scEScm

Certificate

Presented to

Slamet Widodo

Participated As

Paper Presenter

The 1st International Conference on
Sustainable Civil Engineering Structures
and Construction Materials

*"Enhancing The Role of Civil Engineering
for Sustainable Environment"*

11 - 13 September 2012
Yogyakarta, Indonesia

organized by

KIT
Karlsruhe Institute of Technology

Chairperson

GADJAH MADA

Prof. Bambang Suhendro, Ph.D

ORGANIZING ASSOCIATION :

EDITORS :

Priyosulistyo
Bambang Suhendro
Shunji Kanie
Iman Satyarno
Teerapong Senjutichai
Andreas Triwiyono
Djoko Sulistyo
Suprapto Siswosukarto
Ali Awaludin

Published by :
Department of Civil and Environmental Engineering
Universitas Gadjah Mada, Yogyakarta, INDONESIA
Website : http://tsipil.ugm.ac.id
Tel : +62-274-545675
Fax : +62-274-545676

ISBN : 978-602-95687-7-6

The texts of the papers in this volume were set individually by the authors or under their supervision. Only minor corrections to the text may have been carried out by the publisher. By submitting the paper in the 1st International Conference on Sustainable Civil Engineering Structures and Construction Management, the authors agree that they are fully responsible to obtain all the written permission to reproduce figures, tables, and text from copyrighted material. The authors are also responsible to give sufficient credit included in the figures, legends, or tables. The organizer of the conference, reviewers of the papers, editors, and the publisher of the proceedings are not responsible for any copyright infringement and the damage they may cause.

Effects of Steel and Polypropylene Fiber Addition on Interface Bond Strength between Normal Concrete Substrate and Self-Compacting Concrete Topping

Slamet Widodo
Doctoral Student at Department of Civil Engineering, Diponegoro University, Semarang, Indonesia

Iman Satyarno
Department of Civil and Environmental Engineering, Gadjah Mada University, Yogyakarta, Indonesia

Sri Tudjono
Department of Civil Engineering, Diponegoro University, Semarang, Indonesia

Abstract: Based on facts that the composite action in semi-precast and strengthened structural system depends on the bond strength of the interface between concrete faces of different ages, this preliminary research is aimed to investigate effects of mixed polypropylene (PPF) and steel fiber (SF) addition on the hardened properties of Self-Compacting Concrete (SCC) and its bond strength when used as topping layer on normal concrete substrate. Effects of hybrid fiber addition on the hardened properties of SCC were investigated based on the compressive, splitting tensile and flexural strength of concrete specimens which is tested in 28 days of age. In the next step, the tensile and shear strength of the interface were evaluated using indirect splitting tensile and bi-surface shear test method. In this research, fiber addition were prepared using 1 kg/m^3 PPF and various SF addition ranging from 15 kg/m^3, 20 kg/m^3, 25 kg/m^3 and 30 kg/m^3. Test results indicate that hybrid fiber addition does not affect the compressive strength significantly but it leads positive improvement to the splitting tensile and flexural strength of hardened SCC and also improve the bond strength between SCC and normal concrete. Hybrid fiber addition of 1 kg/m^3 PPF which is combined with 20 kg/m^3 SF can be suggested as optimum composition for Hybrid Fiber Reinforced Self-Compacting Concrete (HyFRSCC) that will be used as topping or overlay material based on its hardened properties and interface strength.

Keywords: SCC, hardened properties, interface strength, polypropylene, steel fiber.

1. INTRODUCTION

In construction field, the problem that related with different ages of concrete layers, both for new structures, strengthening and rehabilitation of existing ones become more prominent. Proper bond strength at the interface is required for composite action between new and old concrete. The strength capacity of tensile and shear stresses at the interface between concrete faces of different ages is very important to create force transfer between pre-cast elements, including add in-situ concrete to pre-cast elements or to existing cast-in-place sections. Even for conventional reinforced concrete construction in which entirely cast-in-situ structures, construction joints are sometimes unavoidable due to geometric or technical considerations. Figure 1 and Figure 2 illustrates the working stresses which can be observed in concrete interface for common structural application.

