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Fresh and Hardened Properties of High Strength Self-Compacting Concrete Reinforced by Fibers

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Abstract*— Self Compacting Concrete (SCC) possesses exceptional flow ability characteristics in its fresh state, but producing SCC with superior mechanical properties often is a challenge to the construction industry. High strength self-compacting fibrous concrete (HSSCFC) combines the benefits of SCC in the fresh state and shows improved characteristics in the hardened state due to the addition of the fibers and mineral additives. The main objectives of this study are to investigate the feasibility of producing HSSCFC using locally available materials and investigate the effect of inclusion different types of fibers (steel, polypropylene, and combination of steel and polypropylene) with different volume fractions on the properties of HSSCFC. The key characteristics of HSSCFC (filling ability, passing ability and segregation resistance) were assessed by using slump flow, T50 mm, L-Box and GTM screen stability. Tests also were carried out to quantify the effect of fibers on mechanical properties of HSCCFC (compressive strength, splitting tensile strength and bending strength). Test results indicate that local material can produce HSCCFC. All mixes achieved a cube compressive strength of 75±5 MPa. It was found that it is possible to achieve the high strength and high workability of SCC while using fiber reinforcement.

***Index Terms*—** High strength self-compacting fibrous concrete; hybrid fibers; steel fibers; polypropylene fibers.

I. INTRODUCTION

The term self-compacting concrete refers to a new special type of concrete mixture, characterized by high resistance to segregation that can be cast without compaction or vibration [1]. The concept of self-compacting concrete was proposed in 1986 by Hajime Okamura [2]. The prototype, however, was first developed in Japan in 1988 by Ozawa [3]. This new concrete was deliberately designed to be able to fill every corner of the form and encapsulate all reinforcements only under the influence of gravitational forces, without segregation or bleeding. These advantages make self-compacting concrete particularly useful wherever placing is difficult as in heavily reinforced concrete members or in complicated work forms. Through extensive research, it has been established that the addition of fibers to concrete considerably improves its structural properties such as compressive strength, static flexural strength, impact strength, tensile strength, ductility, and toughness [4,5]. Producing high strength concrete (HSC) is always one of the major goals of concrete technology. For more than thirty years, high strength concrete with compressive strength, ranging from 60 MPa and up to 140 MPa, had been used worldwide in large buildings, towers, and long span bridges buildings. Building elements made of high strength concrete are usually densely reinforced with small spacing between reinforcing bars which may lead to defects in concrete [6]. Introducing fibers into the concrete matrix can improves its mechanical properties and enable the utilization of HSC, while maintaining a ductile behavior.

This study was composed of two parts. The first part was based on producing the high strength self-compacting fibrous concrete with locally available materials in Egypt. The second part was based on studying the effects of using different types of fibers (steel, polypropylene, and the hybrid between steel and polypropylene) on fresh and mechanical properties of high strength self-compacting fibrous concrete.

II. EXPERIMENTAL PROGRAM

A. Materials

Cement: - The type of cement used in all of the concrete mixtures was Portland cement type CEM I 52.5 N. It was supplied by El-Suez Cement company and complied with the requirements of ES 4756-1 [7] and BS EN 197-1 [8]. The chemical composition of cement type CEM I 52.5 N is presented in Table 1. The calculation of the main compounds of Portland cement is based on the work of Bogue is given in Table 2. The physical and mechanical properties of cement are given in Table 3.

Table 1 The Chemical Composition of the Used Cement

Oxide composition	Per cent
Lime CaO	61.09
Silica SiO_2	21.58
Alumina Al_2O_3	4.94
Ferric Oxide Fe_2O_3	3.56
Magnesia MgO	1.65
Sulfuric Anhydride SO_3	3.22
K_2O	0.18
Na_2O	0.5
Loss on ignition, L.O.I	2.6

Table 2 The Main Compounds of Cement

Compounds	Content (%)
Tricalcium Silicate C_3S	37.16
Dicalcium Silicate C_2S	33.91
Tricalcium Aluminate C_3A	7.07
Tetracalcium Aluminoferrite C_4AF	10.82

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Table 3 The Physical and Mechanical Properties of Cement

Property	Test results	ES 4756-1/2013 EN 197-1/2011
Specific surface area (cm^2/gm)	3600	Not less than 2750
Initial setting Time (min)	70	Not less than 45 min
Final Setting Time (min)	210	--
Compressive strength 2 days	24.2	Not less than 20 (MPa)
Compressive strength 28 days (MPa)	55.8	Not less than 52.5 (MPa)

Silica fume: - The used silica fume was locally produced in Egypt. The physical properties of the silica fume are shown in Table 4.

