Mechanical Properties Improvement of Self Compacting Concrete (SCC) using Polypropylene Fiber

V A Noorhidana[1], L Irianti[1], and T Junaedi[1,*]

[1]*Department of Civil Engineering, Universitas Lampung, Jl. Prof. Sumantri Brojonegoro No.1, Bandar Lampung, Indonesia*

[*]*Email: vera.agustriana@eng.unila.ac.id*

Article Information:

Received:
6 March 2021

Received in revised form:
2 May 2021

Accepted:
5 May 2021

Volume 3, Issue 1, June 2021
pp. 41 – 46

http://doi.org/10.23960/jesr.v3i1.80

Abstract

SCC (self-compacting concrete) is a type of concrete that can compact itself without the help of external compaction. Thus, it can fill all parts of the formwork that are narrow and have tight reinforcement. A problem that often arises in the use of SCC is the segregation of concrete mixture, which reduces the strength of the concrete. This paper presents the effect of polypropylene fiber on the fresh concrete workability, compressive strength, splitting-tensile strength, and flexural-tensile strength of SCC concrete. The variations of the polypropylene fiber added to the SCC mixture are 0%, 0.05%, 0.067%, 0.1%, and 0.15% of the concrete's volume, with a water-cement ratio of 0.5 and 0.38 and dense-graded and gap-graded coarse aggregate. Each concrete variation is made into cubes (150x150x150 mm^3) for the compressive strength test, cylinders (dia.150mm; height 300mm) for splitting-tensile test, and prisms (100x100x400 mm^3) for the flexural-tensile test. The experiments were carried out with concretes with the age of 28 days. The result showed that, polypropylene fiber could reduce the segregation in the SCC concrete mixture. The optimal polypropylene fiber percentage is 0.05%, which could improve the compressive strength by 12.2%, the splitting strength by 17.7%, and flexural strength by 322.3% compared to SCC concrete without polypropylene fiber.

Keywords: *SCC, polypropylene fiber, water-cement ratio, gap-graded, segregation.*

I. Introduction

SELF compacting concrete (SCC) is an innovation from conventional concrete where vibrators are not required for compaction during the casting process. However, the concrete mixture could flow by itself because of its weight to fill gaps in the tightly-reinforced formwork and reach optimal compactness [1].

The composition of the SCC is identical to conventional concrete, which includes sand, coarse aggregate, cement, and water, with the addition of superplasticizer to increase workability or other admixtures such as fly ash or silica fume. The workability of SCC has to comply with the EFNARC's requirement, which is 550 – 850 mm in terms of the result of the Slump Flow Test [1].

SCC has mechanical properties that are superior to conventional concrete. Arezumandi et al. [2] have studied the topic and concluded that SCCs show higher compressive strength and fracture energy than conventional concrete. Desnerck et al. [3] has researched the stress-strain relationship of SCCs and concluded that the ultimate stretch of SCC is caused by a uniaxial load higher than the ultimate strain of conventional concrete.

Porosity is still a problem for SCCs. The porosity of SCC is affected by the water-cement ratio (W/C) used in the concrete mixture. The higher the W/C being used, the higher the resulting porosity. Segregation is also a problem for SCCs, where coarse aggregate and cement paste are segregated because of the low viscosity of the SCC mixture.

Conventionally, the concrete manufacturing process uses dense-graded coarse aggregate in the mixture. However, dense-graded coarse aggregates are not always available because of the limited aggregate source and insufficient stone crusher, which forces the use of gap-graded coarse aggregate. The research done by Irianti et al. [4] shows that the compressive strength of concrete with gap-graded coarse aggregate is lower than concretes with dense-graded coarse aggregate.

Polypropylene fiber is a synthetic fiber added to a concrete mixture to form fiber reinforced concrete. Fiber-reinforced concrete can be defined as concrete with a composition of coarse aggregate, fine aggregate, cement, water, and several fibers to improve the properties of the concrete [5]. Fibers added to the concrete mixture will spread randomly in every direction of the concrete and, thus, be able to withstand stress from every direction. The advantage of using polypropylene in the concrete mixture is that it can withstand chemical damage, and its surface is waterproof to prevent fiber clumping during the mixing process [6].

