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EXPERIMENTAL STUDY ON SOME FRESH AND MECHANICAL PROPERTIES OF POLYPROPYLENE FIBER REINFORCED SELF COMPACTING CONCRETE

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Abstrak

Self Compacting Concrete (*SCC*) merupakan jenis beton yang mampu mengalir dan memadat dengan memanfaatkan berat sendirinya, serta dapat mengisi secara homogen cetakan meskipun dalam kondisi penulangan yang rapat tanpa memerlukan pemadatan. Sebagaimana karakteristik beton pada umumnya, *SCC* juga bersifat getas. Untuk mengatasi kelemahan ini, dapat dilakukan penambahan serat guna meningkatkan kekuatan tarik dan ketahanan retak beton. Penelitian ini dilakukan untuk mengetahui efek penambahan serat polypropylene terhadap empat karakteristik utama beton segar *SCC*, serta pengaruhnya terhadap kuat tekan, kuat tarik belah, dan ketahanan kejut *SCC*. Penambahan serat polypropylene dilakukan dengan volume fraction sebesar 0%, 0,05%, 0,1%, dan 0,15%. Dalam penelitian ini, akan dilakukan pengujian beton segar yang meliputi: *flowability* (*slump-flow*), *viscosity* (T500), *passing ability* (*J-Ring Test*), dan ketahanan segregasi. Sedangkan karakteristik beton yang diuji meliputi kuat tekan, kuat tarik belah, dan ketahanan kejut beton. Penambahan serat polipropylene menyebabkan berkurangnya *flowability/ filling ability*, *passing ability*, dan rasio segregasi *SCC* sedangkan nilai viskositas *SCC* meningkat. Karakteristik beton segar *SCC* masih dapat dicapai saat serat polypropylene ditambahkan sebesar 0,10% dari volume beton. Penambahan serat polypropylene dapat meningkatkan kuat tekan, kuat tarik belah, dan ketahanan kejut beton. Penambahan serat polypropylene ke dalam adukan *SCC* dapat dilakukan dengan nilai optimum volume fraction sebesar 0,10%.

Kata kunci: Polypropylene, *Self-Compacting Concrete* (*SCC*), sifat mekanik

Abstract

The Self-Compacting Concrete (SCC) can be defined as a type of concrete that is able to flow and to consolidate under its own weight, completely fill the formwork even in the presence of dense reinforcement, maintaining its homogeneity and without the need for any additional compaction. Similar with other types of cement-based materials, SCC also has a brittle characteristic. This research is conducted to investigate effects of polypropylene fiber addition on four key characteristics of SCC in the fresh state, and assess the effects of polypropylene fiber on compressive, splitting tensile strength, and impact resistance of hardened SCC. In this research, concrete mixes were prepared containing 0, 0.05, 0.10, and 0.15 percent of volume fraction. Fresh properties were evaluated based on its passing ability, flowability, viscosity, and segregation resistance using J-ring, Slump flow, and Sieve Segregation Resistance tests. After 28 days of curing, compressive strength tests, Brazilian splitting tensile test, and drop-weight impact resistance were done. It is found that polypropylene fibers reduce flowability and passing ability but it increases viscosity and segregation ratio of SCC. Furthermore, polypropylene fiber reduces deformability of SCC in the fresh state. After 28 days of curing, concrete samples tests indicate that polypropylene fiber addition increases the compressive strength, tensile strength, and impact resistance of hardened SCC. It can be suggested that polypropylene fibers allowed to be added into SCC mixes up to 0.10 percent by volume of concrete.

Keywords: *mechanical properties, polypropylene, Self-Compacting Concrete (SCC)*

1. INTRODUCTION

Development of Self-Compacting Concrete (SCC) is a desirable achievement in the construction industry in order to overcome problems associated with cast-in-place concrete. Due to its high deformability and resistance to segregation, it has the capacity to completely fill the formwork, easy to flow in complex forms with congested reinforcement and encapsulate the reinforcement without any influence of the workers skills. This is in contrast to traditional concrete, where the difficulties in compaction could cause entrapped air voids and reduce the strength and durability of concrete. Self-Compacting Concrete (SCC) can be defined as an engineered material consisting of cement, aggregates, water, filler, and chemical admixtures to take care of specific requirements, such as, high flowability, passing ability, adequate viscosity, and segregation resistance. In the fresh state, this type of concrete is able to flow and to consolidate under its own weight, completely to fill the formwork even in the presence of dense reinforcement, maintaining its homogeneity and without the need for any additional compaction.

