Bond Strength between Hybrid Fiber Reinforced Lightweight Aggregate Concrete Substrate and Self-Compacting Concrete as Topping Layer

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Abstract

Structural performance evaluation of composite concrete slabs that constructed using partially precast concreting system which utilizing Hybrid Fiber-Reinforced Lightweight Aggregate Concrete (HyFRLWAC) as stay in-place formwork and self-compacting concrete (SCC) as topping layer were conducted in this research. This paper focused on determining the appropriate strength limit criteria of interface between two different concrete layers. The tensile strength was tested using pull-off test, while concrete cohesion was investigated based on modified bi-surface shear test, and dual L-shaped shear test used to determine the effect of normal force on the shear strength of concrete interface. Sample variants were designed based on the substrate surface conditions, compressive strength of the topping layer, and magnitude of perpendicular normal force which working on interface area. The substrate surfaces were prepared in as-placed and grooved conditions for tensile test, cohesion, and shear strength test. Test results indicate that tensile strength, cohesion and shear strength of the concrete interface are affected by surface condition of the substrate, compressive strength of the topping layer, and the normal force that acting perpendicularly on the concrete interface area. Proposed formulation for bond strength prediction between HyFRLWAC as substrate and SCC as topping layer also presented in this paper.

Keywords: Composite Concrete Slab, HyFRLWAC, Old and new concrete interface, SCC

1. Introduction

1.1. Background

Nowadays, composite concrete are widely implemented for construction works in accordance with the rapid development of concrete construction technology. In this technique, it can be observed that the cross-section of this structural element consists of two concrete layers or more, and each layer of concrete has different physical or mechanical characteristics. Composite concrete can be found in application of partial depth precast concrete construction, in which the precast concrete used as stay in place formwork while cast in-place concrete used for topping layer. Expected benefits from the application of partially precast concrete systems include: saving component cost for formwork and scaffolding as well as labor costs, better quality control, faster construction period, as well as to minimize weather constraints in the implementation of construction works.

Partially precast concrete applications that utilizing Hybrid Fiber-Reinforced Lightweight Aggregate Concrete (HyFRLWAC) is expected to provide more significant benefits as it has lower self-weight when compared to normal concrete. Therefore, the installation process becomes easier and faster, as well as the dead-load that acting on the structural system can be reduced. In this research, pumice breccia which can be found abundantly in Indonesia proposed to be utilized as the coarse aggregate to produce stay in place formwork. Pumice breccia is a type of coarse grained pyroclastic sedimentary rocks which has a relatively low density and low mechanical strength. Crushed pumice breccia has a dry-loose bulk density less than 1000 kg/m3, therefore, can be classified as lightweight aggregate. Structural lightweight concrete can be produced when the mixtures utilized the pumice breccia as coarse aggregate and its volume fraction range between 55% and 75% to the total volume of aggregate [1].

Fibers addition into concrete mixture mainly aimed to increase the concrete ability in inhibiting the occurrence of cracks that may occur during construction process and service life. Added fibers may also increase the bond strength between lightweight concrete with the reinforcement bar. Hybrid fibers using polypropylene and steel fibers is expected to provide better performance of concrete to resist the micro and macro-crack caused by the shrinkage of concrete and also by the action of mechanical load. Moreover, the existence of micro-fiber is expected to increase the pull-out strength of the macro-fiber. The compressive strength of lightweight concrete can be improved proportionally up to 22.44% when the hybrid polypropylene-steel fiber is added with the combination of 0.1% PPF and 1.0% SF then tends to decrease but still shows better performance compared to the reference concrete mixture. The flexural strength of fiber-reinforced lightweight concrete specimens can be improved proportionally up to 187.46% when the hybrid polypropylene-steel fiber is added with the combination of 0.1% PPF and 1.5% SF then decreases but still exhibits much better flexural performance compared to the reference concrete [2].

Utilization of self-compacting concrete (SCC) offers the advantage of its highly flow-able characteristic and does not require any compaction process, so will be suitable to be used for the topping layer of composite flooring system which is relatively thin. SCC is also highly pump-able (easily pumped to reach casting location) so as to facilitate and speed up the construction work, as well as to minimize labor requirements. The use of normal concrete in thin layers of topping that can lead to difficulties in the process of pumping and compaction which will increase the possibility of cavity occurrence in the interface area.

In general, structural elements are expected to work as a monolithic system. Therefore, the bond between two layers of concrete that are used will be a very decisive factor. In composite concrete construction, the occurrence of early cracks or delamination on the interface should be minimized. Once the structure is used, the components of the external force that can lead to separation of the two layers of concrete are the shear force and tensile force which is acting perpendicularly to the concrete interface. Thus, these forces must be addressed [3].

