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# EFFECT OF MACRO-SYNTHETIC POLYPROPYLENE FIBER ON MECHANICAL PROPERTIES AND DRYING SHRINKAGE CRACKING OF SELF-CONSOLIDATING CONCRETE

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**ABSTRACT:** Development in the concrete industry led to an increasing need for faster construction, high-performance, energy-saving, and eco-friendly concrete technology. Self-consolidating concrete (SCC) has become a promising concrete technology to shorten construction time and reduce labor needs. However, SCC has susceptible to shrinkage cracking due to high binder and low aggregate content. On the other hand, fiber has been used to control cracking and increase post-cracking behavior and toughness. Fiber addition into the SCC mix has become a common method to improve cracking resistance, even though it may reduce workability. In this study, the effect of macro-synthetic fiber on the drying shrinkage of SCC is evaluated using free and restrained shrinkage tests. SCC mixtures include concrete containing different percentages of polypropylene (PP) fiber content (0.25, 0.5, 0.75, and 1.0% by volume). Besides that, compressive strength, splitting tensile strength, and workability in terms of Slump flow, J-Ring, and V-Funnel of fiber-reinforced SCC are also investigated. The results show that the addition of macro-synthetic fibers can delay crack formation due to drying shrinkage compared to plain SCC.

*Keywords: Self-consolidating concrete, Polypropylene fiber, Mechanical properties, Shrinkage*

## 1. INTRODUCTION

Self-consolidating concrete (SCC) has become more frequently used in concrete construction due to its better workability and efficiency in construction time and labor needs [1]. However, SCC is prone to shrinkage cracking due to high binder and low aggregate content [2,3]. Shrinkage cracking on concrete structures may reduce structural performance and durability. On the other hand, introducing fiber into a concrete mixture has been known to be used to control cracking and increase post-cracking behavior. At the same time, fibers may replace some minimum steel reinforcement. The addition of fiber into the SCC mixture is expected to improve cracking resistance and increase the hardened properties of concrete, such as tensile, flexural, and toughness. However, high fiber content may also reduce concrete workability, which may discard the beneficial factor of SCC. Hence, the effect of fibers on SCC, namely fiber-reinforced self-consolidating concrete (FRSCC), needs to be investigated to obtain an optimum dosage resulting in the best performance of FRSCC. The synergetic effect between fiber and SCC has also been investigated by several researchers [4-6]. However, the effect of the fiber content of macro-synthetic polypropylene fibers on drying shrinkage still needs to be investigated.

Various type of fiber has been used in the concrete mix, such as steel fiber, glass fiber, or synthetic fiber, e.g., polyester, polypropylene, polyethylene, or natural fiber. Among them, steel fiber is the most common and widely used. For steel fiber in SCC as studied by Javadian A. et al. [7], several parameters affect the workability and flexural toughness such as fiber content, aspect ratio, and fiber length. There is also variation in the fiber shape, such as straight monofilament, multifilament, crimped, embossed, or with an end-hook. Fiber with a rough surface and end-hook has been known to improve its anchorage to concrete [8, 9].

Fiber size can be categorized as macro- and micro-fiber depending on fiber length and the aspect ratio, i.e., diameter to length ratio. Mashreq et al. [10] study the effect of micro-polypropylene fiber from 0 to 0.5% on compressive and flexural strength. The results show that compressive strength and flexural strength increased by increasing fiber content up to 0.3%. Beyond this fiber content, the strength started to decline. Arsalan et al. [11] also study the effect of micro-polypropylene fiber in concrete with a length of 12 mm with a proportion ranging from 0.06% to 2.16%. It was found that fiber content increased compressive, splitting, and flexural strength in concrete and reached the maximum value of 0.36%.

A study from Abbas et al. [12] using micro-polypropylene fiber with a length of 12 mm and fiber percentage from 0.5 to 1.5 % indicated an increase of bond strength between concrete and steel bar with an increase in fiber content.