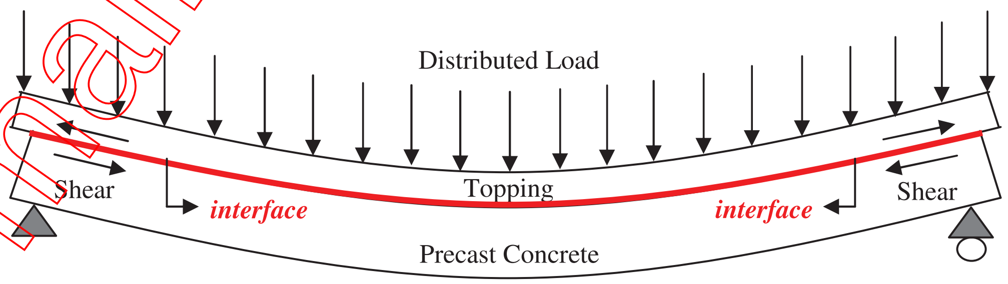


Figure 1. Horizontal shear stress along the interface of a composite flexural member

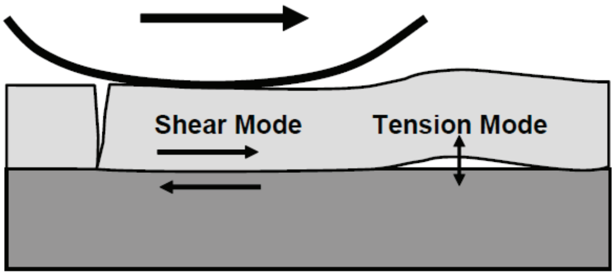


Figure 2. Adhesion stress modes in the upper pavement layers under service conditions (Raab and Partl, 2004)

Nowadays, semi-precast, repair and strengthening technique for concrete structures has been widely used, including of thin layer application of fiber reinforced concrete (FRC) onto the old concrete layer. Addition of steel fibers generally contributes on the energy absorbing mechanism (bridging action), while non-metallic fibers offer its ability to delay the formation of micro-cracks and avoid catastrophic breaking and also has much lower density (Sivakumar and Santhanam, 2007). In order to optimized the benefits of fiber addition in concrete construction, the application of different fiber types into fresh concrete mixes was introduced and commonly known as hybrid fiber reinforced concrete (HyFRC). It becomes more popular in these recent years and expected to provide better physical and mechanical properties in concrete construction.

Another benefit that possibly obtained by fibers addition in concrete mixture is reducing cracks potential of concrete due to the restrained shrinkage (Hwang and Khayat, 2008). This type of shrinkage mostly found in topping or overlay cases that caused by the difference of shrinkage rate between substrate and topping or overlay layer as shown in Figure 3.

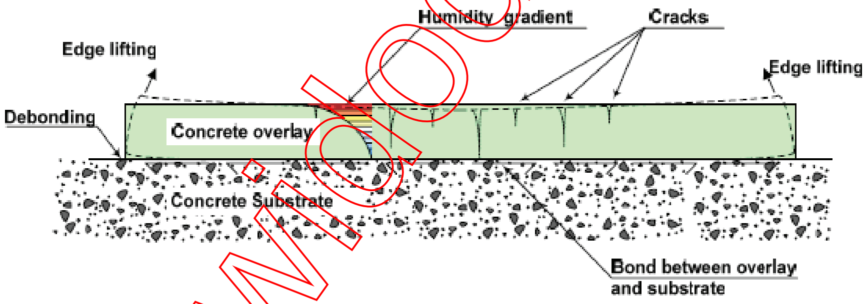


Figure 3. Cracking and edge lifting of a concrete overlay exposed to shrinkage (Carlswarld, 2006)

In the other hand, a continuous development and application of self-compacting concrete (SCC) technology is growing rapidly. The use of SCC offers considerable benefits for thin topping and overlay works due to its ability to flow, spread, and compacting by its own weight. Fibers addition offers positive effects for their ability to limit concrete shrinkage cracks at early age and to enhance some of the concrete properties, but fibers addition in SCC mixes also resulted negative effects on the flowability and passing-ability of fresh SCC (Widodo, 2010). Therefore, proper concrete composition of fiber reinforced self-compacting concrete should be identified.

