Effect of Forta-Ferro Fibers on Fresh and Mechanical Properties of Ultra High Performance Self Compacting Concrete

M. H. Arafa, M. A. Alqedra, H. G. Almassri

***Abstract*— This research presents an experimental study of the effect of polypropylene fiber on Ultra High Performance Self Compacting Concrete (UHPSCC). Local available materials and inclusion of polypropylene fiber with different quantities are investigated to produce UHPSCC. The experimental program comprises investigating four different quantities of polypropylene fiber namely; 4.55, 9.1, 13.65 and 18.2 kg/m3. The current study focuses on the influence of polypropylene fiber on both fresh and hardened properties such as flowability, filling ability, passing ability, compressive strength, splitting strength and flexural strength of UHPSCC.**

The results revealed that addition of polypropylene fibers improves the compressive strength of UHPSCC in the range of 1% to 7% compared with the non-fibrous UHPSCC. They also enhance the tensile strength in the range of 20% to 30%, and improve the flexural strength within the range of 16% to 26%. Moreover, it is concluded that the optimum polypropylene fiber is 13.65 kg/m3 of concrete with splitting tensile strength of 8MPa and flexural strength of 10MPa.

***Index Terms*— flexural capacity, pre-cracked, shallow beams, stiffness. UHPFRC, UHPC,**

I. INTRODUCTION

Cement mortar and concrete made with Portland cement is a kind of most commonly used construction material in the world [1]. These materials have brittle behavior 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. Many attempts have been done to convert cementitious system to a structural material with desirable physical and mechanical properties [2].

The use of fibers in brittle matrix materials has a long history going back at least 3500 years when sunbaked bricks reinforced with straw were used to build the 57 m high hill of AqarQuf near Baghdad. [3]

Fibers are used for polymer reinforcement also in fiber-reinforced concretes (FRCs) [4]. Various fibers such as those made from polypropylene (PP) have also been applied. Polypropylene fibers can be produced as monofilaments or as collated fibrillated fiber. The fibers are chemically inert, have hydrophobic sources, and are very stable in the alkaline environment of concrete and resist plastic shrinkage cracking. The use of polypropylene fibers improve the tensile strength and improve the flexural strength, toughness and ductility but also obviously improves the impact resistance and fracture properties such as Barchip, Forta-Ferro fibers [4, 5].

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In this research, FORTA FERRO polypropylene fiber is used to obtain the influence of such fibers on the UHPSCC. FORTA FERRO polypropylene is made from 100% virgin copolymer/polypropylene consisting of a twisted bundle

non-fibrillated monofilament and a fibrillated network fiber. This twisted bundle delivery system ensures that the fiber mixes well into the concrete and distributes evenly throughout the concrete matrix. The fiber absorbs maximum energy without breakage and is designed to retain its cross sectional shape thus avoiding brittle failure in high load situations.

The objective of this study is to investigate the influence of polypropylene fibers on the fresh and hardened properties of Ultra High Performance Self-Compacting Concrete by using local available materials. The fresh concrete tests are slump flow, v-funnel and L-box ratio and the hardened concrete tests are compressive strength, splitting strength and flexural strength.

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II. EXPERIMENTAL PROGRAM

i. Materials

The Portland cement used in this study meets the requirements of ASTM C150 [6] specifications and label as CEM I 42.5R. Crushed basalt with a maximum size of 5mm is used as coarse aggregate. In addition, quartz sand with the range of 0.3 to 0.8 mm and quartz powder of a maximum size of 10μmare used as fine aggregate. Besides, grey silica fume which conforms to the requirements of ASTM C1240-05 [7] is used. In addition, a superplasticizer (PLAST.B101P), delivered from YASMO MISR Company of Egypt is used to ensure suitable workability.

Polypropylene fiber with aspect ratio 80 delivered from Forta-Ferro Company is used. Forta-Ferro FORTA FERRO is produced from 100% virgin copolymer/polypropylene consisting of a twisted bundle non-fibrillated monofilament and a fibrillated network fiber. This twisted bundle delivery system ensures that the fiber mixes well into the concrete and distributes evenly throughout the concrete matrix. The fiber absorbs maximum energy without breakage and is designed to retain its cross sectional shape thus avoiding brittle failure in high load situations. Table (I) presents the physical and mechanical properties of used Forta-Ferro Polypropylene fiber.