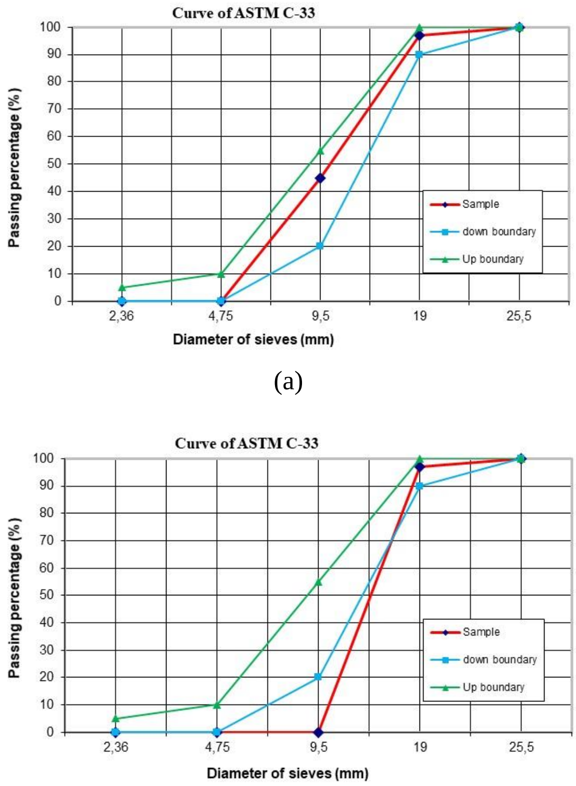
Researches on SCC are still being done to study the factors affecting its mechanical properties. One of the factors to be examined is the effect of the addition of polypropylene fiber. In this study, the manufacturing of the specimens is done by two variations of W/C, which are 0.5 and 0.38, with dense-graded and gap-graded coarse aggregate. This research is done to study the effect of variations of polypropylene fiber volume fraction (Vf), which are 0.5%, 0.05%, 0.067%, 0.1%, and 0.15%, on the compressive strength, splitting strength, and flexural strength of SCC. Polypropylene fiber volume fraction of 0.067% is recommended in PT Sika brochure, which is equivalent to 600 grams per cubic meter of concrete volume. Hence, the optimal fiber volume fraction that gives the best performance in terms of workability and strength can be obtained.

II. Materials and Methods

This research was done experimentally in the Materials and Construction Laboratory in the Faculty of Engineering, Universitas Lampung. The primary material for the manufacturing of SCC was sand (ex. Gunung Sugih, Lampung Tengah), coarse aggregate with max. size is 19mm (ex. Tanjungan, Lampung Selatan), Padang brand cement (OPC Type 1), water, polypropylene fiber (produced by PT. Sika), and superplasticizer HRWR Viscocrete 3115n produced by PT. Sika. The polypropylene fiber had a length of 12mm and a diameter of 18 microns. The addition of fiber divided into four variations: 0.05%, 0.067%, 0.1%, and 0.15%. On the other hand, the coarse aggregates were divided into two grades: dense-graded and gap-graded. The sand and the coarse aggregate had been examined according to ASTM C-33. The composition of the materials per m^3 concrete-mix is shown in Table 1. Fig. 1 shows the coarse aggregate grades used in this research, which are dense-graded and gap-graded.

The main equipment used in the research were the Compression Testing Machine (CTM) for compressive strength test, loading frame and hydraulic jack for the flexural strength test, and other supporting tools for the mixing process of the concrete mixture.

The manufacturing of the specimens was done by mixing the concrete materials until they formed a homogeneous mixture. Moreover, a slump flow test was done to measure the workability of the SCC mixture. Subsequently, the concrete mix was poured into a cubic mold (150×150×150mm) for compressive strength test, cylindrical mold (dia. 150mm, height 300m) for splitting strength test, and prism mold



(a)

(b)

Figure 1. The coarse aggregate grading, (a) Dense-graded, (b) Gap-graded

Table 1. The materials composition of SCC (per m^3).