Based on facts that the performance of semi-precast and strengthened structural system depends on the bonding behavior between old and new concretes, this preliminary research aimed to investigate the effects of hybrid fiber (mixed polypropylene and steel fibers) addition on compressive, splitting tensile and flexural strength of hardened SCC. Furthermore, effects of fiber addition on interface tensile and shear bond strength of HyFRSCC which used as topping or overlay layer on normal concrete substrate is also wanted to be known. Therefore, the optimum addition of hybrid fiber into SCC mixes which aimed to be used as topping or overlay layer can be predicted based on the experimental results.

2. EXPERIMENTAL WORKS

2.1. Materials and Mix Proportion

In this research, polypropylene (PPF) and steel fibers (SF) were chosen and mixed as hybrid fiber. Polypropylene used due to its 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. Steel fiber chosen as the macro fiber based on its proven ability on the energy absorbing mechanism (bridging action), and its ease to be found. The steel fiber that applied in this research is straight type local steel fiber having 25 mm length, and 0.7 mm of diameter.

The mixtures were prepared with Pozzolan Portland Cement (PPC). Continuously graded crushed aggregate which has specific gravity of 2.48 and maximum size of 20 mm was used as coarse aggregate as is commonly used the case in SCC mixes. Coarse aggregates were washed to remove fine sandy particles that can hinder the rheological properties of the fresh concrete. Well-graded natural sand which has specific gravity of 2.65 was employed as the fine aggregate. Silica fume, polycarboxylate based superplasticizer, Air Entraining Agent (AEA), and set retarder were also utilized as concrete admixtures in this research. Fiber addition were applied using 1 kg/m^3 of polypropylene fibers (based on the optimum PPF addition that achieved in the previous preliminary research), and various steel fiber addition of 15 kg/m^3, 20 kg/m^3, 25 kg/m^3 and 30 kg/m^3 into the mixes. Detail of mixes proportion can be found in the following Table 1.

Table 1. Mix Proportion

Material	Mix Type				
	A	B	C	D	E
Water (lt/m^3)	227.00	227.00	227.00	227.00	227.00
Portland Cement (kg/m^3)	490.00	490.00	490.00	490.00	490.00
Silica fume (kg/m^3)	25.80	25.80	25.80	25.80	25.80
Coarse Aggregate (kg/m^3)	575.00	575.00	575.00	575.00	575.00
Sand (kg/m^3)	950.00	950.00	950.00	950.00	950.00
Superplasticizer (lt/m^3)	4.28	4.28	4.28	4.28	4.28
Air Entraining Agent (lt/m^3)	0.30	0.30	0.30	0.30	0.30
Set Retarder (lt/m^3)	1.45	1.45	1.45	1.45	1.45
Polypropylene (kg/m^3)	1.00	1.00	1.00	1.00	1.00
Steel fibers (kg/m^3)	0.00	15.00	20.00	25.00	30.00