Table (I) Physical Properties of FORTA FERRO Polypropylene Fibers

Compliance	ASTM C-1116
Origin	Virgin Copolymer/Polypropylene
Fiber form	Monofilament/Fibrillated Fiber system
color	Gray
Acid/Alkali resistance	Excellent
Specific Gravity	0.91
Length	38 – 54 mm
Tensile Strength	570 – 660 MPa

ii. MIXTURES PROPORTIONS

Five series of mix proportions, one of which is control mixture and four mixtures with polypropylene fiber are prepared. The proportions of mixtures are given in Table (II). As shown in Table (II), four quantities of polypropylene fiber (4.55, 9.1, 13.65 and 18.2 kg/m3) were utilized.

Table (II): Mix properties of UHPSCC with PP fiber.

Materials (kg/m^3)	Cement	Water	Silica fume	Quartz	Basalt	Super-plasticizer	PP fiber
Control	950	333	238	1330	1425	29	0
Mix(1)	950	333	238	1330	1425	29	4.55
Mix(2)	950	333	238	1330	1425	29	9.1
Mix(3)	950	333	238	1330	1425	29	13.65
Mix(4)	950	333	238	1330	1425	29	18.2

iii. PREPARATION AND TESTING OF SPECIMENS

The specimens are prepared by mixing the cement, basalt, silica fume and 50 % of the fibers on dry basis for two minutes. Then mix the water and 40% of the superplasticizer for one minute. The remaining superplasticizer and fibers are added and mixing continues for another five minutes.

The Compressive strength tests are carried out using the 100 mm cube specimens based on ASTM C109 [8] (2008), while for tensile splitting strength tests are performedusing150x300 mm cylinders based on ASTM C496 [7] (2004). The flexural strength tests are done on 100x100x500 mm prisms based on ASTM C293 [10] (2008) with central point load.

In the fresh state, slump flow diameter, V-funnel and L-box ratio of UHPSCC with fiber are measured according to EFNARC 2005 Guidelines [11]. Table (III) includes the criteria of Self compacting concrete according to EFNARC 2005.

Table (III) Self Compacting Concrete Criteria

Method	Minimum Range	Maximum Range
Slump flow (Abram Cone), mm	550	850
T500 mm Slump flow, second	2	9
V- funnel, second	6	12
L – Box (h2/h1)	0.8	1

In hardened state, compressive strength, tensile splitting strength and flexural strength are performed at 7, 14 and 28 days expect flexural strength test; it is performed at 7 and 28 days.

III. Results and Discussion

The influence of FORTA FERRO polypropylene fibers which added to UHPSCC on the results of the slump flow, V-funnel and L-Box test results are obtained. Also, the results of compressive strength, tensile strength and flexural strength of FORTA FERRO polypropylene fibrous UHPSCC are discussed. The following paragraphs present and discuss these results.

i. Effect of Fibers on the Fresh Properties of UHPSCC

a. The effect of fiber on slump flow

Four quantities of polypropylene fiber, namely; 4.55, 9.1, 13.65 and 18.2 kg/m3, have been used. The influence of these four quantities of fibers on the flowability of UHPSCC using the slump flow diameter test is presented in Figure (1).

