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The Effect of Polypropylene Fibers on the Behavior of Fiber Self-Compacting Concrete

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Abstract

Fiber self-compacting concrete (FSCC), is a concrete that has been combined with fiber in its mix design. Extensive benefits of self-compacting concrete (SCC) in full fill the mold and achieving full compaction without vibration, with good behavior after concrete cracking, raise the idea of self-compacting concrete production. The fundamental challenge in this area is the unsatisfactory performance of concrete with fibers; In other words, using fibers in concrete will reduce concrete fluidity. Therefore, determining the appropriate percentage of fibers in SCC can be a precursor to extending the use of FSCC. In this study, polypropylene fibers with 0.5, 1, 0.1, and 2% of concrete mix design have been added to the self-compacting concrete mix design. Its impact on the performance of concrete has been evaluated using time and diameter of slump-flow, L-Box, J-ring, and V-funnel flow time tests. Based on the criteria defined by EFNARC standard, it was indicated that the FSCC containing 0.5% polypropylene fibers has an acceptable performance. Additionally, the effect of polypropylene fiber on the mechanical properties of hardened concrete has been studied using compressive strength and tensile tests and shown that changes in FSCC compressive strength and tensile with 0.5% polypropylene fiber are negligible. (DOI:**https//doi.org/10.52547/JCER.5.4.56**)

Keywords: Fiber self-compacting concrete; Polypropylene; Compressive strength; Tensile strength.

1. 2. Introduction

For the last four decades, SCCs have been widely used to improve concrete casting. SCCs have the ability to fit and compress under their own weight with no or low energy requirements. Their adhesion is enough that during the transfer, grain detachment or bleeding does not occur. [1-3] This specification causes concreting in dense reinforcement structures (such as floor slabs, docks, and other structures) can be possible without vibration. On the other hand, due to the adequate fluidity of SCC, fast pumping, and in consequence, production of uniform and dense concrete surfaces would be possible. These advantages make extensive use of SCC in different areas of reinforced concrete structures implementation [4-8].

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Table 1.
Chemical and physical properties of cement

Chemical composition (%)								Physical properties
MgO	SiO2	Al2O3	Fe2O3	C3A	SO3	L.O.I	I.R	Specific surface
1.4	21.2	4.6	3.8	6	2.45	1	0.5	3100

Table 2.
Self-compacting concrete's mix design

	cement Kg/cm^2	Water Kg/cm^2	Micro silica	Sand Kg/cm^2	Gravel Kg/cm^2	super plasticizer Kg/cm^2	VMA Kg/cm^2
SCC	400	192	18	870	651	8	3.20

Table 3.
Polypropylene Physical properties

Length (cm)	width (cm)	Thickness (cm)	Ratio of length to diameter
2.06	0.18	0.05	20

Recent research showed that fibers can control crack propagation in concrete [9-12]. Therefore, impact resistance, fatigue, plastic shrinkage cracks reduction, remaining bending strength (after cracking), and energy absorption capacity of concrete be improved [13-15]. The effectiveness of fiber in concrete depends on the type and amount of fibers, shape, length, aspect ratio (ratio of length to the diameter of the fibers), tensile strength, and inhibitory mechanisms [12, 16]. FSCC simultaneously has both SCC and Fiber reinforced concrete (FRC) advantages together. But it should be noted that, if the fiber value exceeds the optimum required amount, fibers may cause a reduction in the performance of the concrete mix and as much as the amount of fiber gets more than the optimum value, the efficiency will be reduced. In this regard, the determination of the optimum amount of fibers used in SCC is the main objective of this research [10, 17-20]. Hence, the mechanical properties of FSCCs should be known to improve the behavior of the SCC while mixing with fibers [21]. In this study, the effect of polypropylene fibers addition on the performance of SCC has been evaluated using time and diameter of slump-flow, L-Box, J-ring, and V-funnel flow time tests. Also, mechanical properties, including tensile and compressive strength of FSCC mix designs were evaluated at the ages of 7, 28, and 90 days.

2. Materials and methods

In accordance with ASTM C105 standard, Portland cement type 2 has been used to prepare the specimens of this study, and its physical and chemical characteristics are presented in Table 1.

Natural sand and manufactured coarse aggregates have been used and limestone powder has been employed as a filler. Aggregates have been used in saturated surface-dry (SSD) conditions; the largest and smallest coarse are 0.12 and 0.475 centimeters respectively. Superplasticizers used in this study are based on high-performance poly-carboxylic with a specific gravity of 1.133 gr/cm. The viscosity modifying additives (VMA) has been used to maintain the integrity of the concrete, and also for the prevention of aggregate detachment and concrete bleeding. VMA specific gravity is 13 gr/cm. Table 2 presents the SCC mix design, used in this study. As shown in Table 2, polypropylene fiber with values of 0.5, 1, 1.5, and 2% of mix design has been added to provide FSCC with the physical characteristics presented in Table 3.

