.5
Bulk density (t/m^3)	1.62	1.76
Max aggregate size (mm)	4.67	-
% Absorption	0.2	-

Table (2): Physical Properties of Straight Steel and Polypropylene Fibers

Type of fiber	Shape of fiber	Length L (mm)	Diameter d (mm)	Aspect ratio L/d	Density (kg/m^3)
Steel (ST)	Straight	63	0.9	70	7800
Polypropylene (PP)	Straight	12	0.018	666	910

Table (3): Technical Data (at 25°C) for Superplasticizer Addicrete BVS

Base	Sodium ligno sulphonate + Napthalin sulphonate
Appearance	Brown liquid.
Density	1.21 ± 0.01 kg/l
Chloride content	Nil
Air entrainment	Nil
Compatibility	All types of Portland cement

III. MIX PROPORTIONS

Six mixes of concrete were produced to cast a series of test specimens divided from mix M1 to mix M6. M1is a plain concrete, M2 is a mixture steel fibers, M3 mixture is a polypropylene fiber, M4 mixture is containing steel fibers by 0.25% polypropylene fiber by 0.75% , M5 mixture is containing steel fibers by 0.5% polypropylene fiber by 0.5%, and M6 mixture is containing steel fibers by 0.25% + polypropylene fiber by 0.75% are shown in Table (4). For each six mixes 3 cubes, 3 Cylinders, 3 beams contains a complete mix, and 3 beams contain a half mix plus plain concrete were pouring.

IV. EXPERIMENTAL METHODOLOGY

A. Compression Strrength Test

For compressive strength test, cube specimens of dimensions 100 x 100 x 100 mm were casted for all mixes. The moulds were filled with concrete. After 24 hours the specimens were demoulded and were transferred to curing tank. Where they were allowed to cure for 28 days. These specimens were tested in compression testing machine. Compression testing machine having 2000 KN is used for loading. In each category, three cubes were tested and their average value is reported by using following formulae.

Compressive strength = Load / Area (kg/cm^2)

Table (4): Mix Proportions of Concrete Mixes

Mix	Mixture ID	Water	Cement	Fine Agg.	Coarse Agg.	Super plasticizer	Fiber weight (kg/m^3)	
		(kg/m3)					ST	PP
M1	Plain	202.5	450	748	936	4.5	0	0
M2	PP	202.5	450	748	936	4.5	0	2
M3	ST	202.5	450	748	936	4.5	117	0
M4	ST 0.25 % PP0.75 %	202.5	450	748	936	4.5	29.25	1.5
M5	ST 0.5 % PP0.5 %	202.5	450	748	936	4.5	58.5	1
M6	ST 0.75 % PP0.25 %	202.5	450	748	936	4.5	87.75	0.5

B. SPLITTING TENSILE STRRENGTH TEST

For tensile strength test, cylinder specimens of dimension 100 mm diameter and 200 mm length were casted. The specimens were demoulded after 24 hours of casting and were transferred to curing tank. Where they were allowed to cure for 28 days. These specimens were tested under compression testing machine. In each category, three cylinders were tested and their average value is reported. Tensile strength was calculated as follows as split tensile strength.

Tensile strength (kg/cm^2) = $2P / \pi DL$

Where: P = failure load, D = diameter of cylinder, L = length of cylinder.

C. FLEXURAL STRRENGTH TEST

For the flexural strength of concrete, beam specimens of size 500 x 100 x 100 mm were casted. The samples were demoulded after 24 h from casting and kept in a water tank for 28 days curing. The specimens were placed in UTM and tested for flexural strength. Three beams from full fiber concrete and three from half fiber concrete were tested as showing in figure (1). Their average value is reported. Flexural strength was calculated as following formulae.