Study on macro-polypropylene fiber use in SCC, particularly the influence on mechanical properties and shrinkage is still limited. This study was focused to investigate the effect of macro-synthetic polypropylene fibers on SCC on fresh and hardened properties, especially on drying shrinkage. Two drying shrinkage tests were carried out using free and restrained shrinkage tests according to ASTM C341 [13] and ASTM C1581 [14]. The main parameter is the variation in fiber content of 0, 0.5, 0.75, and 1.0% by volume. Based on the test results, the effect of fiber content on drying shrinkage cracking was confirmed.

## 2. RESEARCH SIGNIFICANCE

The use of fiber in concrete construction has been widely used in various applications with various types of materials and fiber types. Steel fiber is the most commonly used fiber that has been extensively researched. Research conducted concerning the effect of fiber on compressive, tensile, and flexural strength including its effect on shrinkage. The use of synthetic fibers such as polypropylene has also begun to be used to improve performance against cracking and toughness. However, there is still little research on the application of macro synthetic polypropylene fiber in SCC, especially since there are many variations in the aspect of fiber texture, aspect ratio (ratio of length to diameter), and fiber content. This study provides evidence of the effect of macro-synthetic polypropylene fiber on improving mechanical properties including improving performance against shrinkage cracking. The findings may provide ideas and references for the use of this type of fiber and the risk of shrinkage cracking in SCC applications.

## 3. EXPERIMENTAL PROGRAM

### 3.1 Material and Mixture Proportion

Type I cement of Portland cement composite (PCC) was used as a binder for the SCC mixture. To achieve the workability of SCC, a polycarboxylate high-range water reducer (HRWR) was added to the mixture without an additional shrinkage-reducing agent or mineral pozzolan. The maximum aggregate size was limited to 12.5 mm for coarse aggregate with a specific gravity of 2.73 and 1.09% of absorption. Natural sand finer than 2.4 mm was used with a specific gravity of 2.39 and 5.5% absorption as a fine aggregate. The mixture proportion was designed for specified concrete strength of 50 MPa, and a low water-to-cement ratio of 0.32 was used to achieve higher concrete strength. The concrete mixture proportion is given in Table 1. The properties of polypropylene fibers used in this study are given in Table 2 and Fig.1. The fiber percentage of volume fractions of 0, 0.25, 0.5, 0.75, and 1.0. All concrete mixture parameters keep constant for all specimens, except for the coarse aggregate content adjusted to the fiber content.

Table 1 Concrete mix proportions

| Mix No. | w/c | Cement ($kg/m^3$) | Aggregate ($kg/m^3$) | | Fiber content (%) |
|---|---|---|---|---|---|
| | | | Coarse | Fine | |
| NF | 0.32 | 618 | 781 | 801 | 0.0 |
| F0.5 | 0.32 | 618 | 776 | 801 | 0.5 |
| F0.75 | 0.32 | 618 | 774 | 801 | 0.75 |
| F1.0 | 0.32 | 618 | 772 | 801 | 1.0 |

Table 2 Polypropylene fiber properties

| | |
|---|---|
| Fiber shape | Monofilament with continuous embossed |
| Specific Gravity | 0.92 |
| Length, L (mm) | 60 |
| Diameter, d (mm) | 0.4 |
| Aspect ratio (L/d) | 150 |
| Modulus elasticity (GPa) | 10 |
| Tensile strength (MPa) | 640 |

Fig.1 Polypropylene fibers

### 3.2 Fresh Concrete Test

Workability is crucial in fresh concrete properties, especially for self-consolidating concrete. As mentioned in the introduction, fiber addition may affect the workability performance of SCC. There are three main aspects of workability performances in SCC, i.e., filling ability, passing ability, and segregation resistance, that should be evaluated. The filling ability was measured by slump flow test according to ASTM C1611 [15] see Fig.2(a). The filling ability or flowability is expressed in terms of the slump flow value of the diameter of 450-760 mm (18 – 30 inches). The passing ability test was conducted using the J-Ring test specified in ASTM C1621 [16] as shown in Fig. 2 (b). The segregation resistance test was carried out using the V-funnel test (Fig. 2 (c)) according to EFNARC [17] and was also visually examined during the slump flow test.