Material	Weight (kg)	
	W/C-0,5	W/C-0,38
Cement	432	569
Sand	834	765
Coarse aggregate (1-2)	834	765
Water	216	216
Polypropylene *		
0%	0	0
0,05%	0,45	0,45
0,067%	0,6	0,6
0,1%	0,9	0,9
0,15%	1,35	1,35
Superplasticizer	4,32	5,69

(*) according to fiber variation.

(100×100×400 mm). Three specimens are made for each variation.

Twenty-four hours after the casting process, the specimens were removed from the mold and soaked in a water tank for 26 days. The tests were carried out when the concretes reached the age of 28 days. The compressive strength test was done according to SNI 1974-2011, the splitting strength test was done according to SNI 2491:2014, and the flexural strength was done according to SNI 4431:2011.

The result of the tests on all the variations of the specimens are shown in Table 2 and Table 3.

III. Results and Discussions

The test result is divided into the result of the fresh concrete test and the hardened concrete test. The slump flow test that was done on fresh concrete is shown in Table 2 and Fig. 2. Meanwhile, the average result of the compressive strength test, splitting strength test, and flexural strength test with variations in polypropylene fiber volume fraction, W/C, and coarse aggregate grade is shown in Table 3. A graphical representation of the result is shown in Fig. 3.

A. Workability

Slump flow test and T_{50} are methods to measure the workability of the SCC mixture according to EFNARC. The slump flow test aims to determine the filling ability and flowability of the SCC. T_{50} is defined as the time needed for the SCC mixture to reach a diameter of 500mm. EFNARC establishes that the requirement for slump flow test is 550-850 mm, with a T_{50} of less than 6 seconds.

As shown in Table 2, with W/C 0.5, the slump flow (SF) value is very high, which is 790 mm, and there is segregation in the concrete mixture (refer to Fig. 2-a). The SF value will decrease if the W/C is reduced and if the polypropylene fiber is increased. By lowering the W/C to 0.38, the SF value and the segregation will decrease. The segregation problem of the SCC with W/C 0.5 may be fixed by adding polypropylene fiber, thus resulting in an SF value that is similar to SCC with W/C 0.38. As shown in Fig. 2-b, the SCC mixture became more homogenous, and segregation did not happen.

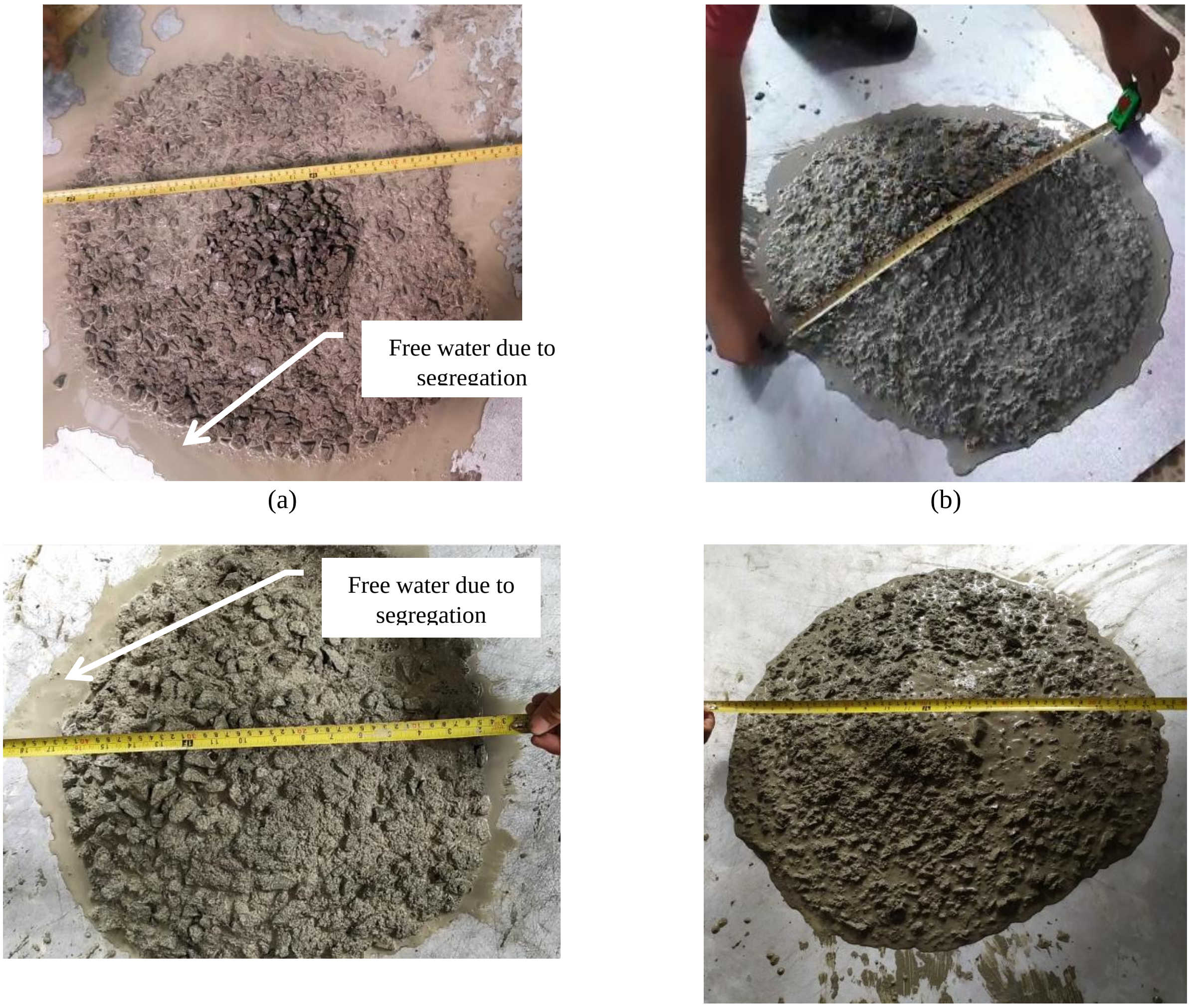
SCC mixture with gap-graded coarse aggregate (code: 0.38-S-0) also undergoes segregation because of the looseness of the aggregate within the concrete mix (see Fig. 2-c). This problem can be fixed by polypropylene that is added to the SCC mixture (Fig. 2-d).