Table 4 Physical Properties of the Silica fume*

Property	Value
Specific surface area (cm^2/gm)	170,000
Particle size (μm)	8.00
Specific gravity	2.2

* The data were obtained from manufactures data sheet.

Quartz powder: - Locally produced quartz powder added in a percentage of 8% by weight of cement. The maximum size was 0.25 mm with a SiO_2 content of 97%, specific surface area of 3100 gm/cm^2, and a specific gravity 2.85.

Aggregate: - Natural crushed dolomite of 4/10mm from Attaka quarry in Suez City in Egypt was used in this study. The physical and mechanical properties of the coarse aggregate are given in Table 5.

Table 5: The Physical and Mechanical Properties of crushed dolomite

Property	Test results	ES 1109-2008 ECP 203-2007
Specific gravity (gm/cm^3)	2.65	-
Bulk density (kg/m^3)	1650	-
Water absorption (%)	2.1	Not more than 2.5%
Abrasion Resistance (%)	19	Not more than 30%
Crushing value (%)	21	Not more than 30%
Max. Nominal Size (mm)	10	

The fine aggregate was well-graded sand of 0/4mm with specific gravity of 2.65. The fineness modulus of o/4 mm fine aggregate was 2.89. The Absorption and density of the fine aggregate were equal to 0.6% and 1750 kg/m3 Testing of aggregate was carried out according to ES 1109/2008. The physical and mechanical properties of aggregate complied with both ES1109/2008[10], and the Egyptian Code of practice ECP203-2007[11].

Polypropylene Fibers: - Polypropylene monofilament (Fig. 2) used in this study. Mixing ratio compatible with (EFNARC, 2005) [11]. The physical properties of polypropylene fibers are presented in Table 7.

Water: - Tap water was used throughout the mixing and curing procedures for the concrete in this study.

Super plasticizer: - a high-range water-reducing (HRWR) of aqueous solution of modified polycarboxylate basis (Viscocrete 3425) was used to increase the workability and viscosity of the concrete mixes. Viscocrete 3425 – complies with ASTM-C-494Type G and F.***Fibers: -***

Steel Fibers: - Corrugated segment steel fibers (Fig. 1) were used in this study. The physical properties of corrugated segment steel fibers presented in Table 6.

Table 6: Physical Properties of Corrugated Segment Steel Fibers

Property	Steel Fibers
Length (mm)	30
Width (mm)	2
Thickness (mm)	0.6
Specific gravity (gm/cm^3)	7.85

Fig. 1 Corrugated Segment Steel Fiber

Fig. 2: Polypropylene Fibers

Table 7: Physical Properties of Polypropylene Fibers *

Property	Polypropylene Fibers
Length (mm)	18
Width (μm)	18

***By manufactures data sheet**

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B. Mix proportions

Seven types of mixture concrete (M_0 to M_6) produced. For all mixtures, 500 kg/ m^3 Portland normal cement, 12% Silica fume, 8% quartz powder, and 1.25% super plasticizer of cementitious materials weight used. Water added 0.33 of (w/cm). The control mixture (M_0), made without fibers, steel fibers added to(M_1 and M_2) by (0.4 and 0.8)%. Polypropylene fibers added to (M_3 and M_4) by (0.05 and 0.1)%, and hybrid fibers added to (M_5 and M_6) by (0.6% steel +0.03% polypropylene and 0.3% steel +0.06% polypropylene). The components of mixtures for 1 m^3 listed in Table 8.

Table 8: The Components Mixtures for 1 m^3 Concrete (kg/ m^3).