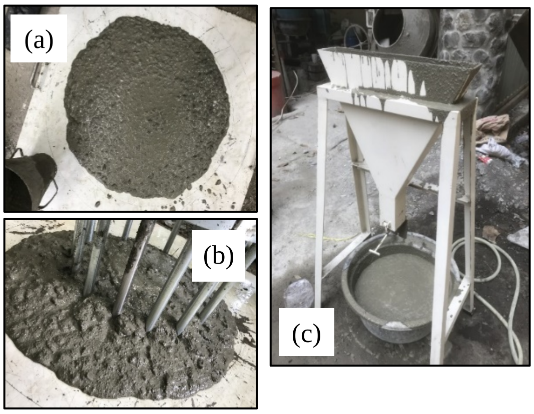


Fig.2 Fresh concrete test (a) Slump flow (b) J-Ring (c) V-funnel

### 3.3 Mechanical Concrete Test

Compressive, splitting tensile, and modulus of elasticity tests was undertaken to measure the mechanical properties of concrete as shown in Fig. 3. The test procedures for compressive, splitting tensile, and modulus of elasticity tests follow the procedure as specified in ASTM C39 [18], ASTM C496 [19], and ASTM C469 [20], respectively. Compressive strength was tested at 3, 7, 14, 28, and 59 days. A concrete cylinder with a diameter of 150 mm and a height of 300 mm is used for compressive, splitting tensile, and modulus of elasticity tests. For each test result, an average of three samples were reported.

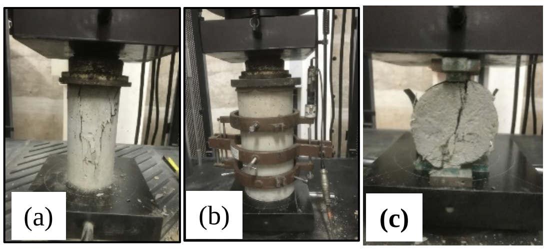


Fig.3 Mechanical concrete test (a) Compressive (b) Splitting (c) Modulus

### 3.4 Free and Restrained Shrinkage Test

This study carried out two types of shrinkage tests: free and restrained shrinkage ring tests. The main parameter of this study was the percentage of polypropylene fibers by volume (0.5%, 0.75%, and 1%), including plain concrete (0% fibers) as control specimens. Two specimens for each parameter were made for free drying and restrained shrinkage ring tests. The free-drying shrinkage test procedures were specified in ASTM C 341 [13]. The specimen's size was 100 x 100 x 400 mm, and the embedded stud gauges were placed at two locations and the middle along the longitudinal direction of the specimens as reference points. The extensometer measured the length change or shrinkage strain between two reference points. The specimen and test setup are shown in Fig. 4 (a).

The restrained shrinkage test aims to examine the cracks that occur due to the drying shrinkage of concrete. The shrinkage ring test was conducted according to ASTM C1581 [14]. The test configuration of the shrinkage ring test is shown in Fig. 4 (b). The shrinkage strain of concrete was measured from the stress that occurred at the inner steel ring determined by using four strain gauges attached to the internal steel ring. Strains in the steel rings are monitored at intervals of 30 minutes and recorded with the data acquisition system. The strain recording started on the second day after concrete casting and removing the outer steel mold. The top and bottom of the concrete ring surface were sealed with silicone rubber and a plastic base. Therefore, concrete drying only proceeds on the exposed surface, the outer circumferential surface of the concrete. The concrete cracking was visually inspected every day, marked the time and the strain, and mapped the pattern.