On every specimen with a polypropylene fiber volume fraction of 0.15%, the T_{50} value was not recorded since the SF diameter never reaches 500 mm. In general, adding polypropylene in the SCC mixture will decrease the SF value and increase the T_{50} value. This is because the adhesive property of the fiber in the concrete mix makes the cement paste more viscous so that the flow of the concrete mixture is hampered.

Table 2 shows that the addition of 0.05% and 0.067% polypropylene fiber result in SF and T_{50} values that are adequate with the requirements in every variation. Meanwhile, the addition of polypropylene with a fiber volume fraction higher than 0.1% gives an SF and T_{50} that do not qualify with the workability requirements of SCC.

Table 2. Slump flow test results.

Specimen code	Coarse aggregate grading	W/C	Polypropylene (%)	Slump flow test		T_{50}	
				Test result (mm)	EFNARC (550-850mm)	Test result (second)	EFNARC (< 6 second)
0.5-N-0	Dense-graded	0.5	0	790	OK	4.2	OK
0.5-N-0.05			0.05	575	OK	4.6	OK
0.5-N-0.067			0.067	550	OK	4.9	OK
0.5-N-0.10			0.10	490	Not OK.	-	Not OK.
0.5-N-0.15			0.15	425	Not OK.	-	Not OK.
0.38-N-0	Dense-graded	0.38	0	635	OK	3.0	OK
0.38-N-0.05			0.05	580	OK	3.9	OK
0.38-N-0.067			0.067	545	Not OK.	5.2	OK
0.38-N-0.10			0.10	515	Not OK.	5.7	OK
0.38-N-0.15			0.15	455	Not OK.	-	Not OK.
0.38-S-0	Gap-graded	0.38	0	575	OK	4	OK
0.38-S-0.05			0.05	565	OK	5	OK
0.38-S-0.067			0.067	535	Not OK.	5.6	OK
0.38-S-0.10			0.10	510	Not OK.	6	OK
0.38-S-0.15			0.15	365	Not OK.	-	Not OK.