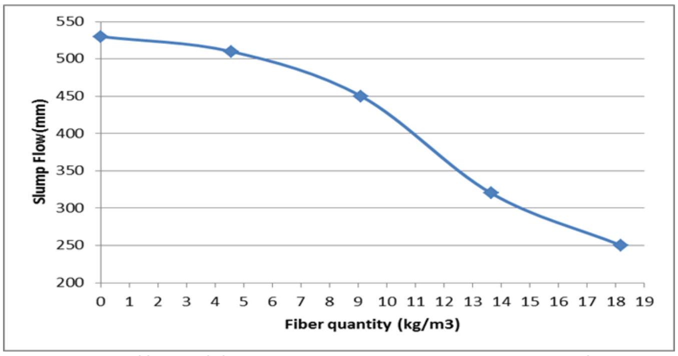

Fig. (1): Effect of fiber quantity on UHPSCC slump flow

It can be said that from Figure (1) that increasing fiber content decreases the flowability of UHPSCC. Including fiber content up less than 9.1 % kg/m3 ensures slump flow which nearly complies with the ENFRAC, 2005. The results showed that adding fiber content of more than 9.1% kg/m3 reduces the flowability to a level which does not satisfy ENFRAC guidelines for SCC. This can be attributed to the fact that as the amount of fibers increase this will restrict the movement of the mixture. The length of used fibers is 54mm, which has a high respect ratio. This aspect ratio could have a negative effect on the flowability of the mixture. The flowability could be increased by reducing the aspect ratio of the fibers through using shorter fiber length.

b. The effect of fiber on V-Funnel results

The V-funnel time is the time in seconds between the opening of the bottom outlet and the light becomes visible from the bottom. The V- funnel time corresponding to the UHPSCC having fiber contents of 4.55, 9.1, 13.65 and 18.2 kg/m3 were obtained and presented in Table (IV).

Table (IV): V-Funnel Times at several fiber contents for UHPSSC.

Fiber Content (kg/m3)	V-Funnel (sec)
0	8
4.55	12
9.1	16
13.65	22
18.2	-

Table (IV) reveals that when increasing fiber content from 0 to 13.65 kg/m3 the V-funnel time increases from 8 s to 22 s, indicating a reduction in the filling ability of UHPSCC. At fiber content greater than 4.55 kg/m3, mixtures do not meet the ENFRAC requirements of flow time, as V-funnel time above 12 seconds will be very cohesive. Moreover, at fiber content higher than 13.65 kg/m3, the fibrous UHPSCC does not fall from the V-funnel device.

c. The effect of fiber on L-Box results

The L-Box test was used to investigate the passing ability of the fresh UHPSCC. The four polypropylene fiber contents (4.55, 9.1, 13.65 and 18.2 kg/m3) were applied to obtain the influence of fiber on the passing ability of UHPSCC. All these fiber contents fail in the L-Box test, because the fiber prevents the movement of concrete through the bars of the device as the spaces were closed by fibers.

ii. Effect of Fibers on the Hardened Properties of UHPSCC

a. The effect of fibers on compressive strength

The influence of 4.55, 9.1, 13.65 and 18.2 kg/m3 fiber contents added to UHPSCC on the 7, 14 and 28- days compressive strengths is presented in Table (V) and Figure (2).

Table (V) 7, 14 and 28- days compressive strengths at several fiber contents for UHPSSC.

Mixture #	Fiber content Kg/m3	7 day - Mean Compressive Strength (MPa)	14 days - Mean Compressive Strength (MPa)	28 days - Mean Compressive Strength (MPa)	Strength increase %
Control	0	53	-	71.8	-
Mix(1)	4.55	53.4	68.4	72.7	1.3%
Mix(2)	9.1	55.2	69.6	73.4	2.2%
Mix(3)	13.65	62.3	72.3	77	7.2%
Mix(4)	18.2	56.44	63.5	72.5	1.0%

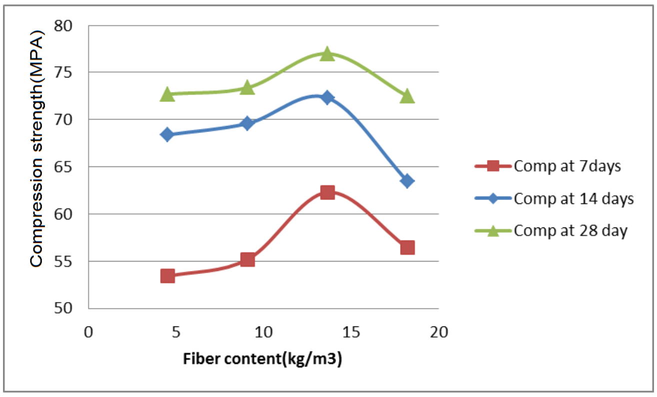

Fig. (2): compressive strengths at several fiber contents with UHPSSC.