For making concrete, Initially, the dry materials are mixed for 1 minute and then half of the water (which is obtained in the mix design) is added to the mixture gradually along with the superplasticizer and mixed for another three minutes. After stopping the operation for 1 minute, the other half of the water along with VMA is added and mixed for 2 minutes.

For cylindrical specimens, a standard metal mold with dimensions of 35× 10 cm is used. After the materials were mixed, tests have been conducted on fresh concrete. Then concrete is poured into the lubricated mold where all molds are filled without any vibration or shock in one step. After 24 hours all the specimens have been transformed and kept in water. In this research 24 specimens were prepared with 0.5, 1, 1.5, and 2% polypropylene fibers and 6 control specimens.

Table 4.
FSCC Performance Testing Results

specimens	**Slump Flow Time (*sec*)**	**Slump Flow Diameter (*cm*)**	**J-Ring (*cm*)**	**L-Box (H_2/H_1)**	**V-Funnel Time *(Sec)***
A	2.20	76.00	2.50	0.81	4.40
B	2.50	73.00	3.00	0.79	6.80
C	2.70	69.00	3.00	0.73	11.40
D	3.10	65.00	4.00	0.69	16.50
E	3.80	61.00	5.00	0.61	18.80

3. Results and discussion

After the materials were mixed in the mixer, a performance test has been conducted. The flow speed of SCC depends on its viscosity. SCCs must meet the following four features:

1. The ability to fill the mold with its own weight
2. Segregation resistance of the aggregate
3. The ability to pass through the rebar without segregation of aggregates
4. The smooth surface

The capability of specimens to achieve SCC characteristics has been evaluated using time and diameter of slump-flow, L-Box, J-ring and V-funnel flow time tests where the results show in Table 1. (A) is the control specimen and specimens B, C, D and E have 0, 0.5, 1, 1.5 and 2% of propylene respectively.

The slump flow time test (T50) is a criterion to determine the viscosity of SCC. In Figure 2, the alteration chart of (50T) slump flow time, due to the use of propylene fibers in concrete mix design is provided. As can be seen, with increasing fiber content, the slump flow time increases which show that the concrete fluidity has fallen. Although increasing the use of polypropylene fibers decreases the fluidity, according to the specification for SCC (EFNARC) standards all specimens have appropriate slump time as self-compacting concrete (Based on the specification for the SCC EFNARC standard, the flow time of self-compacting concrete should be between 2 and 0 seconds).

a) L-Box

b) J-ring

c) V-funnel
Figure 1. SCC test instruments

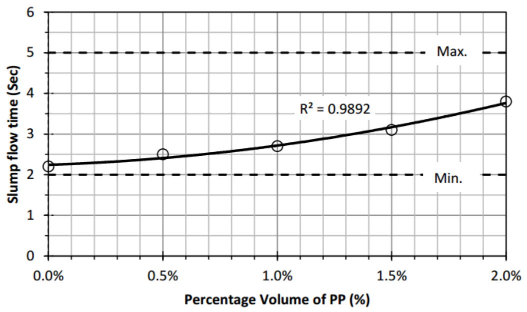

Figure 2. Slump flow time test results (50T)

The results of the diameter of slump flow test is shown in Figure 3. This test is a common method for determining the flow properties of concrete, in the horizontal plane with no obstructions. It is equal to the average of diameter of the concrete after removing the Abram cone. As can be seen by increasing the percentage of polypropylene fibers, slump flow diameter decreases. For example, using 2% of polypropylene fibers in concrete mix designs, thereby reducing the diameter of the slump from 76 to 61 cm. Thus, according to the specification for SCC (EFNARC) standard, when polypropylene fibers amount is more than 1.5%, the concrete cannot be considered as SCC (Based on the specification for the SCC EFNARC standard, the diameter of the slump flow should be between 65 to 80 cm).

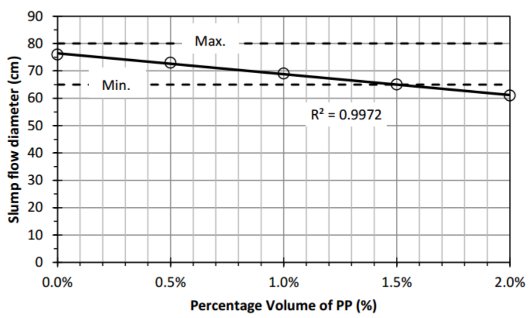

Figure 3. Diameter of slump flow test results

The results of the J-ring test are provided in Figure 4. This test is to identify the SCC's capability to pass through the rebar. As can be seen, by increasing the percentage of propylene fibers, the results of this experiment increased which is indicate that the fluidity of SCC decreases. But according to the specification for SCC (EFNARC) standard all specimens satisfy the J-ring test to be considered as SCC. (Based on the specification for the SCC EFNARC standard, the J-ring results should be between 1 to 5 cm).