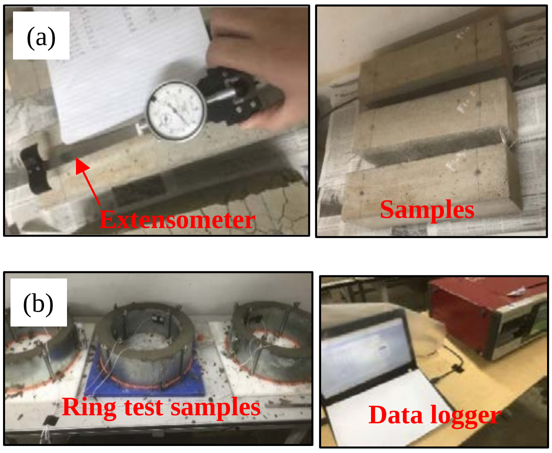


Fig.4 Test setup for (a) Free shrinkage (b) Ring-restrained shrinkage

## 4. RESULTS AND DISCUSSIONS

### 4.1 Fresh Concrete Properties

Table 3 summarizes the test results of the fresh concrete properties of SCC with various polypropylene fiber content investigated in this study. Fiber addition from 0.5% to 1% by volume to the SCC mixture decreases the flowability of SCC, as shown in Fig. 5. Adding 0.75% fiber or more caused the slump flow value to be less than the minimum slump flow for SCC of 450 mm. These findings align with previous research by Nehdi M. and Ladanchuk J. D. [1]. As mentioned by Forgeron D. and Omer A. [21] in their study, the macro-synthetic fiber volume fraction below 0.5% still has an insignificant impact on the flowability of SCC. Besides fiber content, fiber length also plays a significant role in the flowability of SCC to move around or through obstacles [21]. As large macro-synthetic fibers with a length of 60 mm and aspect ratio of 150 were used in this study, the impact on flowability and passing ability will be significant.

Similar to slump flow, the addition of macro-synthetic fibers into the SCC mixture also decreases the passing ability of SCC through the J-Ring test, as shown in Fig. 6. Fiber increases passing resistance when the SCC mixture flows through the reinforcement gap.

Macro-synthetic fiber addition to SCC also causes blockage in the V-funnel test, as presented in Table 3. A blockage was found in the narrowed area in the V-funnel instrument. This was also found by Forgeron D. and Omer A. [21] in their research. The usage of smaller fiber lengths or micro-fibers may reduce the potential for blockage.

Table 3 Fresh properties of various FRSCC

| Mix No. | Fresh concrete properties | | |
|---|---|---|---|
| | Slump Flow (mm) | J-Ring (mm) | V-funnel (sec) |
| NF | 626 | 575 | 5.43 |
| F0.5 | 550 | 464 | Blockage |
| F0.75 | 434 | 368 | Blockage |
| F1.0 | 362.5 | 315 | Blockage |

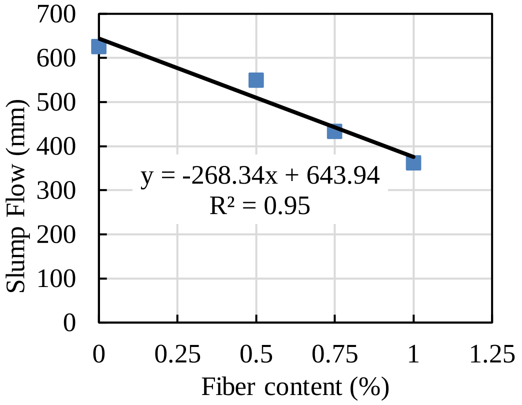


Fig.5 Effect of Polypropylene fibers on slump flow

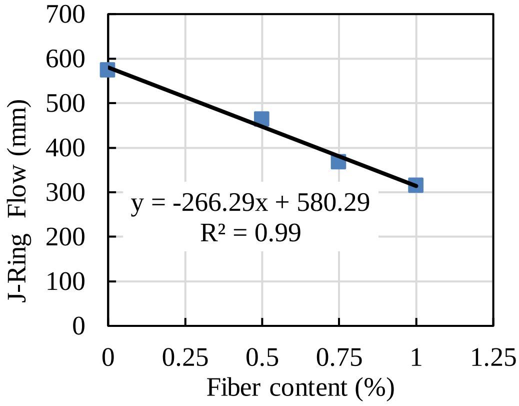


Fig.6 Effect of Polypropylene fibers on J-ring flow

### 4.2 Mechanical Properties

The compressive test results at 3, 7, 14, 28, and 59 days are given in Fig. 7. It was observed that the compressive strength of FRSCC is mostly lesser than that of the control specimens or plain concrete. As shown in Fig. 7, the compressive strength also slightly decreases by increasing the fiber volume, except for 28 days. A lower concrete strength is also found by others [1, 22] when using polypropylene fibers.