Flexural strength (kg/cm^2) = M Y / I

Where: M = P L / 6, Y = 5cm, I = 833.33 cm^4,

P = failure load (kg), and L = 30cm

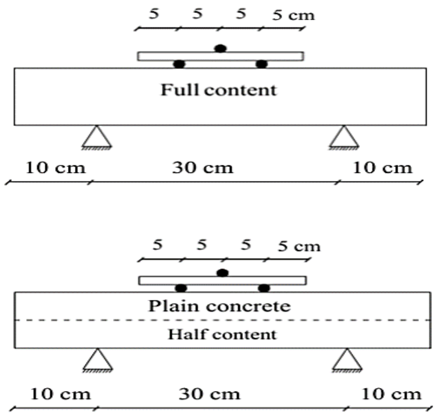

Fig. (1): Shape of Beam for Flexural Strength Test

V. RESULTS AND DISCUSSION

Results of slump test, compressive strength, splitting tensile strength, and flexural strength for six mixes of concrete were shown in table (5).

Table (5) : Results of Slump, Compressive Strength, Splitting Tensile Strength and Flexural Strength Tests.

Mix	Mixture ID	Slump mm	Average compressive strength at 28 days (kg/cm^2)	Average splitting tensile strength at 28 days (kg/cm^2)	Average flexural strength at 28 days full fiber (kg/cm^2)	Average flexural strength at 28 days half fiber (kg/cm^2)
M1	Plain	140	402	55.7	83	-
M2	PP	65	442	61.5	99	85.5
M3	ST	75	475	69.5	119.5	102.5
M4	ST 0.25 % PP0.75 %	50	519	76	137	117.5
M5	ST 0.5 % PP0.5 %	55	541	85.4	139.5	127
M6	ST 0.75 % PP0.25 %	60	583	101	145.5	131.5

A. SLUMP

The slump value was reaches in plain concrete 140 mm. The maximum slump value in the five mixes was reaches in mix M3 of steel fiber mixture 75 mm. The other mixes slump were decreasing, and the value were 50, 55, 60, and 65 mm for M4, M5, M6, and M2 as shown in figure (2).

B. COMPRESSION STRRENGTH

The maximum compressive strength reaches in the mix M6 of 75% steel fiber and 25% polypropylene fiber 583 kg/cm^2, and M1 plain concrete was 402 kg/cm^2. This is increased because of the high elastic modulus of steel fiber and the low elastic modulus of polypropylene fiber work in perfect combination. The compressive strength on the other mixes were 442, 475, 519, and 541 kg/cm^2 for M2, M3, M4, and M5 as shown in figure (3).

C. SPLITTING TENSILE STRRENGTH

The maximum splitting tensile strength reaches in the mix M6 of 75% steel fiber and 25% polypropylene fiber 101kg/cm^2, and M1 plain concrete was 55.7 kg/cm^2. Improved spilt tensile strength can be achieved by increasing the percentage of steel fiber. The higher number of fiber bridging the diametral 'splitting' crack, the higher would be the spilt tensile strength. The increased fiber availability of PP fiber, combined with the high stiffness of steel fiber, resulted in a significant enhancement of the split tensile strength for this combination. The splitting tensile strength on the other mixes were 61.5, 69.5, 76, and 85.4 kg/cm^2 for M2, M3, M4, and M5 as shown in figure (4). Relationship between compressive strength and splitting tensile strength of High Fiber Reinforced Concrete is linearly as shown in figure (5) related by the equation:

$$F_{ff} = 0.3643f_{cu} – 59.256\ (Kg/cm^2)$$

Where: $f_{cu=}$ compressive strength, and f_{ff} = flexural strength for full content fiber

D. FLEXURAL STRRENGTH

For full content mixture, the maximum flexural strength reaches in the mix M6 of 75% steel fiber and 25% polypropylene fiber 145.5 kg/cm^2, and M1 plain concrete was 83 kg/cm^2. The flexural strength on the other mixes were 99, 119, 137, and 139.5 Kg/cm^2 for M2, M3, M4, and M5 as shown in figure (6). It can be observed that, under axial loads, cracks occur in microstructure of concrete and fibers limit the formation and growth of cracks. Relationship between compressive strength and flexural strength of High Fiber Reinforced Concrete is linearly as shown in figure (7) related by the equation:

$$f_t = 0.2428f_{cu} – 44.995\ (Kg/cm^2)$$

Where: $f_{cu=}$ compressive strength, and f_t = split tensile strength.