SCC must satisfy the following workability performance criteria: 1) Flowability: The ease of flow of fresh concrete when unconfined by formwork and/or reinforcement; 2) Viscosity: The resistance to flow of a material (e.g. SCC) once flow has started; 3) Passing ability: The ability of fresh concrete to flow through tight openings such as spaces between steel reinforcing bars without segregation or blocking; and 4) Stability: the ability of SCC to remain homogenous by resisting segregation, bleeding, and air popping during transport, placement, and after placement [1-2].

Due to its characteristics, SCC provides several benefits, such as: faster construction, reduction in site manpower, easier placing, uniform and complete consolidation, better surface finishes, improved durability, increased bond strength, greater freedom in design, reduced noise levels caused by absence of vibration, and safe working environment [3]. Those characteristics of SCC can be achieved by implementing following basic principles in the mix design process; 1) lower coarse aggregate content, 2) increasing paste content, 3) lower water/powder ratio, (powder is defined as cement added with filler, such as: fly ash, silica fume, etc.), and 4) the use of superplasticizer.

Considering lower water-cement ratio and higher content of cementitious materials compared to conventional concrete, SCC should have improved durability and strength. However, similar with other types of cement-based materials, SCC also has a brittle characteristic. This characteristic can be improved by adding fibers in to the concrete mix. Fiber-Reinforced Concrete (FRC) is defined as a concrete containing dispersed randomly oriented fibers. Inherently concrete is brittle under tensile loading and mechanical properties of concrete may be improved by randomly oriented discrete fibers which prevent or control initiation, propagation, or coalescence of cracks. The properties of fibers that are usually of interest are fiber concentration, fiber geometry, fiber orientation, and fiber distribution. Moreover, using a single type of fiber may improve the properties of FRC to a limited level. Shortcut type of fiber can be added to bridge microcracks of which growth can be controlled. This leads to a higher tensile strength of the composite [4].

Unlike its effects to hardened concrete, the presence of fibers in concrete mixes can cause significant deterioration to the concrete workability. On the other hand, workability is very important for SCC to achieve its requirement to flow, pass through tight openings without blocking, and completely consolidate by its own weight. This research was designed to investigate effects of polypropylene fiber addition on some fresh and mechanical properties of SCC.

2. EXPERIMENTAL PROGRAM

2.1. Objectives

This research aims to investigate effects of polypropylene fiber addition on four main characteristics of SCC in the fresh state: flowability, viscosity, passing ability and segregation resistance. Effects of fiber addition on compressive strength, splitting tensile strength, and impact resistance of SCC are also needed. Based on the results of fresh and hardened SCC tests, prediction of optimum volume fraction of polypropylene fiber in SCC mixes can be determined.

2.2. Materials and Mix Proportion

Polypropylene was chosen, because it is inexpensive, inert in high pH cementitious environment and easy to disperse. In this research, monofilament polypropylene with 18 μm diameter, 12 mm length, and 0.91 g/cm^3 density were used. The mixtures were prepared with ordinary Portland cement. Continuously graded crushed granite, with Saturated Surface Dry (SSD) density of 2.48 g/cm^3, was used as coarse aggregate with maximum aggregate size of 20 mm, as is commonly the case in SCC mixes. Coarse aggregates were washed to remove fine sandy particles that can hinder rheological properties. Well-graded pit sand, with SSD density of 2.65 g/cm^3, was employed as the fine aggregate. Silica fume and polycarboxylate based superplastisticizer were also used for this research. Concrete mixes were prepared containing 0, 0.05, 0.10, and 0.15 percent of polypropylene fibers (measured by fibers volume in concrete volume). Detail of mixes proportion for this research can be found in Table 1.