Mix No.	M_0	M_1	M_2	M_3	M_4	M_5	M_6
Cement	500	500	500	500	500	500	500
Silica fume	60	60	60	60	60	60	60
Quartz powder	40	40	40	40	40	40	40
Fine aggregate	785	779	774	784	783	776	779
Coarse aggregate	785	779	774	784	783	776	779
Water	185	185	185	185	185	185	185
Superplasticizer	7. 25	7. 25	7. 25	7. 25	7. 25	7. 25	7. 25
Steel Fibers	0	31.4	62.8	0	0	47.1	23.55
Polypropylene Fibers	0	0	0	0.455	0.91	0.273	0.546

C. Specimen preparation

For each mixture, the ingredients placed into the laboratory mixer in the following order: coarse aggregate and fine aggregate for thirty seconds, then cement was added, silica fume and Quartz powder blended in dry condition and mixed. After sixty seconds from the start of the mixing process, fibers added to the mixture and carefully mixed to achieve a uniform distribution. Seventy-five percent of water added to the mixture. Then the remainder of the water and super plasticizer were added into the mixture gradually to provide homogeneity to the mixture. The total mixing time was four minutes to ensure the uniformity. When the mixture was ready, the fresh tests began (slump flow, T_{500} mm, L-box, and GTM screen stabilities) to measured filling ability, passing ability and segregation resistance. After completing the fresh state tests, the Specimens cast in steel molds. Details of the tests and dimensions of the specimens given in Table 8.

Table 8 Details of the Test Specimens

Tests type	Specimen	Dimensions (mm)
Compressive	Cubic	100 × 100 × 100
Tensile	Cylinder	150 × 300
Bending	Prism	100 × 100 × 500

After casting, the specimens kept at room temperature for twenty-four hours. The specimens were removed and stored in water for twenty-eight days, then taken out of the water at room temperature for twenty-four hours, then tested for compressive strength, splitting tensile strength, and bending strength.

III. EXPERIMENTAL RESULTS

A. Fresh stage properties

In the present study, the fresh state of high strength self-compacting fibrous concrete mixtures assessed by using slump flow test, L-box, and GTM screen stabilities test. The super plasticizer dosage was kept constant to evaluate the effect of fibers on workability. Table 9 summarises the results of the fresh state properties evaluation. Figures 3 and 4 illustrate the slump flow achieved for the different mixes; all mixes reached a satisfactory level of flow ability. The slump flow of the concrete mixes was affected by the inclusion of the fibers. The slump flow diameters of all mixtures were in the range of 780–680 mm, whereas the slump flow time at T_{500} mm of all mixtures was in the range of 2–5 sec.

The L-Box test results presented in Figure 4. The H_2/H_1 was ranged between (0.94-0.83). The results show that the passing ability decreased with increasing fiber content. This because the presence of fibers hampered the concrete mixture from moving through space between barriers. To avoid blockage in L box length of steel fiber should not be longer than three-fourths of the maximum clear distance between the reinforcing bars.

All the mixes visually inspected during the slump flow and L-box tests. It observed that there was no segregation or bleeding in any of the mixes. Also, the GTM screen stability test was conducted to confirm the visual observations for segregation resistance. As can be seen from Figure 4, the GTM% was between (13% -6%). Nevertheless, it should mention that super plasticizer also affected the segregation index of concretes produced in the present study. Super plasticizer significantly improves the flowing ability by enhancing its fluidity, which affects the segregation index. Hybrid fibers effected on the flow of concrete and its workability. Hybrid fibers obstruct flow thereby reducing the flow value and the tendency to form lumps [14]. All mixes generally met the criteria with regards to filling ability, passing ability and segregation resistance requirements.

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Table 9: Fresh Properties of all Mixes.

Mix No.	Slump flow (mm)	T_{500} mm (sec)	L – Box (H_2 /H_1)	GTM (%)
M_0	780	2	0.94	13
M_1	740	2.5	0.90	11
M_2	720	3.5	0.88	10
M_3	750	2.5	0.91	12
M_4	680	4	0.89	9
M_5	710	5	0.83	8
M_6	700	5	0.85	6