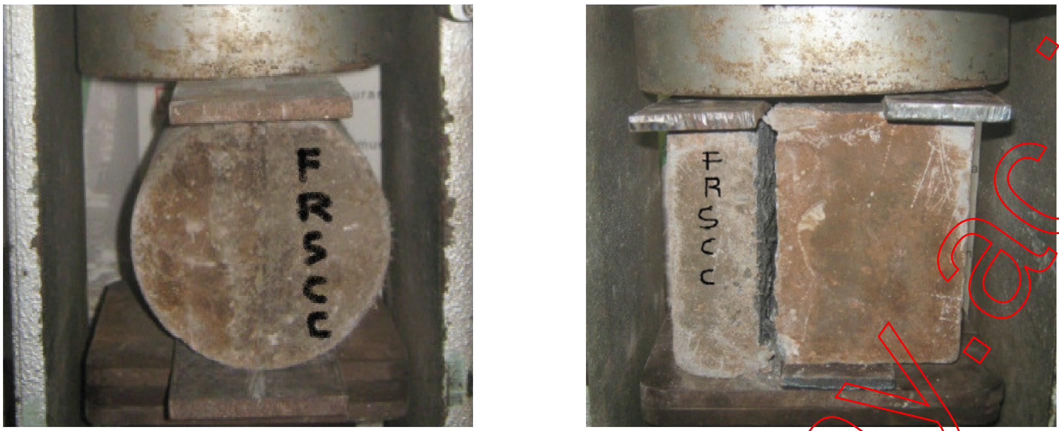
2.2. Test Methods

Fresh properties of SCC were evaluated using slump flow test which is usually required a minimum flow diameter of 600 mm for SCC mixes (EFNARC, 2005). In the first stage of experiment, the compressive, splitting tensile and flexural strength of SCC specimens was investigated. Concrete samples were cured with water immersion method for 28 days.

In the next step, the interface tensile and shear bond strength of HyFRSCC which is used as topping or overlay layer on normal concrete substrate is also investigated. The substrate designed based on Indonesia National Standard of normal concrete mix design with 27 MPa of compressive strength. Concrete substrates were immersed in water for 28 days, and then the topping or overlay layer poured on the SSD substrate, and cured for the next 28 days for interface bond strength tests.

Compressive strength tests for all the variants of concrete mixes with different fiber contents were done on three cylinders of 150 mm in diameter and 300 mm length, according to ASTM C-39. Flexural strength tested based on SNI 03-4154-1996 while Brazilian Tensile Strength test was carried out on three cylinders based on ASTM C-496. The tensile and flexural strength of hardened concrete was taken as the average of those three specimens for each variant.

The interface tensile strength evaluated based on Brazilian tensile strength test which is shown in Figure 4(a). For the interface shear bond strength evaluation, the concrete specimens tested using bi-surface shear test with 150x150x150 mm cubes which is proposed by Momayez et al (2005). The bi-surface shear test method is shown in Figure 4(b). As the results, the interface tensile and shear strength taken as the average of those three specimens for each variant.



(a) Indirect Tensile Test

(b) Bi-surface Shear Test

Figure 4. Interface Bond Strength Test

3. RESULT AND DISCUSSION

3.1. Fresh Concrete Properties

The fresh properties of SCC mixes were evaluated using Slump flow Test set. The measurement of fresh concrete characteristic using slump flow test is shown in Figure 5. Flowability characteristic of SCC mixes determined based on the average those two main diameters of the spread of fresh concrete using a conventional slump cone.

Figure 5. Slump flow measurement

The results of the fresh concrete spread diameter which resulted from slump flow test can be found in the following Table 2. Based on the results, it can be observed that the flowability (Slump Flow) of SCC decreases when the presence of polypropylene and steel fiber increased.

Table 2. Slump flow test results

Mix Type	Shortest Flow Diameter (cm)	Longest Flow Diameter (cm)	Average Flow Diameter (cm)
A	67.00	69.00	68.00
B	59.00	63.50	61.25
C	59.00	62.50	60.75
D	58.00	59.00	58.50
E	54.00	56.00	55.00

3.2. Mechanical Properties

Table 3 shows the compressive, splitting tensile and flexural strength of the hardened concrete specimens which are added with various steel fiber dosages into fresh concrete mixes that contain 0.10% volume fraction of polypropylene fiber which is equal to ±1 kg/m^3, and measured after 28 days of curing.

Table 3. Effects of Hybrid Fiber Addition on Hardened Self-Compacting Concrete Properties

Mix Type	Compressive Strength (MPa)	Splitting Tensile Strength (MPa)	Flexural Strength (MPa)
A	36.00	3.15	3.43
B	34.75	3.40	3.70
C	36.83	4.16	3.99
D	36.15	4.08	3.81
E	32.82	3.33	3.70

Figure 6, Figure 7 and Figure 8 shows the effects of hybrid fiber content on compressive, splitting tensile and flexural strength of the hardened concrete respectively. Test results show that the compressive strength not affected significantly by hybrid fiber addition while the splitting tensile and flexural strength of concrete samples increase in accordance with the increase of hybrid fiber content up to the fiber combination of 1 kg/m^3 of polypropylene and 20 kg/m^3 of steel fiber.