(a) (b)

(c) (d)

Figure 2. The Tampak visual adukan beton SCC pada waktu *slump flow test*, (a) W/C-0.5-dense graded-without polypropylene, (b) W/C-0.5- dense graded-with polypropylene, (c) W/C-0.38-gap graded-without polypropylene, (d) W/C-0.38- gap graded-with polypropylene.

Table 3. The Compressive Strength, Splitting Strength, and Flexural Strength of SCC.

Specimen code	Type of coarse aggregate gradation	W/C	Polypro-pylene (%)	Average of Com-pressive strength (MPa)	Average of Splitting strength (MPa)	Average of Flexural strength (MPa)	The increase of (%)		
							Com-pressive strength	Splitting strength	Flexural strength
0.5-N-0	Dense-graded	0.5	0	28.4	2.7	1.6	0.0	0.0	0.0
0.5-N-0.05			0.05	31.8	2.7	5.7	12.2	3.1	253.7
0.5-N-0.067			0.067	29.9	2.6	4.8	5.4	-2.0	198.2
0.5-N-0.10			0.10	28.0	2.5	3.9	-1.4	-7.1	144.7
0.5-N-0.15			0.15	20.0	1.8	2.4	-29.4	-31.6	51.3
0.38-N-0	Dense-graded	0.38	0	43.9	3.7	2.2	0.0	0.0	0.0
0.38-N-0.5			0.05	45.4	4.0	6.6	3.4	9.2	195.0
0.38-N-0.067			0.067	42.4	3.6	6.1	-3.4	-3.7	171.7
0.38-N-0.10			0.10	39.3	3.2	5.8	-10.4	-13.9	159.9
0.38-N-0.15			0.15	30.2	2.3	2.8	-31.3	-38.5	25.5
0.38-S-0	Gap-graded	0.38	0	40.5	3.3	1.62	0.0	0.0	0.0
0.38-S-0.05			0.05	47.0	3.9	6.8	11.4	17.7	322.3
0.38-S-0.067			0.067	42.8	3.5	5.4	1.5	5.9	233.2
0.38-S-0.10			0.10	38.6	3.1	4.5	-8.4	-5.9	179.3
0.38-S-0.15			0.15	37.7	2.7	2.9	-10.6	-18.2	79.0

B. SCC Compressive Strength

The concrete compressive strength is obtained from the compressive strength test on cubical specimens (150×150×150 mm) with a concrete age of 28 days by utilizing the Compression Testing Machine (CTM). The average compressive strengths are shown in Table 3 and Fig. 3-a.

The bar chart shown in Fig. 3-a implies an increase in compressive strength with 0.05% polypropylene. The compressive strength decreases with the further addition of the amount of fiber in the mixture. The highest average compressive strength was generated by specimen 0.38-N-0,05 which is 45.4 MPa. SCCs with W/C 0.5 gave a low compressive strength. The effect of the addition polypropylene fiber on the compressive strength of SCCs with W/C 0.5 and W/C 0.38 and a variation of 0% - 0.15% polypropylene fiber shows a similar pattern, where the highest compressive strength is generated by fiber volume fraction 0.05% and then decrease as the fiber volume fraction increase.

Gap-graded coarse aggregate (0.38-S-0) causes the compressive strength to decrease by 7.8% compared to concrete with dense-graded aggregate (0.38-N-0). Polypropylene fiber could fix this problem with a usage that is below 0.0667%. Adding a higher amount of polypropylene fiber to the mixture would result in a lower compressive strength.

The effect of polypropylene fiber on the increase of the concretes' compressive strength is insignificant, only around 12%. The decrease of the compressive strength of the SCC from the addition of polypropylene fiber that is higher than 0.05% is caused by the increase in the viscosity of the SCC mixture, which hampered the flow of the mixture into the cavities in the mold. The resulting concrete is highly porous, which causes a decrease in compressive strength. This result is consistent with the research done by Ramujee that obtained a maximum compressive strength with the use of 0.15% polypropylene (42.25 MPa) [7]. The compressive strength decreased when the polypropylene was increased to 0.2%.

C. SCC Splitting Strength

The splitting strength results are obtained from tests done on cylindrical concrete (dia. 150mm; height 300mm) with a concrete age of 28 days by using Compression Testing Machine (CTM). The average results of the splitting strength test are shown in Table 3 and Fig. 3-b.