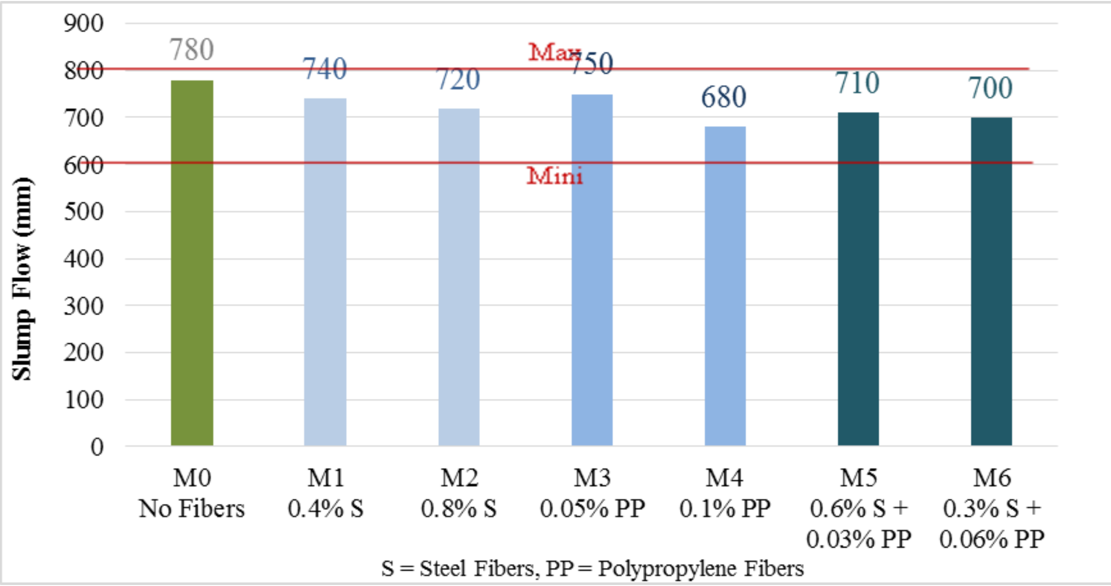

Fig. 3: Effect of Fibers on Slump Flow Test

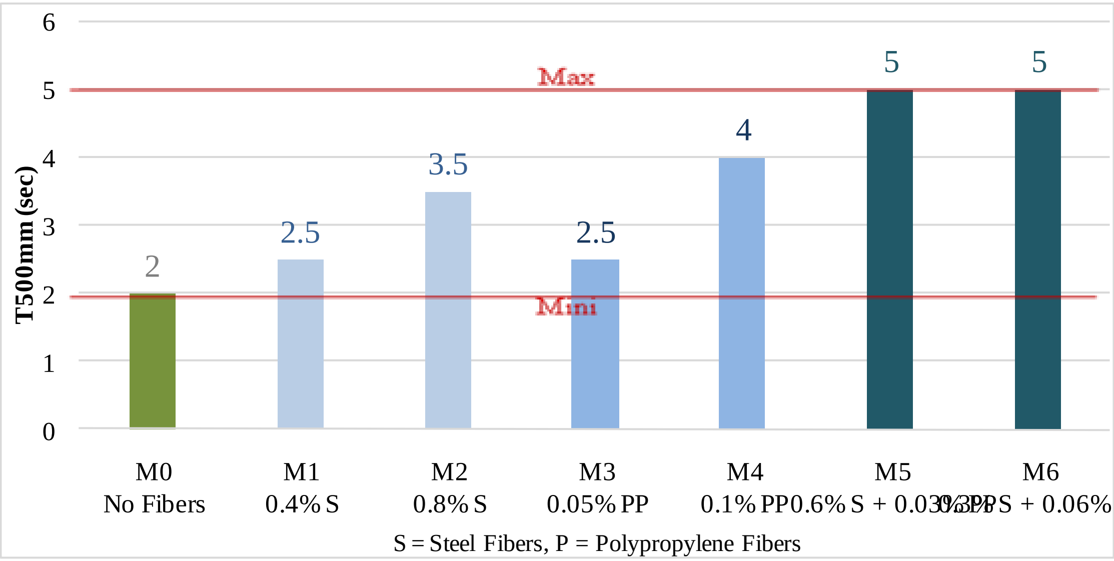

Fig. 4: Effect of Fibers on T_{500} mm (sec) Test

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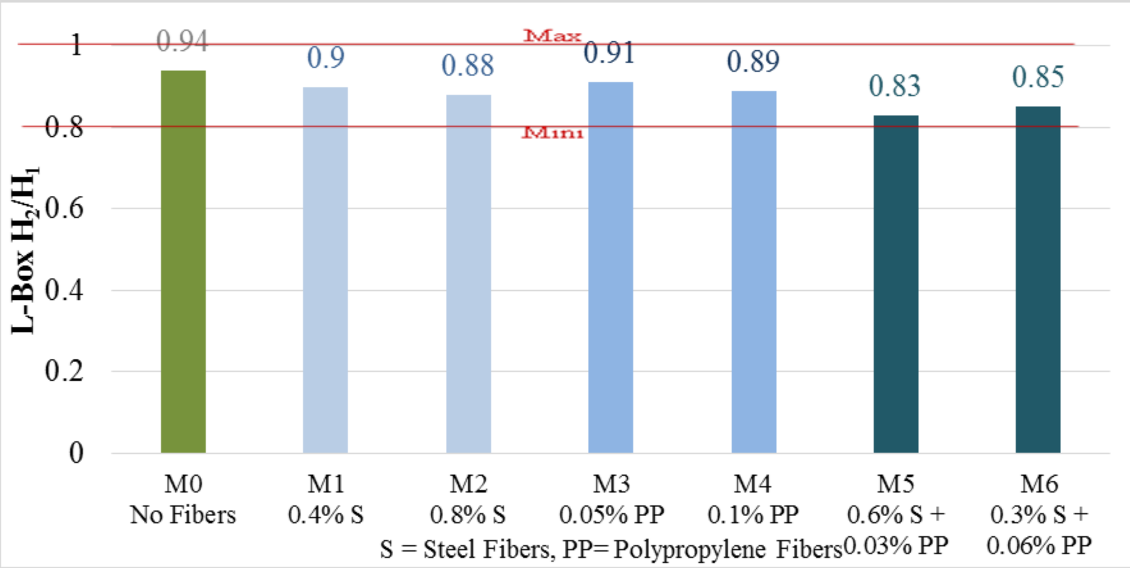

Fig. 5: Effect of Fibers on L–Box Test

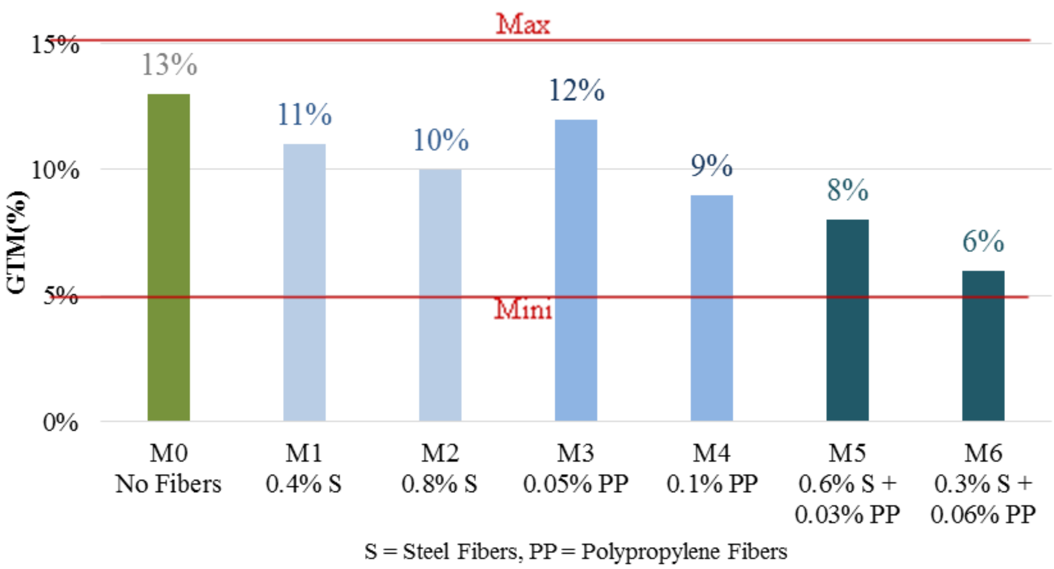

Fig. 6: Effect of Fibers on GTM Screen Stabilities

B. Hardened stage properties

Results of mechanical properties evaluation are illustrated in Figs.7-9.

Compressive strength: All mixes achieved a cube compressive strength of 75±5 .The results of inclusion for steel fibers led to improve the compressive strength of the concrete .Inclusions the short, discrete fibers into the matrix prevent or control the initiation and propagation of cracks, and make them coalesce. This due to the initiation and rapid propagation of cracks in fiber-free concrete, which will reduce the stiffness and load resistance ability. Also, fiber reinforcement can shift the behaviour of self-compacting concrete from strain-softening to strain hardening or pseudo strain-hardening, enhancing the post-cracking performance and ductile behaviour [15, 16].