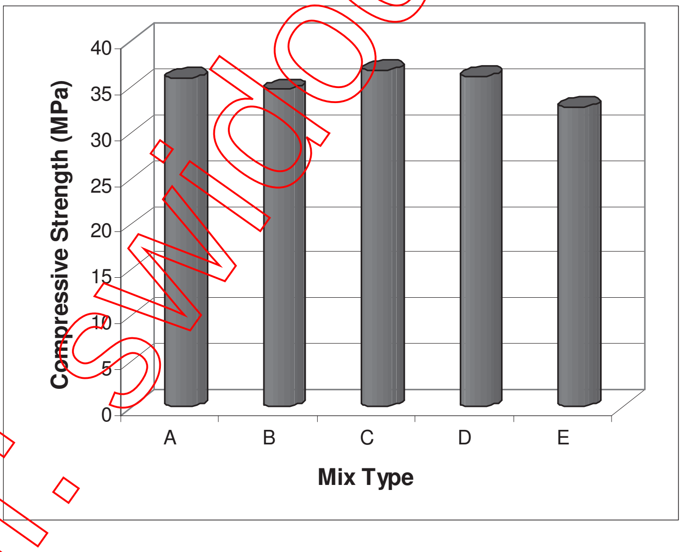


Figure 6. Effects of Hybrid Fiber Addition on Self-Compacting Concrete Compressive Strength

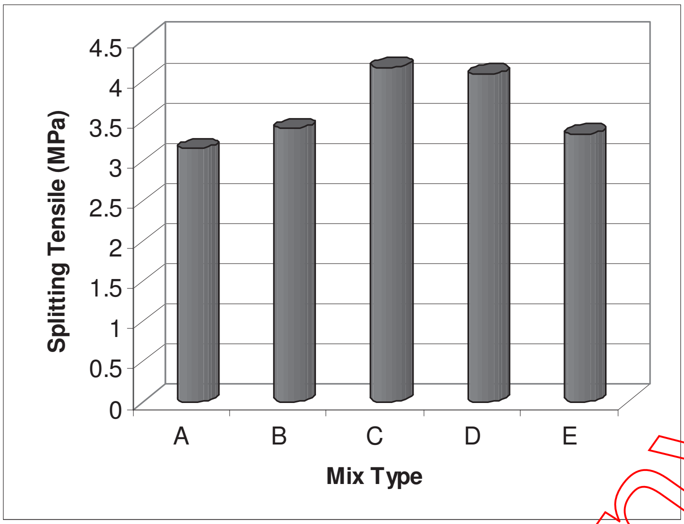


Figure 7. Effects of Hybrid Fiber Addition on Self-Compacting Concrete Splitting Tensile Strength

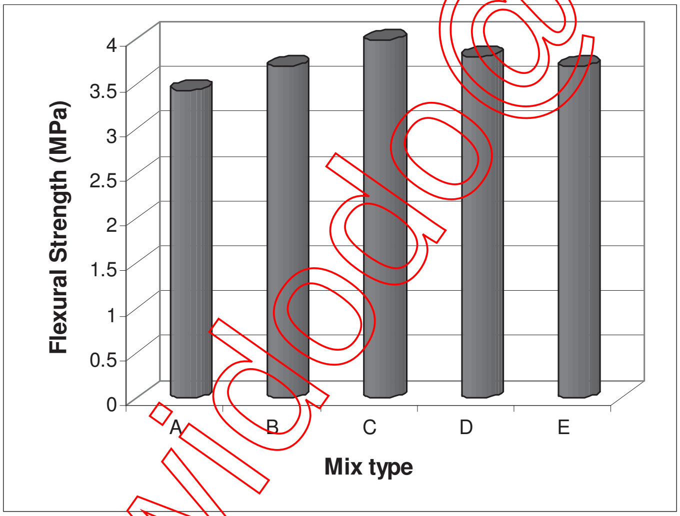


Figure 8. Effects of Hybrid Fiber Addition on Self-Compacting Concrete Flexural Strength