For half content mixture, the maximum flexural strength reaches in the mix M6 of 75% steel fiber and 25% polypropylene fiber 131.5 kg/cm^2, and M1 plain concrete was 83 kg/cm^2. The flexural strength on the other mixes were 85.5, 102.5, 117.5, and 127 Kg/cm^2 for M2, M3, M4, and M5 as shown in figure (6). Relationship between compressive strength and flexural strength of High Fiber Reinforced Concrete is linearly as shown in figure (7) related by the equation:

$$F_{fh} = 0.3643f_{cu} – 59.256\ (Kg/cm^2)$$

Where: $f_{cu=}$ compressive strength, and f_{fh}= flexural strength for half content fiber

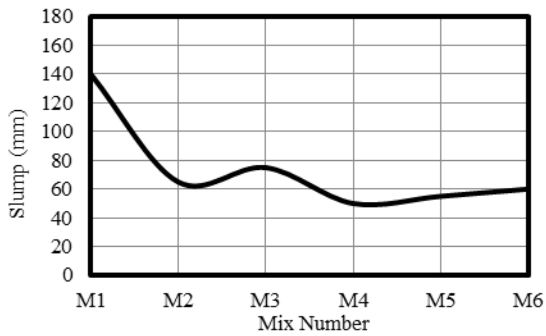

Fig.(2): Relation between Slump for all Mixes

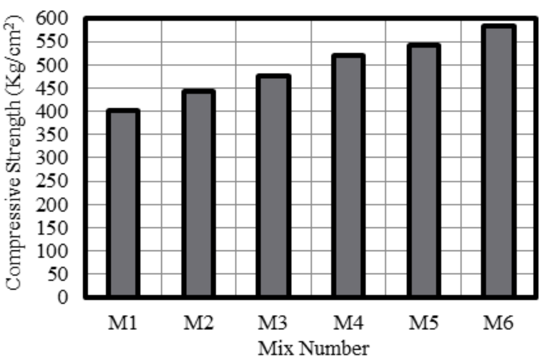

Fig.(3): Relation between Compressive Strength for all Mixes

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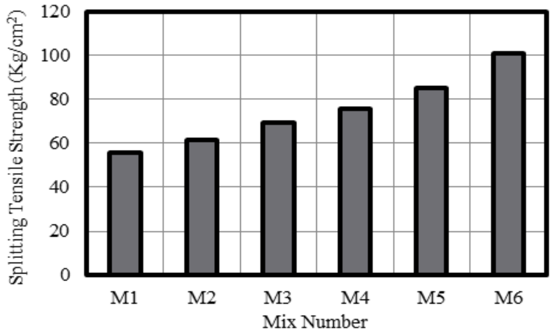

Fig.(4): Relation between Splitting Tensile Strength for all Mixes

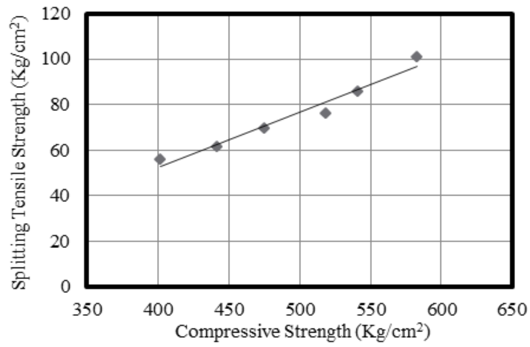

Fig.(5): Relation between Compressive Strength and Splitting Tensile Strength for all Mixes