M5 (0.6% S + 0.03%PP) shows a noticeable increase in compressive strength due to the comparatively high volume fraction of steel fibers and relatively low volume fraction of PP fibers. It was seen that there was a little decrease in compressive strength of mixtures including PP fibers and this is connected to pores created by PP fibers. The hybridization of steel and polypropylene mixtures provides better response to arrest micro and macrocracks, hence improving the compressive strength of concrete [17].

Splitting tensile strength: Results of splitting tensile strength shown in Fig. 8 indicate a significant increase in strength due to the inclusion of fibers. The addition of steel fibers led to an increased HS-SCC splitting tensile strength in the range of (39%-55%). the increase in splitting tensile strength due to inclusions of steel fibers is greater than PP fibers. The splitting tensile strength of the ductile material is higher than brittle materials. Therefore, a gradual increase in the percent of steel fibers

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for different hybridization ratio tensile strength of concrete also increases. Once the split occurs and continues, the steel fibers provide a bridging effect across the split portion. The split portions of the matrix transfer the stresses from the matrix to the fibers and thus steel fibers gradually support the entire load. Stress transfer also improves the tensile strain capacity of the fibrous reinforced concrete and increase the tensile strength [17].

The inclusions of hybrid fibers led to an increased HS-SCC splitting tensile strength in the range of (33%-44%). The failure mode changes from sudden explosive failure resulting in complete damage of the specimen into a more ductile failure in which the specimen is still intact after failure (Fig. 10). This due to the strong bond between fibers and the concrete, and the effect of fibers in preventing concrete from sudden explosive failure [18].

Flexural strength: Flexural strength indicated significant increase in strength due to inclusion of fibers. Fig. 9 shows the flexural strength for different type of fibers. It could be seen from the results that the increase in the flexural strength is significant as the steel volume fraction increases in hybridization, the improvement ranges from 56% to 62%. He ultimate flexural strength of concretes with steel fibers show an increase between 57% to 75% comparing to normal mixes. Therefore, steel fibers are effective to arrest the macro cracks and undergo ductile failure while polypropylenes fibers are only effective to arrest the micro cracks and undergoes brittle failure. Therefore, the steel-polypropylene combination also shows better performance during the bending strength test. Inclusion fibers led to changing the brittle failure mode (sudden failure) of HSC to a more ductile one (Fig. 10).

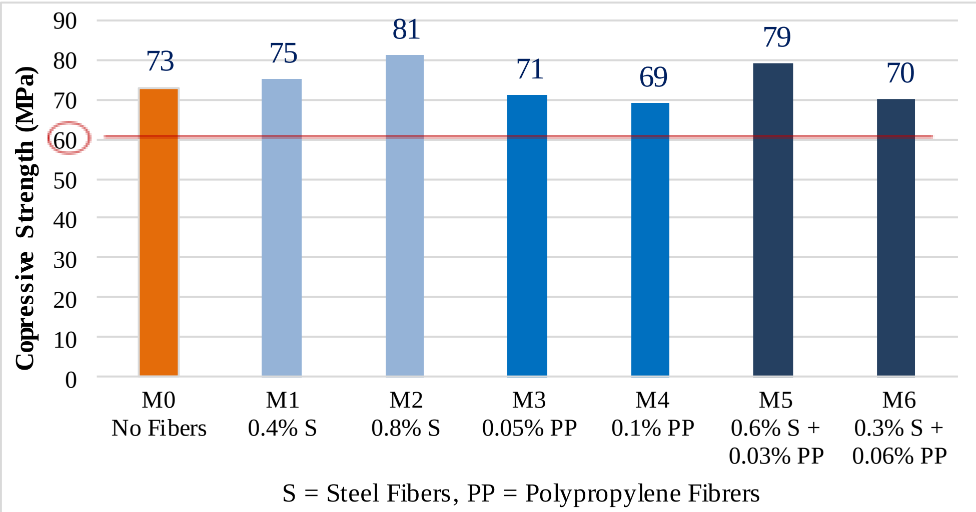

Fig. 7. Effect of Fibers on Compressive Strength (MPa) Test.