The improvement of splitting tensile up to 32.06% and flexural strength up to 16.33% can be achieved, due to the fact that steel fiber able to bridge the macro-cracks while polypropylene fiber bridges micro-cracks of which growth can be controlled. This leads to a higher strength of the hardened concrete. If the fibers addition passes over the optimum value, the instability of the fresh concrete samples can be observed and realized earlier when these mixes do not spread perfectly in the slump-flow tests. This condition could probably leads to a decrease in concrete strength.

3.3. Interface Bond Strength

Table 4, Figure 9 and Figure10 shows the effect of hybrid fiber addition on indirect tensile and shear bond strength of the interface between normal concrete substrate and fiber reinforced self-compacting concrete topping. The SCC mixes were added with various steel fiber dosages into fresh concrete which is containing 0.10% volume fraction of polypropylene fiber that equal to ±1 kg/m^3. The interface bond strength was measured at 28 days of age after the topping layers cast and cured.

Table 4. Effects of Fiber Addition in the Topping Layer on the Interface Bond Strength between Concrete Faces

Mix Type	Indirect Tensile Strength (MPa)	Shear Strength (MPa)
A	0.444	1.200
B	0.964	2.089
C	0.998	2.267
D	0.871	1.756
E	0.912	1.970

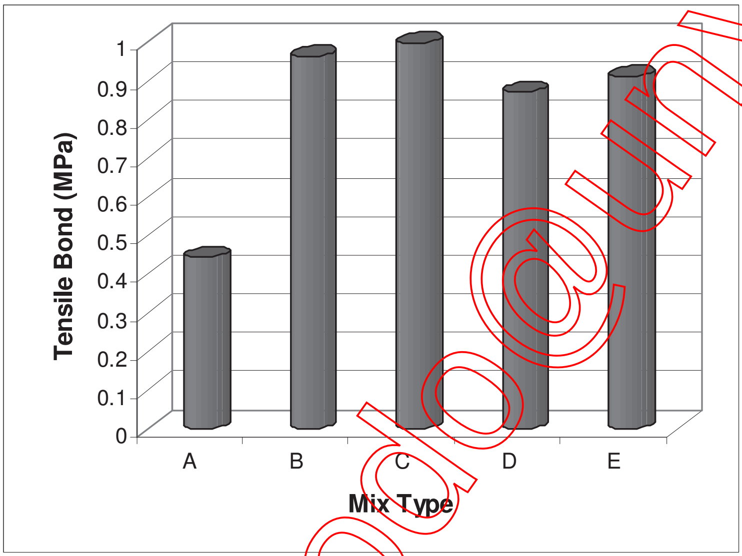


Figure 9. Effects of Hybrid Fiber Addition on Interface Tensile Strength between Self-Compacting Concrete Topping on Normal concrete Substrate

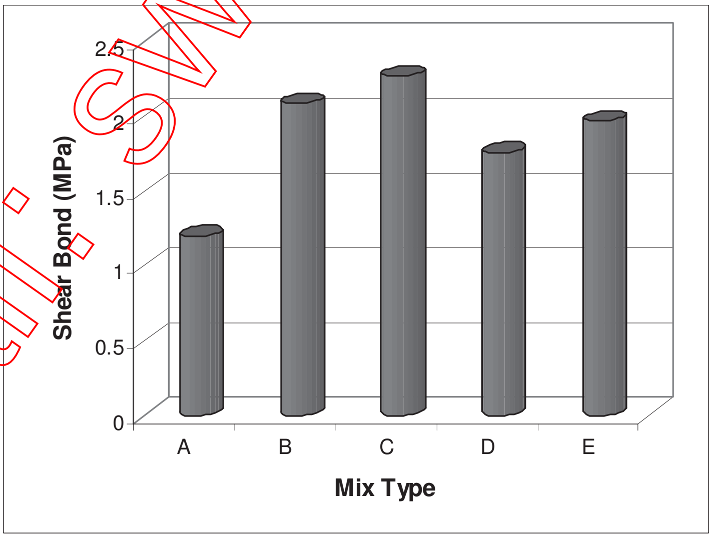


Figure 10. Effects of Hybrid Fiber Addition on Interface shear Strength between Self-Compacting Concrete Topping on Normal concrete Substrate