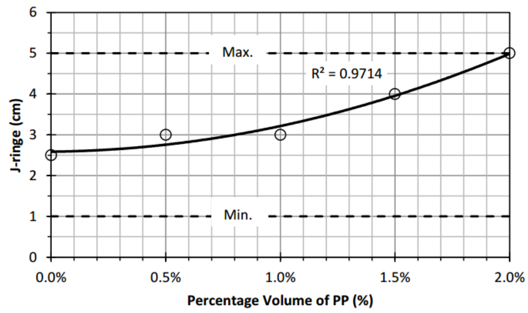

Figure 4. J-ring test results

The results of the L-Box test, show the passing ability of concrete through reinforcement in enclosed spaces (Figure 5). As can be seen, by increasing the percentage of propylene fibers, the passing ability decrease drastically. Based on the specification for EFNARC standard the least value obtained from the L Box test should not be less than 2.5. Hence, only the specimen without fiber and also the specimen with 0.5% polypropylene (Specimen B) with the ratio of H2/H1 which is respectively equal to 0.82 and 0.8, satisfy the specification of SCC. For the rest of the specimens prepared with a higher amount of polypropylene fiber, the ratio of H2/H1 decreases. It shows that concrete cannot fill a significant section of the end part of the horizontal L-Box. This test shows that specimens C, D, and E do not satisfy the specification of SCC.

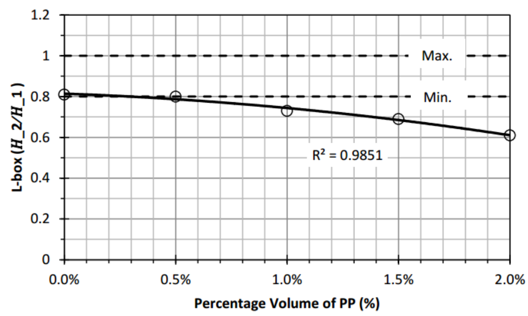

Figure 5. L-Box test results

The V-funnel flow time tests, evaluate the ability of self-compacting concrete to fill the mold. The diagram of V-funnel flow time test results is presented in Figure 6. As can be seen, for the specimen without fiber, the flow time is 4.4 seconds which is less than the minimum value defined by the EFNARC standard. With the addition of fiber, flow time increases. For example, the specimens with 0.5% and 1% of fiber, with a time of 6.8 and 11.4 seconds, satisfy the specification of SCC (According to the specification for the SCC EFNARC standard, the V-funnel flow time tests results should be between 6 to 12 cm). Flow time is considerably increased by the addition of more fibers (1.5 and 2%) so that it goes beyond the limits defined (Figure 6).

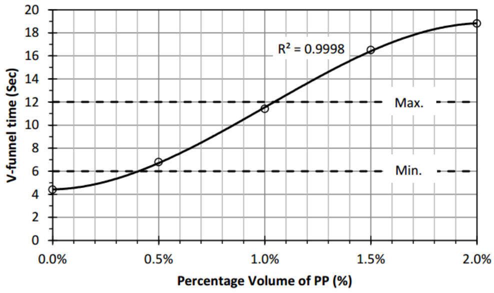

Figure 6. V-funnel flow time tests results

According to Table 4 and figures 2 to 6, the addition of fibers to the concrete leads to reduce the concrete performance (This trend has also been observed for the use of steel fibers in concrete). However, according to Table 5 (where acceptance of each of the specimens is defined based on the limits on the EFNARC standard) specimen (B) can be known as SCC. Concrete performance decreased by increasing the amount of fiber. The first concrete inefficiency is revealed through the L-box test for specimen (C) with 1% fiber. By increasing the percentage of polypropylene fiber to 1.5% the weakness would be more evident as far as specimen D would not satisfy the specification of SCC for V-funnel flow time tests.

3.1. Mechanical properties of FSCC

3.1.1. FSCCs Compressive strength

The compressive strength values of specimens at the age of 7, 28, and 90 days are presented in Table 6.