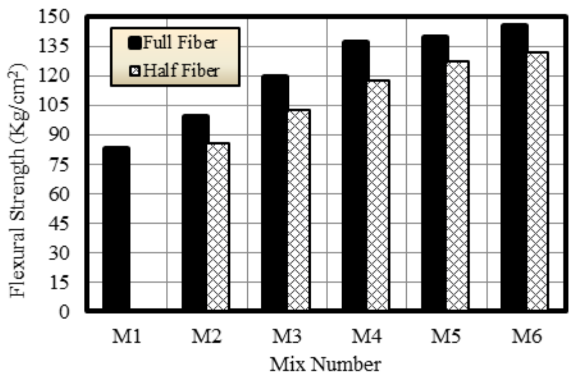

Fig.(6): Relation between Flexural Strength for all Mixes

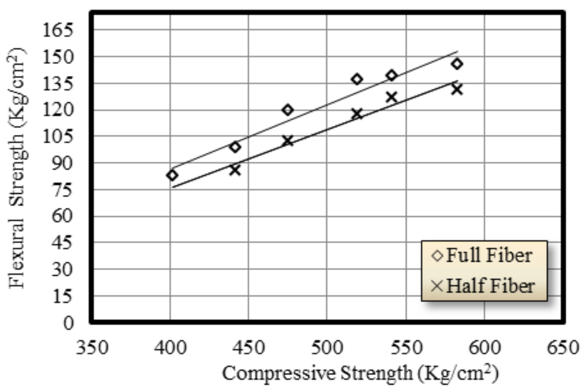

Fig.(7): Relation between Compressive Strength and Flexural Strength for all Mixes

VI. CONCLUSION

Based on the experimental results presented in this paper, the main conclusions are as the follows:

1- The slump value was decreasing in all fibers mixes than plain concrete. The decreasing on slump value on the fibers mixes were 64%, 61%, 57%, 54%, and 46% for M4, M5, M6, M2 and M3 than plain concrete.

2- The compressive strength was increasing in all fibers mixes than plain concrete. The increasing on the fibers mixes were 10%, 18%, 29%, 35% and 45% for M2, M3, M4, M5 and M6 than plain concrete. The maximum increasing is in the mix M6 of 75% steel fiber and 25% polypropylene fiber. This is increased because of the high elastic modulus of steel fiber and the low elastic modulus of polypropylene fiber work in perfect combination.

3- The splitting tensile strength was increasing in all fibers mixes than plain concrete. The increasing on the fibers mixes were 10%, 25%, 37%, 53%, and 81% for M2, M3, M4, M6 and M6 than plain concrete. The maximum increasing is in the mix M6 of 75% steel fiber and 25% polypropylene fiber. Improved spilt tensile strength can be achieved by increasing the percentage of steel fiber. The higher number of fiber bridging the diametral 'splitting' crack, the higher would be the spilt tensile strength. The increased fiber availability of PP fiber, combined with the high stiffness of steel fiber, resulted in a significant enhancement of the split tensile strength for this combination. Relationship between compressive strength and split tensile strength of High Fiber Reinforced Concrete is linearly related by the equation:

$F_{ff} = 0.3643f_{cu} – 59.256$ (Kg/cm²)

4- For full content mixture, the flexural strength was increasing in all fibers mixes than plain concrete. The increasing on the fibers mixes were 19%, 44%, 65%, 68%, and 75% for M2, M3, M4, M5, and M6 than plain concrete. The maximum increasing is in the mix M6 of 75% steel fiber and 25% polypropylene fiber. It can be observed that, under axial loads, cracks occur in microstructure of concrete and fibers limit the formation and growth of cracks. Relationship between compressive strength and flexural strength of High Fiber Reinforced Concrete is linearly related by the equation:

$f_t = 0.2428f_{cu} – 44.995$ (Kg/cm²)

5- For Half content mixture, the flexural strength was increasing in all fibers mixes than plain concrete. The increasing on the fibers mixes were 3%, 24%, 42%, 53%, and 58%) for M2, M3, M4, M5, and M6 than plain concrete. The maximum increasing is in the mix M6 of 75% steel fiber and 25% polypropylene fiber. The difference between Flexural strength for full content mixture and half content mixture is about 20%. So the half content mix is the economic mixture. Relationship between compressive strength and flexural strength of High Fiber Reinforced Concrete is linearly related by the equation:

$F_{fh} = 0.3643f_{cu} – 59.256$ (Kg/cm²)

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