At 7 and 14 days, the compressive strength achieved about 75 % and 93 % of the 28-day respectively, as shown in Figure (3).This may be referred to the high silica fume content. This high silica fume content increases the bond between the cement paste and the aggregate particles and reduces the pores in cement paste, which usually tends to increase the early strength of concrete.

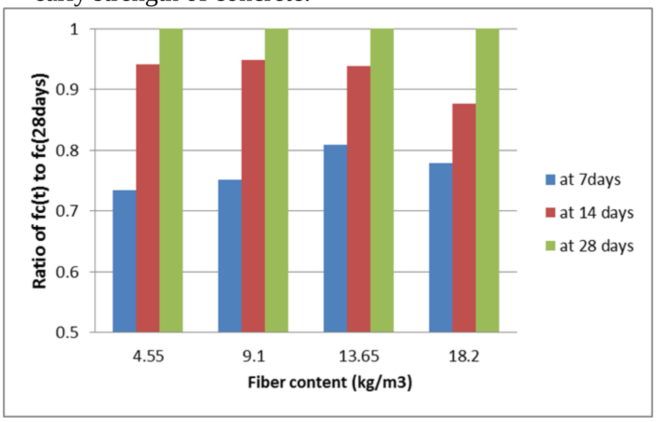

Fig. (3): The ratio of fc (t) / fc (28days) with time for UHPSSC

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The addition of polypropylene fiber causes a small improvement to the compressive strength of UHPSCC from 1% to 7% based on the amount of fiber, as shown in Figure (3). This can be attributed to the fact that the polypropylene fibers in the concrete mixture improve the cohesion with other aggregates resulting in enhancing the mechanical properties of the UHPSCC. Also, this improvement in strength is referred to the good distribution of the Forta-Ferro fibers in the mixture.

b. The effect of fiber on splitting cylinder strength

The splitting cylinder strength results of UHPSCC specimens at 7, 14 and 28 days are summarized in Table (VI) and in Figure (4).

Table (VI) splitting strengths at several fiber contents for UHPSSC

Mixture #	Fiber content Kg/m^3	7 – day mean splitting strength (MPa)	14 – days mean splitting strength (MPa)	28 – days mean splitting strength (MPa)	Strength increase %
Control	0	4.5	-	6.1	-
Mix(1)	4.55	6.4	7.0	7.4	20.6%
Mix(2)	9.1	6.7	7.2	7.6	24.8%
Mix(3)	13.65	7.1	7.4	8.0	30.8%
Mix(4)	18.2	7.1	7.2	7.8	28.0%

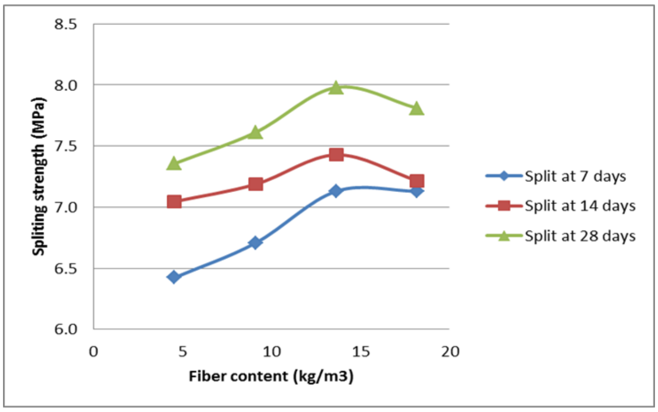

Fig. (4): The variation of splitting strength with fiber content for UHPSSC.

Table (VI) and Figure (4) indicates that the use of polypropylene fiber improves the splitting strength of UHPSCC in the range of 20% to 30%, based on the fiber content. Figure (4) shows that splitting strength increases gradually as fiber content increases from 4.55-13.65 kg/m3 then it decreases beyond fiber content of 18.2kg/m3. The optimum fiber content for splitting strength is found to be 13.65 kg/m3.