Fig. 8 shows the modulus elasticity test results of FRSCC with various fiber content. As shown in Fig. 8, the addition of macro-synthetic fibers on the modulus of elasticity of SCC tends to decrease around 9 to 19% for 0.5 to 1.0% fiber content. This is correlated to the small modulus of elasticity of propylene fibers compared to the modulus of aggregate which some part of aggregate is replaced by fiber.

The splitting tensile test results for variation of fiber volume fractions are presented in Fig.9. The results indicate that adding the polypropylene fiber caused an increase in splitting tensile strength (3.2 to 34.6 %) compared to plain SCC. The splitting strength increase with an increase in fiber content. The maximum increase in tensile strength occurs at 1% of the fiber volume fraction.

Fig. 10 shows the load-displacement curve from the splitting tensile test. The load-displacement relationship of control specimens SCC without fiber is shown in Fig.10 (a). Fig. 10(b-d) shows the load-displacement response of the remaining specimens. The initial linear part up to the splitting crack was similar for all specimens, which represents the behavior of the uncracked that mostly depends on the uncracked concrete tensile capacity. The second part, corresponding to post-cracking behavior, represents the cracked capacity in which concrete has a small contribution. As shown in Fig. 10(a) when the crack occurred showed a sudden drop of the load and after that no more increase in load and deformations. However, for fiber concrete, after cracking the load increase and could maintain larger deformability before the specimens completely split. Moreover, specimens with 1.0% fiber (NF1.0), it has a second peak load after cracking as shown in Fig. 10 (d).