Table 5.
acceptability of specimens based on the limits of the EFNARC standard

specimens	**Slump Flow Time (*sec*)**	**Slump Flow Diameter (*cm*)**	**J-Ring (*cm*)**	**L-Box (H_2/H_1)**	**V-Funnel Time *(Sec)***
A	✓	✓	✓	✓	✓
B	✓	✓	✓	✓	✓
C	✓	✓	✓	×	✓
D	✓	✓	✓	×	×
E	✓	×	✓	×	×

Table 6.
Compressive strength of FSCC

specimens	compressive strength Kg/cm^2		
	7 dayes	28 days	90 days
A	288	389	469
B	261	372	452
C	245	343	438
D	234	331	407
E	221	315	401

In a research study, used polypropylene fibers (1.5 and 0.3%) to improve the physical and mechanical characteristics of concrete in their studies. The result showed that fibers, cause a slight increase in the compressive strength of concrete (about 5%). While Kakoei et al [22] Shown that using higher amounts of fibers (1.5, 2 kg/m3) noticeably increased compressive strength of the concrete. As noted, in the most studies, using of fibers increases the compressive strength of the concrete, however, in this study, the adding fiber to the SCC leads to the reduction of compressive strength of concrete. This decrease in resistance can be attributed to a decrease in concrete performance (due to the use of fiber), by increasing the proportion of fibers, condensing capacity of the SCC will reduce.

Based on the results of section 3.1., specimen (B), with 0.5% fiber, respected all limitations in the standard. As can be seen in figure 7, the use of 0.5% polypropylene fiber in the SCC mix design, reduces the compressive strength of concrete to 4.4% at the age of 28 days. This difference was reduced to 3.6% after 90 days. This difference can be neglected in return for the benefits of polypropylene fibers. On the other hand, for specimen (C) with 1% polypropylene fibers, strength reduction after 28 and 90 days is 12 and 6.5% respectively.

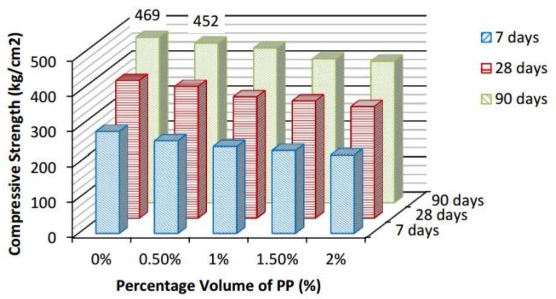

Figure 7. FSCC's compressive strength in different ages

3.1.2. FSCC's tensile strength

Tensile strength at the ages of 7, 28, and 90 days has been shown in Table 7 and figure 8. As can be seen, by increasing the percentage of fiber, the tensile strength increases. That this reflects the positive impact of propylene fibers in enhancing the tensile strength and ductility of concrete.

Table 5.
Tensile strength of FSCC

specimens	Tensile strength Kg/cm^2		
	7 days	28 days	90 days
A	21.1	32.6	33.7
B	21.9	33.2	34.8
C	23.3	36.5	37.3
D	24	38.8	39.1
E	26.9	44.2	45.4

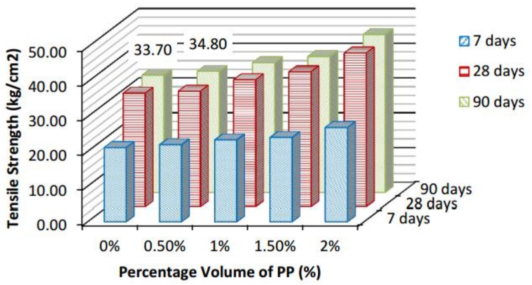

Figure 7. FSCC's Tensile strength in different ages

Investigation on FSCCs shows that by applying 3% polypropylene fiber, the specimen's rupture resistance will be increased to 13.6%. While in this research, after 28 days, the rupture resistance will be increased to 1.8 and 1.2% by adding 0.5 and 1% of fiber respectively. As can be seen, after 90 days, the compressive strength of the specimen (C) is almost equal to the specimen without fiber (by 6.5% reduction) and also by a 12% increase in rupture resistance, which has been able to satisfy the specifications required for SCC. On the other hand, by the experiments carried out on fresh concrete in accordance with the same mix design, specimen (C) can be also considered SCC. In other words, the proposed mix design in accordance with specimen (C), simultaneously has the advantages of both fiber concrete and self-compacting concrete.

4. Conclusion

The present research has shown that adding fiber caused a reduction in the compressive strength of concrete while the tensile strength and ductility of the concrete increased. Although adding 0.5% polypropylene fiber in the SCC mix design, reduces the compressive strength by 3.6%, this value is negligible in return for its several advantages. The results also showed that specimen (C) with 1% polypropylene fiber can satisfy both FSCC and SCC specifications and its compressive strength is almost equal to the specimen without fiber; but its rupture resistance increased up to 12%. The results of the L-BOX test for the specimen (C) revealed that increasing the fiber percentage reduces self-compacting concrete performance.

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