At 7 and 14 days specimens results, the splitting strength achieved about 87 % and 93 % of the 28-day respectively, as shown in Figure (5). This can be attributed to the strong bond between silica fume and cement paste, which leads to higher increase the early strength of concrete.

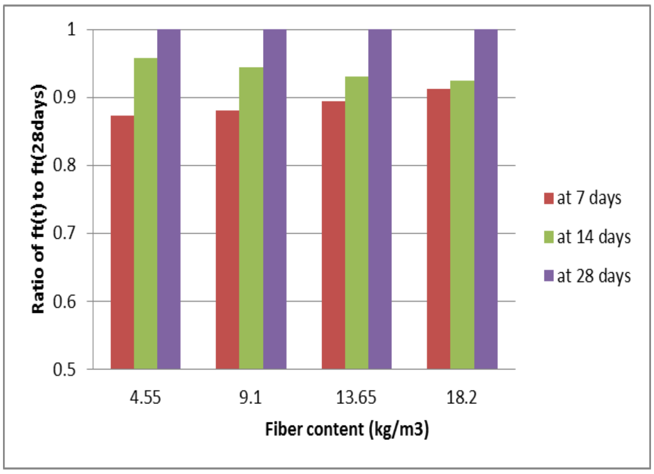

Fig. (5): The ratio of ft (t) to ft (28days) with time for UHPSSC.

c. The effect of fiber on flexural strength

The 7 – day and 28 – day flexural strength results of UHPSCC specimens are included in Table (VII) and in Figure (6).

Table (VII) Flexural strength of fibrous UHPSCC at several fiber contents.

Mixture #	Fiber conten t Kg/m3	7 – day mean flexural strength (MPa)	28 – days mean flexural Strength (MPa)	strength increase %
Control	0	6.8	7.94	-
Mix(1)	4.55	7.96	9.26	16.6%
Mix(2)	9.1	8.00	9.36	17.8%
Mix(3)	13.65	8.20	9.77	23.1%
Mix(4)	18.2	7.93	10.01	26.1%

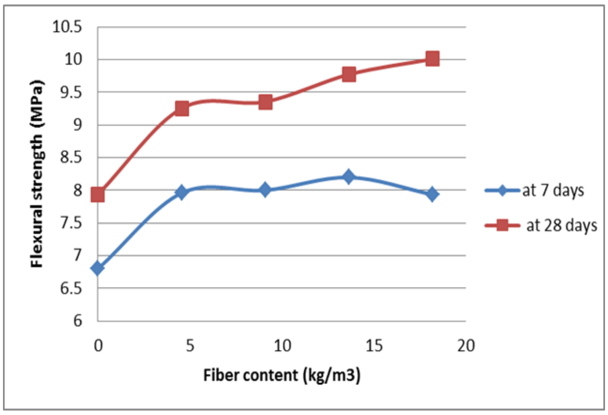

Fig. (6): The variation of flexural strength with fiber content for UHPSSC

The results showed that the use of polypropylene fibers improves the flexural strength of UHPSCC within range (16%-26%) based on the fiber content, as shown in Table (VII). Figure (6) shows that the mean modulus of rupture strength increases slowly at fiber content from 4.55 to 18.2kg/m3. The optimum fiber content is found to be 18.2 kg/m3for flexural strength. This is due to contribution of polypropylene fibers to undertake the tensile load before fracture of the samples. In addition, the existence of fibers delays the growth of micro cracks and thereby improving the ultimate tensile stress capacity according to ACI 544.1R-96.