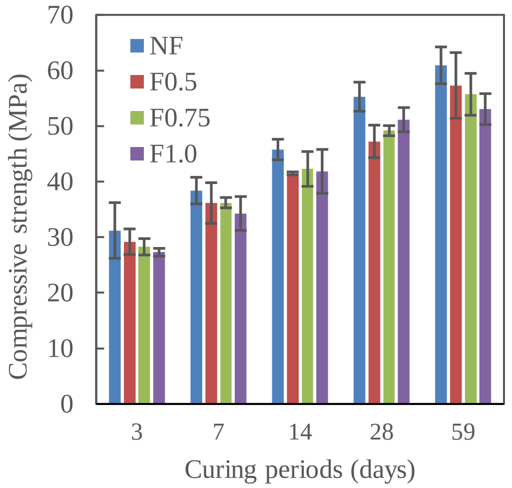


Fig.7 Effect of PP fibers on compressive strength

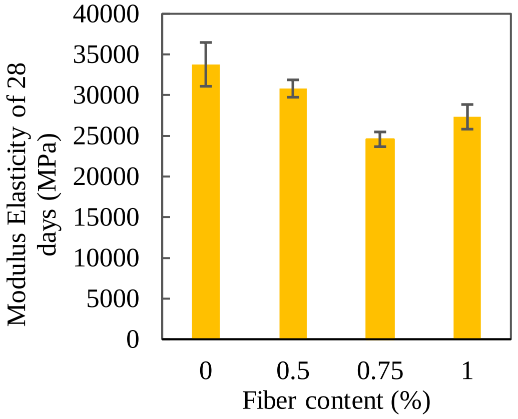


Fig.8 Effect of PP fibers on modulus elasticity

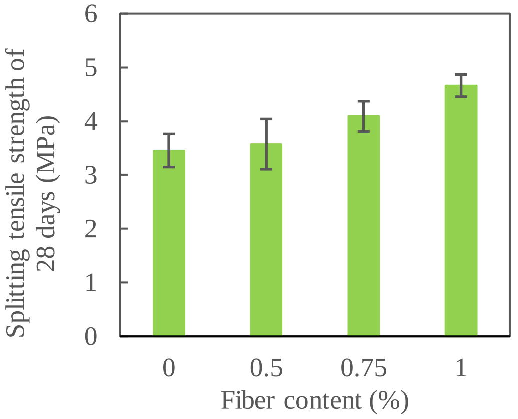


Fig.9 Effect of PP fibers on splitting strength

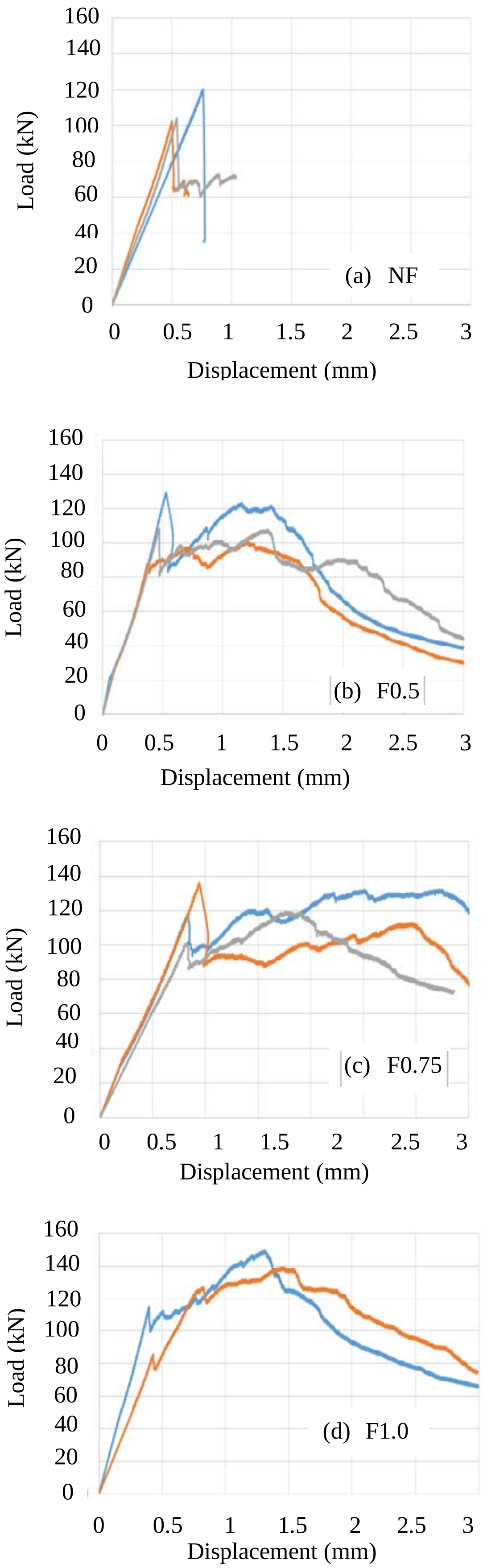


Fig.10 Load displacement of splitting tensile test

### 4.3 Free Shrinkage

The effect of polypropylene fiber addition to SCC on free shrinkage can be seen in Fig. 11. It can be seen from the figure that the addition of polypropylene fiber slightly alters the free shrinkage strain of SCC. Similar behavior in that polypropylene fiber has an insignificant effect on free shrinkage strain reported by *Grzybowski* M. and *Shah* S. P. [23] and Sarigaphuti M., Shah S.P., and Vinson K.D. [24] for normal-weight concrete, and Daneti S. B., Wee T., and Thangayah T. [25] for lightweight concrete.