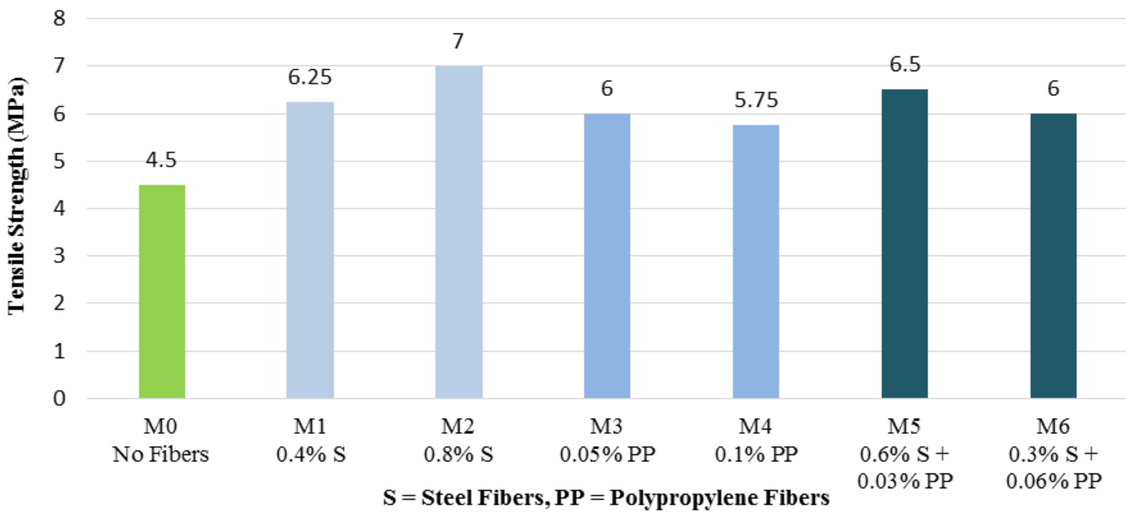

Fig. 8: Effect of Fibers on Splitting Tensile Strength

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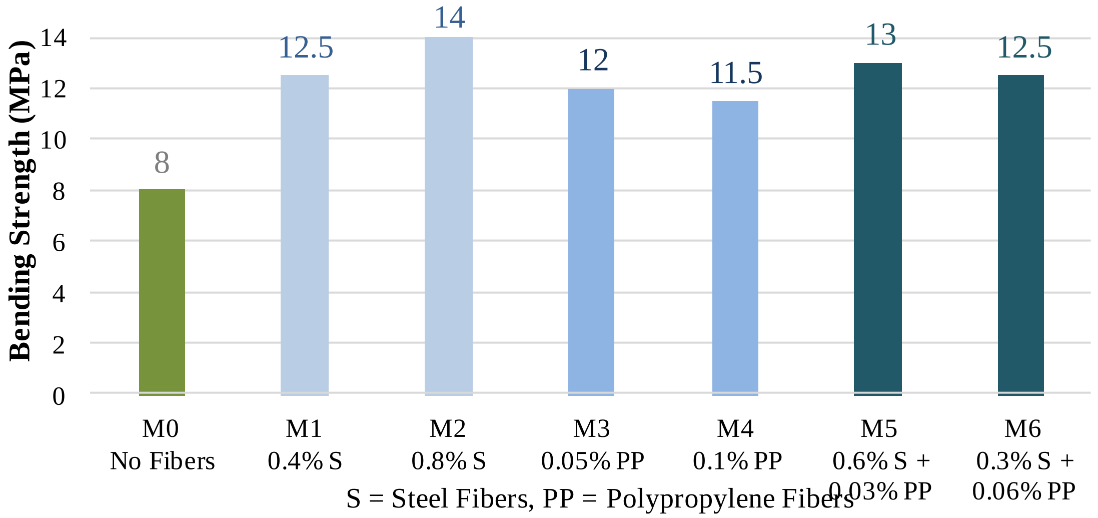

Fig. 9: Effect of Fibers on Flexural Strength.

Fig. 10 Failure modes of the concrete mixes under various loading (right with fiber and left without fiber).

IV. CONCLUSIONS

In this paper, the behavior of HSSCFC concerning fresh and hardened properties was investigated. The main conclusions drawn from this study are:

•Available local materials in Egypt; could be used to produce high strength self-compacting fibrous concrete.

• High strength self-compacting fibrous concrete can be produced through the use of hybrid , PP fibers and Short steel fibers(length of steel fiber should not be longer than three-fourths of the maximum clear distance between the reinforcing bars).