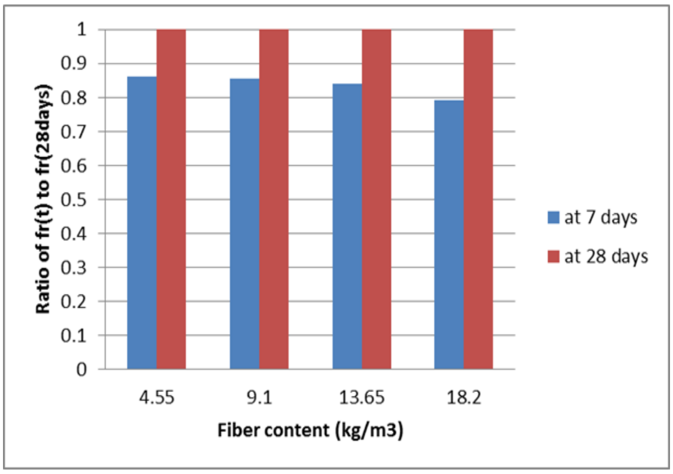

Fig. (7): The ratio of fr (t) / fr (28days) with time for UHPSSC

At 7 days, the flexural strength achieved about 84 % of the 28-day strength, as shown in Figure (7). This can also be referred to the stronger bond developed by fibers between cement, silica fume and aggregates.

IV. CONCLUSIONS

Based on the results of this particular testing program, the following conclusions can be drawn out:

- Adding fiber content of 4.55kg/m3 of concrete lead to a slight increase of 4 % in the slump flow compare with the non-fibrous UHPSCC. When fiber content is increased to 9.1 kg/m3 a reduction of 15 % in slump flow is recorded. Further increasing fiber content from 9.1 kg/m3 to 18.2 kg/m3 results in further reduction in slump flow of about 53%.
- The current study showed that using polypropylene fibers causes a small improvement of the compressive strength of UHPSCC within range (1%-7%).
- The results indicated that utilizing polypropylene fibers improves the splitting strength of UHPSCC within range (20%-30%) based on the fiber content with respect to the non-fibrous tensile splitting strength of 8MPa.
- At 7 and 14 days, the cylinder splitting strength achieved about 87 % and 93 % of the 28-day respectively.
- At 7 days, the results indicated that the obtained flexural strength is about 84 % of the 28-day.
- The addition polypropylene fiber improves the flexural strength of UHPSCC within range (16%-26%) with respect to the non-fibrous flexural tensile strength of 10.01 MPa.

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VI. REFERENCES

[1] Roohollah Bagherzadeh, Hamid Reza Pakravan, Abdol-Hossein Sadeghi, Masoud Latifi, Ali Akbar Merati,2012," An Investigation on Adding Polypropylene Fibers to Reinforce Lightweight Cement Composites (LWC)", journal of Engineered Fibers and Fabrics ,vol.7,Issue 4.

[2]Bentur A and Mindess S., 2007,“Fiber Reinforced Cementitious Composites”, 2th ed., p.11-235.
[3]Newman, J. and Choo, B., 2003,” Advanced concrete technology (processes)”, Elsevier Ltd, Oxford.
[4]Deng Z, Li J., 2006,” Mechanical behaviors of concrete combined with steel and synthetic macro-fibers”, Journal of Physical Science, vol. (2), pp. 57-66
[5]Laukaitis, 1997,” A. Influence of carbon fibers addition on porous silicate concrete formation and product properties”.
[6]ASTM C150, 2004, “Standard specifications of Portland cement American Society for Testing and Materials Standard Practice C150”, Philadelphia, Pennsylvania.
[7]ASTM C109, 2004, “Standard Test Method for Compressive Strength of cube Concrete Specimens”, American Society for Testing and Materials Standard Practice C109, Philadelphia, Pennsylvania.
[8]ASTM C496, 2004, “Standard Test Method for Splitting Tensile Strength of CylindricalConcrete Specimens”, American Society for Testing and Materials Standard Practice C496, Philadelphia, Pennsylvania.
[9]ASTM C293, 1994, “Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with center-Point Loading)”, American Society for Testing and Materials Standard Practice C293, Philadelphia, Pennsylvania.
[10] ACI 544.1R-96, State-of-the-art report on fiber reinforced concrete, Farmington Hills, Michigan: American Concrete Institute, 2002.
[11] EFNARC, 2005, The European Guidelines for Self-Compacting Concrete Specification, Production and Use, Farnham, Surrey GU9 7EN, UK, website: www.efnarc.org, ISBN: 0953973344