Compared with the steel fiber addition reported by Daneti S. B., Wee T., and Thangayah T. [25], the steel fiber contributes to a 12% reduction in free shrinkage strain. This could be due to the steel fiber having higher stiffness (modulus elasticity) and strength than polypropylene fibers resulting in higher restraining against shrinkage. In Fig. 11, the polypropylene-FRSCC produces a higher free shrinkage strain than plain SCC. This could be attributed to the aggregate content in mixture proportion being reduced with fiber's addition to having a constant cement-to-coarse aggregate ratio or filler content. Coarse aggregate content is known to have a significant effect on the shrinkage of concrete. Higher aggregate content will produce lower concrete shrinkage. Thus, when polypropylene fiber is added to the SCC mixture causes a decrease in shrinkage resistance when coarse aggregate content is reduced and also has lower modulus elasticity.

### 4.4 Restrained Shrinkage

The deformation development obtained from the restrained shrinkage test measured in the steel ring is shown in Fig. 12. The time to cracking, $t_{cr}$ values in days are also indicated in the figure for each fiber volume fraction or percentage. When tensile stress resulting from the restrained shrinkage in the concrete exceeds the concrete tensile strength, cracks can develop. As shown in Fig. 9, crack with a complete fracture or full-depth crack are associated with a sudden drop or a compatible drop in the strain. Polypropylene fiber addition to the SCC mixture can reduce cracking potential by delaying the crack formation, as indicated in Fig. 12. This agrees with previous findings by Kassimi F. and Khayat K. H. [26] which compared the cracking potential of plain SCC and FR-SCC.