Table 1. Mix proportion

Material	Volume Fraction of Polypropylene Fibers			
	0.0%	0.05%	0.1%	0.15%
Polypropylene fibers (kg/m^3)	0.00	0.45	0.90	1.35
Water (lt/m^3)	212.00	212.00	212.00	212.00
Portland Cement (kg/m^3)	435.00	435.00	435.00	435.00

Tabel 1. (continued)

Silica fume (kg/m³)	48.00	48.00	48.00	48.00
Coarse Aggregate (kg/m³)	648.00	648.00	648.00	648.00
Sand (kg/m³)	926.00	926.00	926.00	926.00
Superplasticizer (lt/m³)	4.80	4.80	4.80	4.80

Table 2. Effects of polypropylene fiber addition on fresh properties of SCC

Volume fraction of Polypropylene fiber (%)	Flowability/ Slump flow (mm)	Viscosity/ T_{500} time (sec)	Passing ability/ J-Ring Test (mm)	Segregation Ratio/ GTM Screen Stability Test (%)
0,00	748,33	1,03	4,00	4,24
0,05	686,67	1,13	7,00	1,16
0,10	556,67	1,40	7,92	0,82
0,15	428,33	Cannot reach 500 mm of diameter	10,58	0,76

2.3. Test Methods

Fresh properties of SCC were evaluated based on its four key characteristics; passing ability, flowability, viscosity, and segregation resistance. Those characteristics were measured using following instruments; J-ring Test [1], Slump flow, and Sieve Segregation Resistance tests [2]. In the hardened state, the compressive, splitting tensile, and impact resistance of SCC were investigated. Concrete samples were cured with water immersion method for 28 days at the temperature of 23±2°C.

Compressive strength tests for all the variants of concrete mixes with different fiber contents were carried out on three cylinders of 150 mm in diameter and 300 mm length, according to ASTM C-39. Brazilian Tensile Strength test was carried out on three cylinders based on ASTM C-496, and the tensile strength of concrete was taken as the average of the those three cylinders for each variant. Drop-weight test was conducted using ACI 544 Committee recommendations to determine the impact resistance of concrete samples.

Each type of the freshly mixed concrete was cast into cylinder molds to make 15x30 cm cylindrical specimens. The cylindrical specimens were cured in lime-saturated water for 28 days. Then, each cylindrical specimen was sawed into four 15x30 cm cylindrical disks for the drop-weight test. In the test, a cylindrical disc was set on a base plate within four positioning lugs, and impacted by repeated blows. The blows were introduced through a 4.45 kg hammer falling continually from a 457 mm height onto a 63.5 mm steel ball, which stood at the center of the top surface of the disc. The number of blows to the first visible crack on the top surface was defined as the first-crack strength, while the number of the blows to generate the three-lug-touching action of the disc was the failure strength [5]. The impact resistance was taken as the average of those four cylindrical discs for each variant.

3. RESULT AND DISCUSSION

3.1. Fresh Properties

Table 2 shows the effects of polypropylene fibers addition on four key characteristics of SCC in the fresh state to evaluate its workability performance criteria. Figure 1, 2, 3 and Figure 4 show the effects of fiber content on flowability, viscosity, passing ability and segregation ratio of the fresh concrete respectively.