The improvement of interface indirect tensile up to 124.77% and the interface shear strength up to 88.92% can be achieved, due to the fact that hybrid fibers having better ability in reducing cracks potential of concrete due to restrained shrinkage. This leads to a higher strength of the interface between concrete faces. When the fibers addition passes over the optimum value, the instability of the fresh concrete mixes which was visually observed earlier in the slump-flow tests may have negative effect that lead to a decrease in concrete interface strength.

4. CONCLUSIONS

1. Flowability (Slump Flow) of SCC decreases when the presence of polypropylene and steel fiber increased.
2. The compressive strength of self-compacting concrete samples can not increased significantly by hybrid fiber addition into the mixes.
3. The splitting tensile strength of self-compacting concrete shows 32.06% improvement with an addition of hybrid fibers containing 1 kg/m^3 of polypropylene and 20 kg/m^3 of steel fiber.
4. The flexural strength of self-compacting concrete increases 16.33% with the application of hybrid fibers that combine 1 kg/m^3 of polypropylene and 20 kg/m^3 of steel fiber.
5. The interface indirect tensile bond strength between normal concrete substrate and self-compacting concrete topping can be improved up to 124.77% with an addition of hybrid fibers which contain 1 kg/m^3 of polypropylene and 20 kg/m^3 of steel fiber.
6. Test results indicate that interface shear bond strength between normal concrete substrate and self-compacting concrete topping increases up to 88.92% when hybrid fibers applied with 1 kg/m^3 of polypropylene and 20 kg/m^3 of steel fiber.

REFERENCES

Carlswärd, J. (2006). "Shrinkage cracking of steel fibre reinforced self compacting concrete overlays Test methods and theoretical modeling."*Doctoral Thesis*, Luleå University of Technology.

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

EFNARC. (2005). *The European guidelines for self-compacting concrete specification, Production and Use*. Norfolk UK: European Federation for Specialist Construction Chemicals and Concrete Systems.

Okamura, H. and Ouchi, M. (2003). "Self-compacting concrete." *Journal of Advance Concrete Technology*, Vol. 1, No. 1, pp. 5-15.

Hwang, S.D., and Khayat, K.H. (2008). "Effect of mixture composition on restrained shrinkage cracking of self-consolidating concrete used in repair." *ACI Materials Journal*, V. 105, pp. 499-509.

Hsie, M., Tu, C., Song, P.S. (2008). "Mechanical properties of polypropylene hybrid fiber-reinforced concrete." *Materials Science and Engineering A 494*, pp. 153–157.

Momayez, A., Ehsani, M.R., Ramezanianpour, A.A., and Rajaie, H. (2005). "Comparison of methods for evaluating bond strength between concrete substrate and repair materials." *Cement and Concrete Research 35*, pp. 748–757.

Momayez, A., Ramezanianpour, A.A., Rajaie, H., and Ehsani, M.R. (2004). "Bi-surface shear test for evaluating bond between existing and new concrete." *ACI Materials Journal V. 101, No. 2, March-April 2004*, pp. 99–106.

Sivakumar, A., and Santhanam, M. (2007). "Mechanical properties of high strength concrete reinforced with metallic and non-metallic fibres." *Cement & Concrete Composites 29*, pp. 603-608.

Raab, C., and Partl, M.N. (2004). "Interlayer shear performance: experience with different pavement structures." *3rd Eurasphalt & Eurobitume Congress*. Vienna.

Widodo, S. (2010). "Experimental study on some fresh and mechanical properties of polypropylene fiber reinforced self compacting concrete." *Media Teknik Sipil Volume 10 Nomor 2*, pp.65-70.