•All mixes containing fibers achieved self-compacting properties *(filling ability, passing ability and segregation resistance).* PP fibers reduced the slump flow more than steel fiber. This is attributed to the higher surface area and aspect ratio of PP fiber.

• The hardened properties are improved by the incorporation of fibers in HSSCF. The flexural and splitting tensile strengths of all HSSCFC were higher than that of control mix by 43%-75% 28%-56%, respectively.

•Inclusion fibers led to changing the brittle failure mode (sudden failure) of HSC to a more ductile one.

•Using a hybrid of steel fibers and polypropylene fibers in concrete led to combine advantages of both fibers types and reducing the overall cost of production.

REFERENCES

[1] Neville, A.M., "Properties of Concrete", 5th edition, London, 2011.

[2] Okamura, H., "Self-compacting high-Performance concrete", Concrete International 19(7): 50-54, 1997.

[3] Ozawa, K., "Development of High-Performance Concrete Based on the Durability Design of Concrete Structures", 2(1), 1989.

[4] Final Report of RILEM TC 188-CSC, "Casting of self-compacting concrete", Materials and Structures, 2006.

[5] Alonso M. C., Sanchez M., Rodriguez C., Barragan B., "Durability of SCC Reinforced with Polymeric Fibers",

 DOI:10.17605/OSF.IO/V64CQ

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ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 6, Issue 9, March 2017

Interaction with Environment and Behavior Against High Temperatures", 11th International Inorganic-Bonded Fiber Composites Conference, Madrid-Spain, 2008.

[6] Jianxin Ma1, Jorg Dietz1, "Ultra High Performance Self Compacting Concrete", Diplng Institution, University of Leipzig Lacer No. 7, 2002.

[7] ES 4756-1/2013, "Cement-Part 1: Composition, Specifications and Conformity Criteria for Common Cements", Egyptian Organization for Standardization and Quality, Egypt.

[8] BS EN 197-1/2011, "Cement-Part 1: Composition, Specifications and Conformity Criteria for Common Cements", 2011.

[9] ES 1109/2008, "Aggregate Specification, Egyptian specification", 2008.

[10] ASTM C494, "Standard specification of chemical admixtures for concrete American Society for Testing and Materials Standard Practice", C494, Philadelphia, Pennsylvania, 2004.

[11] EFNARC, "Specification and Guidelines for Self-Compacting Concrete", European Federation for Specialist Construction Chemicals and Concrete, 2005.

[12] Karatas, M., Gunes, A., "Engineering properties of self-compacting concrete produced by polypropylene and steel fiber", Periodical Polytechnic Civil Engineering, 95-102, 2015.

[13] Yakhlaf, M., "Development of carbon fiber reinforced Self-Consolidating Concrete Patch for Repair Applications", Master thesis, Waterloo University, Ontario, Canada, 2013.

[14] Gupta, S., "Development of high strength self-compacting mortar with hybrid blends of polypropylene and steel fibers", International Journal of Engineering and Technology, 4 (10), 571-576, 2014.30(10), 4286-4292, 2009.

[15] Zende, A. A., Khadirnaikar, R.B., Faruk, U., "Effect of steel fibers on self-compacting concrete", International conference on electrical electronics and optimization techniques, 2240-2244, 2016.

[16] Yehia, S., Douba, A., Abdullahi, O., Farrag, S., "Mechanical and durability evaluation of fiber-reinforced self-compacting concrete", Construction and Building Materials, 121, 120-133, 2016.

[17] Darole J. S., Kulkarni V.P., Shaikh A.P., Gite B.E., "Effect of Hybrid Fiber on Mechanical Properties of Concrete", International Journal of Engineering Research and Applications, 3(4), 1408-1411, 2013.

[18] El-Dieb, A. S., Reda Taha M.M."Flow characteristics and acceptance criteria of fiber-reinforced self-compact concrete (FR-SCC) construction and building materials 27(2012)585-596.

[19] Graybeal, B.A. compressive behavior of ultra-high performance fiber reinforced concrete ACI Mater 2007. 104 (2): 146-52.

[20] Tottijs MC, Barragan BE, Zerbino RL. Physical - mechanical properties and mesostructure of plain and fiber reinforced self - compacted concrete .construct Build Mater 2008:22(8):1780-8.

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