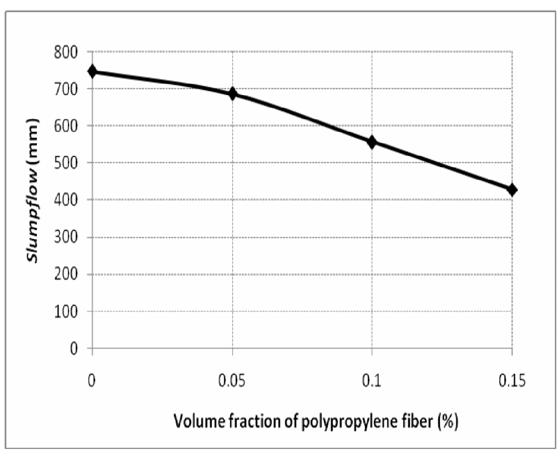

Figure 1. Effect of polypropylene fiber on flowability

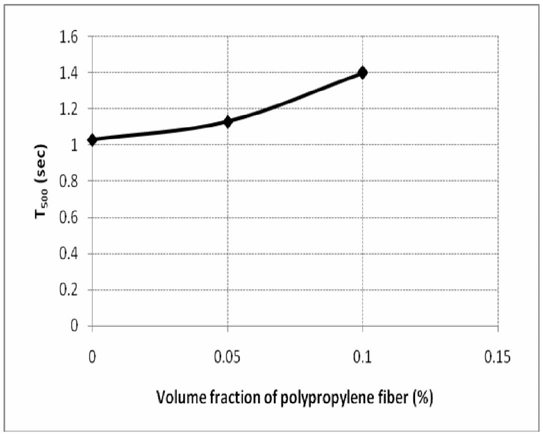

Figure 2. Effect of polypropylene fiber on viscosity

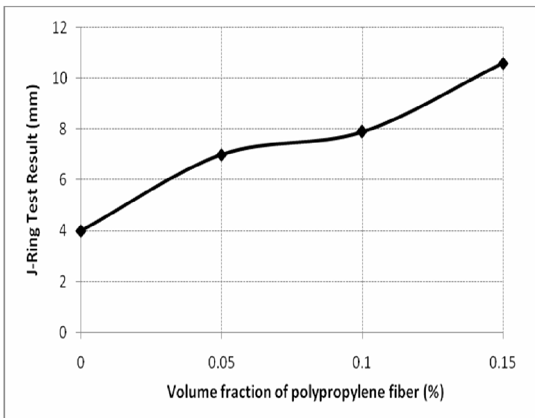

Figure 3. Effect of polypropylene fiber on passing ability

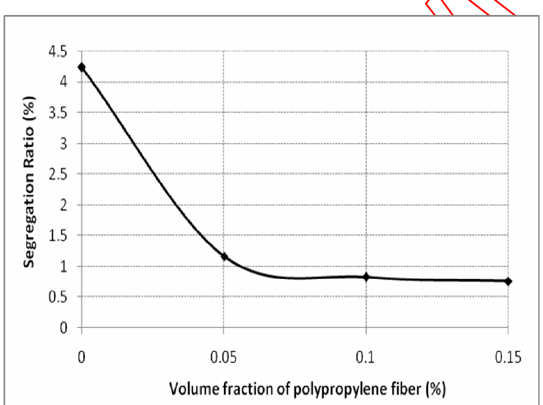

Figure 4. Effect of polypropylene fiber on segregation ratio

Test results clearly indicate that the addition of Polypropylene fibers results in deterioration of fresh properties of SCC. It is clearly seen that flowability (Slump Flow), passing ability (J-Ring), and segregation ratio of SCC decreases when the presence of polypropylene fiber increased. Whereas, the viscosity increases in accordance with the volume fraction of polypropylene fibers content. Based on the results of flowability, viscosity and passing ability tests, it can be assessed that with polypropylene fiber addition up to 0.10% by volume of concrete, the mix can still meet the requirement of flowability, viscosity and passing ability of SCC as stated in the guidelines that published by EFNARC. The deformability of SCC reduces with the presence of polypropylene fiber. This could be caused of more surface area that should be lubricated by the cement paste and water. In the same time, polypropylene fibers also reduce the potential energy that needed by the fresh concrete to be able to flow by its own weight due to the increase of friction between aggregates and the fibers in the concrete mixes.

3.2. Mechanical Properties

Table 3 shows the compressive, splitting tensile strength, and impact resistance of the concrete samples that measured after 28 days of curing

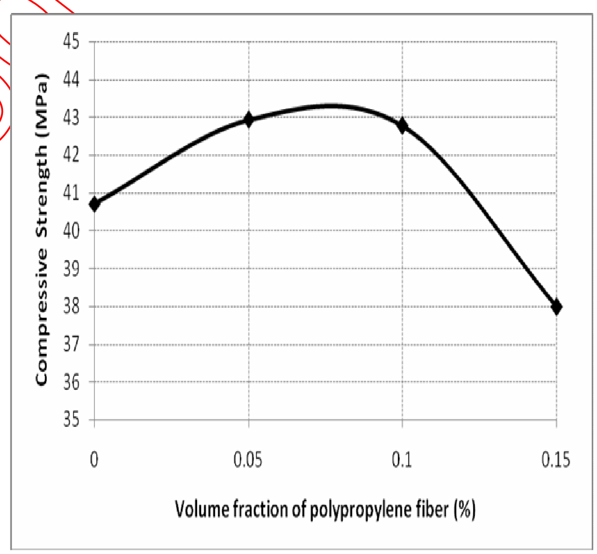

Figure 5. Effect of polypropylene fiber on compressive strength

Table 3. Effects of polypropylene fiber addition on some mechanical properties of SCC

Volume fraction of polypropylene fiber (%)	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Impact Resistance (blows)	
			Firs-crack	Failure
0.00	40.71	4.106	71	76
0.05	42.93	4.264	111	121
0.10	42.78	4.374	196	200
0.15	37.99	3.938	31	35