The average splitting strength result is shown in Table 3 and Fig. 3-b. The results imply that the addition of polypropylene can increase the splitting strength of SCC with both W/C 0.5 and 0.38 and with both dense-graded and gap-graded coarse aggregate. The highest increase is obtained by adding polypropylene with a fiber volume fraction of 0.05%, with a rise of 17.7% (on specimen 0.38-S-0.05). The use of polypropylene fiber that is higher than 0.05% decreases the concretes' splitting strength, except on specimen 0.38-S-0.067. This deviation in the pattern may be attributed to the polypropylene fiber that is not distributed equally on every specimen.

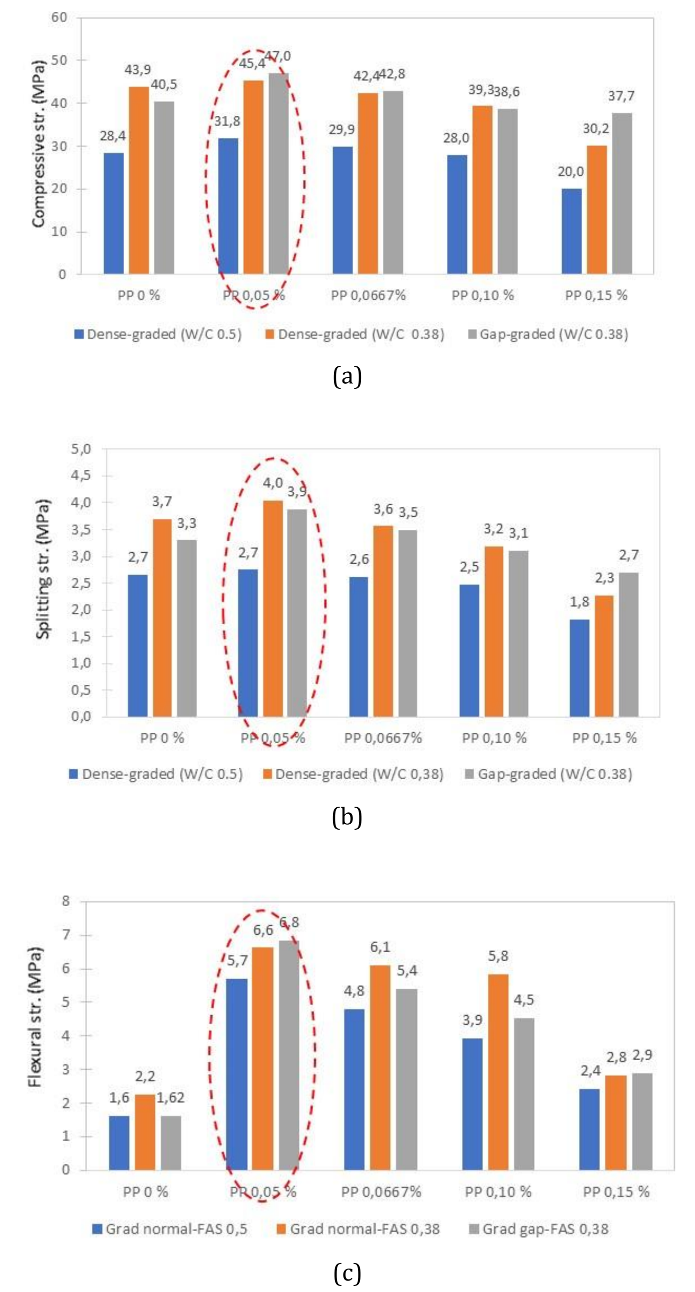


Figure 3. Mechanical properties of SCC according to percentage addition of polypropylene fiber, (a) Compressive strength, (b) Splitting tensile strength, (c) Flexural strength.

D. SCC Flexural Strength

A flexural strength test was done on a prism specimen (100x100x400 mm) based on SNI 4431:2011, by using a hydraulic jack and a proving ring installed on a loading frame. The loading rate was between 8 – 10 kg/cm^2 per minute.