Table 4. summarized the measured time to

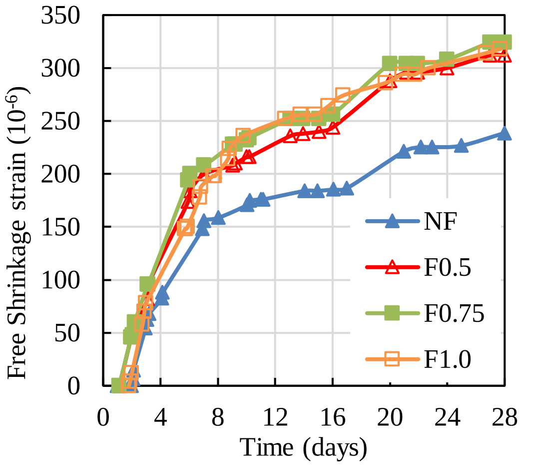


Fig.11 Effect of Polypropylene fibers on free shrinkage

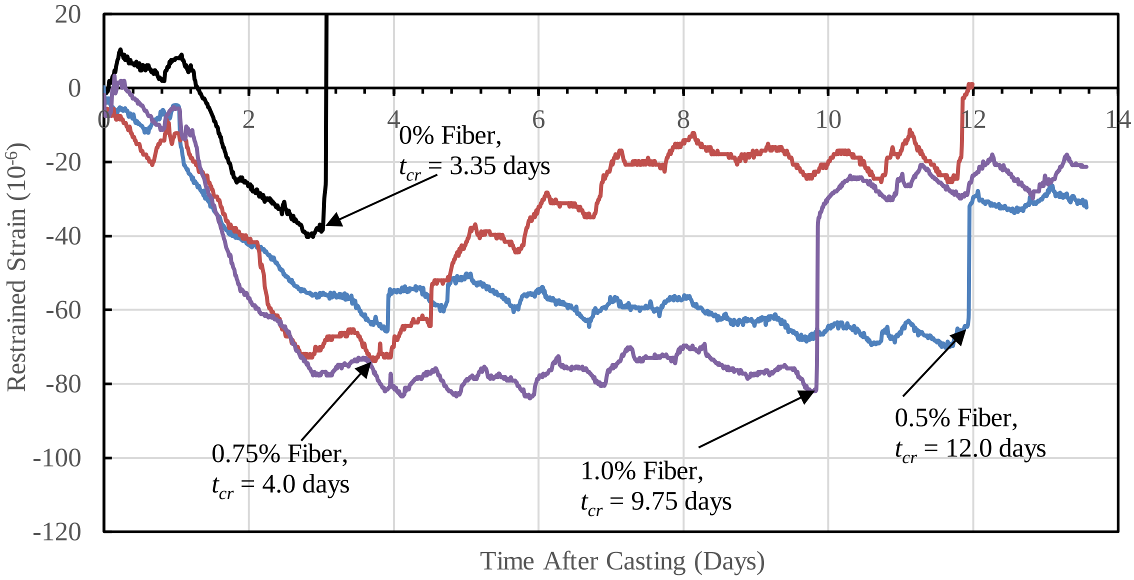


Fig. 12 Effect of Polypropylene fibers on restrained shrinkage

cracking, strain at cracking, and the number of cracks for all specimens. The cracking age for non-fiber SCC is 3.25 days and it increases for polypropylene fiber addition became 4 to 12 days.

Table 4 Cracking age and measure strain

| Mix No. | Time to cracking, $t_{cr}$ (days) | Measured strain at $t_{cr}$ (x$10^{-6}$) | Crack number |
|---|---|---|---|
| NF | 3.25 | 38.39 | 1 to 2 |
| F0.5 | 12.0 | 69.77 | 2 |
| F0.75 | 4.0 | 72.87 | 2 |
| F1.0 | 9.75 | 81.9 | 2 |

The effect of fiber volume fraction on cracking time shows an unclear trend. However, the measured strain at cracking time increased with increasing fiber content, as shown in Table 4. Macro-synthetic polypropylene fiber addition also has smaller crack width than plain SCC, as shown in Fig. 14.

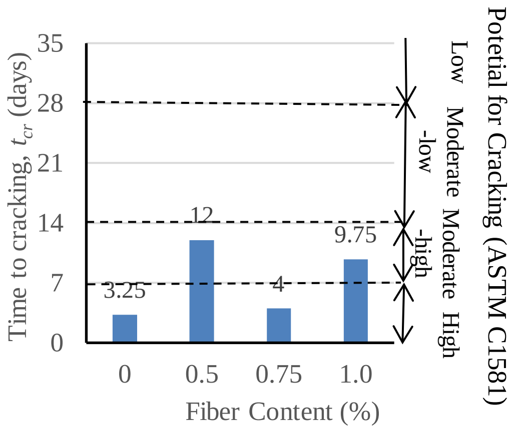


Fig.13 Time to cracking of restrained shrinkage.

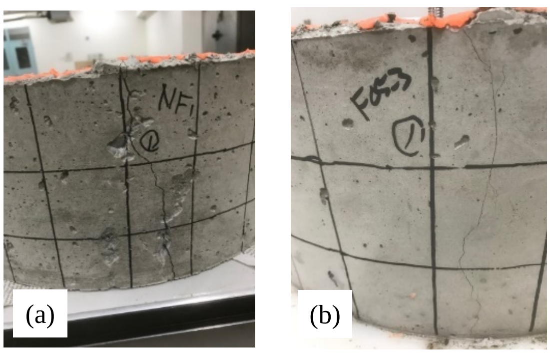


Fig.14 Crack of ring test specimens. (a) NF (b) F0.5

## 5. CONCLUSIONS

This study evaluated the effect of macro-synthetic polypropylene fibers on fresh and hardened concrete properties, including drying shrinkage of self-consolidating concrete. The main parameters in this study are a variation of the volume fraction of fibers. The following conclusions can be drawn:

1) Addition of macro-synthetic polypropylene fibers into the SCC mixture reduces the workability performance in terms of Slump flow, J-Ring, and V-Funnel values of SCC. The reduction increases with the increase in fiber volume fraction.
2) Fiber's addition from 0.5 to 1% of volume fraction can increase the splitting tensile strength (3.2 to 34.6 %) and can decrease the compressive strength (5.7 to 14.6%).and modulus of elasticity (9 to 19%) compared to plain SCC.
3) From the restrained shrinkage test, adding 0.5 to 1% of polypropylene fibers in the SCC mixture can lower the cracking potential, with thin cracks appearing within 4 to 12 days.

## 6. ACKNOWLEDGMENTS

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