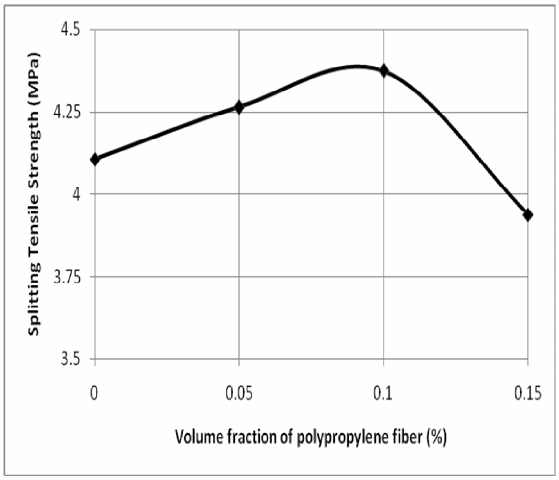

Figure 6. Effect of polypropylene fiber on splitting tensile strength

Figure 5, Figure 6 and Figure 7 show the effects of fiber content on compressive, splitting tensile strength and impact resistance of the samples respectively. The results show that compressive, tensile strength, and impact resistance of concrete samples increase with an increase of fiber content up to 0.10 percent by concrete volume, and then tend to decrease after 0.15 percent of polypropylene addition.

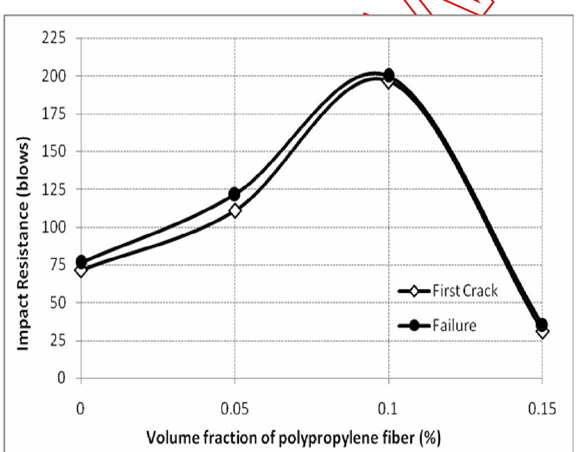

Figure 7. Effect of polypropylene fiber on impact resistance

This could be achieved, due to the fact that polypropylene fiber bridges micro cracks of which crack growth can be controlled. This leads to a higher strength of the composite. When the fibers addition passes over 0.15 percent by concrete volume, the instability of the concrete samples which was realized earlier in the fresh concrete tests could have probably lead to a decrease in concrete strength

4. CONCLUSIONS

1). Flowability (Slump Flow), passing ability (J-Ring), and segregation ratio of SCC decreases when the presence of polypropylene fiber increased, while the viscosity increases in accordance with the fibers content.

2). The concrete mixes can still meet the requirement of flowability, viscosity and passing ability of SCC with polypropylene fiber addition up to 0.10% by volume of concrete.

3). The compressive strength of concrete samples increases with an increase of fiber content up to 0.05 percent by concrete volume, and then tend to decrease after 0.15 percent.

4). The splitting tensile strength of concrete samples increases with an increase of fiber content up to 0.10 percent by concrete volume, and then tend to decrease after 0.15 percent.

5). The impact resistances of concrete samples increase with an increase of fiber content up to 0.10 percent by concrete volume, and then tend to decrease after 0.15 percent.

6). Based on the evaluation of fresh and hardened properties of SCC, it seems that polypropylene fibers allowed to be added into the concrete mixes up to 0.10 percent by concrete volume.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] EFNARC, 2002. "Specification & guidelines for self-compacting concrete". *English ed.*, Norfolk UK: European Federation for Specialist Construction Chemicals and Concrete Systems.

[2] EFNARC, 2005. " The European Guidelines for Self-Compacting Concrete Specification, Production and Use". Norfolk UK: European Federation for Specialist Construction Chemicals and Concrete Systems.

[3] Okamura, H. and Ouchi, M., 2003. "Self-Compacting Concrete". *Journal of Advance Concrete Technology*, Vol. 1, No. 1, pp. 5-15.

[4] Hannant, D.J., 1979." Fiber Cements and Fiber Concretes". Chicester: John Wiley & Sons.

[5] Song, P.S., Wu, J.C., Hwang, S., and Sheu, B.C., 2005. "Statistical Analysis of Impact Strength and Strength Reliability of Steel–Polypropylene Hybrid Fiber-Reinforced Concrete". *Construction and Building Materials*, Vol. 19, pp. 1-9.