The average flexural strength results are shown in Table 3 and Fig. 3-c. The results show that the addition of polypropylene fiber may increase the flexural strength of SCC significantly with both W/C 0.5 and 0.38 and with both dense-graded and gap-graded coarse aggregate. The highest increase is obtained from polypropylene with a fiber volume fraction of 0.05% that generates an increase of 322% (on specimen 0.38-S-0.05). However, the increase of flexural strength decreases as the polypropylene fiber volume fraction gets higher.

The flexural strength increase is caused by the random distribution of the polypropylene fiber within the concrete matrix, which allows the concrete to withstand stress from every direction. The polypropylene fiber reinforces the cement paste within SCC since it can act as a bridge during microcracking until the fiber is pulled-out.

Table 2 and Table 3 show that the W/C value and the coarse aggregate grading affect the value of slump flow, T_{50}, compressive strength, splitting strength, and flexural strength in SCC. The addition of 0.05% polypropylene fiber generates a maximum increase in compressive strength, splitting strength, and flexural strength. The addition of polypropylene fiber that is higher than 0.05% will reduce the concrete's compressive and flexural strength compared to concrete without the addition of polypropylene fiber, as shown in Table 3.

On the other hand, adding polypropylene that is higher than 0.05% will still increase the flexural strength of the concrete, albeit sub-optimally. The use of 0.067% polypropylene is recommended on the PT Sika polypropylene fiber brochure, which could generate an increase in flexural strength as much as 198% (0.5-N-0.067), 171% (0.38-N-0.067), 233% (0.38-S-0.067). However, its contribution to the increase of the concrete's compressive strength is insignificant.

IV. Conclusions

SCC is a type of concrete designed to flow and compact on its own because of its weight, thus applicable for a structural element with a tight and narrow reinforcement. Segregation of coarse aggregate and cement paste becomes a problem for SCC. This study shows that the addition of polypropylene into the SCC mixture could fix the segregation problem, although reducing the workability (slump flow value). Because of that, the addition of polypropylene is restricted to a maximum of 0.9 kg/m^3 (V_f = 0.1%). Moreover, the addition of polypropylene fiber does not affect compressive strength significantly while remarkably increasing flexural strength by 195% - 322.3% with the use of 0.45 kg/m^3 (V_f = 0.05%) polypropylene for every variation of W/C and grading of coarse aggregate. Therefore, it can be concluded that the optimal polypropylene fiber volume fraction that may be added into SCC is 0.05% (0.45 kg/m^3).

Acknowledgment

The authors gratefully acknowledge to Universitas Lampung for sponsoring this research in 2021. We would also express thanks to, Adipati Syahidullah Ulini'am dan Melinda Gusti for providing the data in this article.

References

[1] EFNARC, "Specification and guidelines for self-compacting concrete." *European Federation of National Trade Associations Representing Producers and Applicators of Specialist Building Product*. Hampshire, U.K., 2005.

[2] M. Arezumandi and M. Ezzell, JS. Volz, "A comparative study if the fracture behaviour, creep, and shrinkage of chemically based self-concolidating concrete". *Front. Struct. Civ. Eng*., 8(1): 36-45. Higher Education Press and Springer-Verlag Berlin Heidelberg, 2013.

[3] P. Desnerck, G. De Schutter, L. Taerwe, "Stress-strain behaviour of self-compacting concretes containing limestone fillers." Structural Concrete, 13: 95-101, 2012.

[4] L. Irianti, S. Sebayang, RA Wibowo, "Pengaruh agregat kasar bergradasi celah terhadap kuat tekan beton". *Jurnal Rekayasa*, Vol.19, No.2., 2015.

[5] ACI Committee 544. "State of the art report on fiber reinforced concrete - Report : ACI 544 IR-82." Farmington Hills : American Concrete Institute, 1982.

[6] P. Gunawan, Wibowo and N. Suyawan, "Pengaruh penambahan serat polypropylene pada beton ringan dengan teknologi foam terhadap kuat tekan, kuat tarik belah dan modulus elastisitas." Matriks Teknik Sipil, Vol.2, No.2, Surakarta, 2014.

[7] K. Ramujee, "Strength Properties of Polypropylene Fiber Reinforced Concrete." *International Journal of Innovative Research in Science, Engineering and Technology*. India, 2013.