In accordance with its requirements, it is currently possible to construct composite concrete that combines layers of normal concrete with a special concrete, and also combination between a special concrete with other special concrete (e.g.: high strength concrete, lightweight concrete, fiber reinforced concrete, self-compacting concrete) to get a more optimal structural performance. The use of different types of concrete will give different results on the bond strength between two layers of concrete.

The load transfer mechanism at the interface of two concrete layers is contributed by cohesion, friction, and dowel action. Therefore, these components should be considered in the design process to obtain better bond strength prediction [4]. The *fib* Model Code 2010 presents a design formulation to predict the interface shear strength as the sum of those three load transfer mechanisms [5].

The cohesion of the interface between the two layers of concrete will influenced by several factors i.e. the cleanliness of the surface of the substrate from substances contaminants that can cause slippery concrete surface, roughness which is determined by treatment on the surface of the substrate, the composition of the fresh concrete for topping material, casting and compaction technique for concrete topping, curing, and age of the concrete [6].

The interface bond strength is closely related to the compressive strength of concrete overlay. Previous researchers verified significant indications that the pozzolanic material addition i.e. silica fume in to the mixture of concrete overlay can improve the bond strength of the concrete interface [7]. The bond strength also tends to increase in accordance with the increasing compressive strength of concrete overlay. The ratio between the bond strength with the compressive strength of concrete overlay is approximately 0.1. Even though, the ratio of interface bond strength to the compressive strength of concrete overlay tends to decreased when compressive strength of concrete overlay was increased [8].

Several other researchers have focused to investigate the contribution of shear connector to the interface bond strength between new and old concrete layers, and then proposed some design expressions, but did not perform any detailed investigation to determine the magnitude of each components that may contribute to the bond strength of concrete interface, both for high strength concrete [9], and normal concrete for the construction of precast concrete [10].

This research was conducted to provide recommendations formula for calculation of the strength limit of concrete interface without shear connectors between two layers of special concrete with different ages (HyFRLWAC as substrate and SCC as topping layer), with different condition of the substrate surface (smooth/as-placed, rough in the longitudinal direction, and rough in the transverse direction), which can be developed to be applied for partially precast floor slabs.

1.2. Objectives

The main objectives of this research include: (1) evaluating tensile strength of interface between HyFRLWAC substrate and SCC topping, (2) examining cohesion between HyFRLWAC substrate and SCC topping, (3) investigating friction between HyFRLWAC substrate and SCC topping considering normal stress that acting perpendicular to the interface area, and (4) proposing formulation to predict interface shear strength between HyFRLWAC substrate and SCC topping which can be applied for partially precast concrete slab design.

2. Experimental Work

2.1. Materials and Mix Proportion

The substrate and topping concrete mixtures were prepared with blended cement which satisfies to the requirements in the Indonesian National Standards. The detail of its chemical compounds is presented in Table 1.

TABLE 1: Chemical composition of portland cement

Chemical Compounds	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LoI
Mass (%)	23.13	8.76	4.62	58.66	0.90	2.18	1.69

In this research, the coarse aggregate for HyFRLWAC mixture utilize continuously graded crushed lightweight pumice breccia from Bawuran Mountain, Bantul District in the Special Province of Yogyakarta which is one of the largest pumice breccia deposits in Indonesia. This pumice breccia has dry-loose bulk density of 760 kg/m^3 with particle density of 1620 kg/m^3 which is satisfied to the technical specification of lightweight aggregate. The coarse aggregate with maximum size of 20 mm were pre-wetted and submerged in water in 24 hours and then air-dried to be in saturated surface dry condition before mixing process. Well-graded natural sand with specific gravity of 2.65 was employed as the fine aggregate. Silica fume, and naphthalene formaldehyde sulfonate based high range water reducer (HRWR) which is comply ASTM C 494-92 Type F were also utilized as concrete admixture.

HyFRLWAC mixture also prepared using polypropylene fiber (PPF) and steel fiber (SF) which were chosen and mixed become hybrid fiber, and HyFRLWAC then utilized as stay in-place formwork (substrate layer). 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/cm3 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 hooked-end steel fiber having 60 mm length, and 0.75 mm of diameter.

Detail of HyFRLWAC mixture proportion that possesses 20.14 MPa of average compressive strength can be found in the following Table 2.

TABLE 2: Mixture proportion of HyFRLWAC as stay in-place formwork (substrate layer)

Material	**(kg/m^3)**
Water	225,00
Portland cement	455,00
Silica fume	45,00
Coarse aggregate (pumice breccia)	606,81
Fine aggregat (sand)	538,52
Viscoflow	4,70
Plastiment VZ	0,70
Polypropylene	0,90
Steel fiber	67,00

After mixing process and casting of fresh concrete into the formwork, the surface of the substrate was prepared in accordance with the design of test variants, i.e. as-placed, and grooved, in both the longitudinal and transverse directions. Resulted surface condition of substrate layers can be observed in Figure 1.

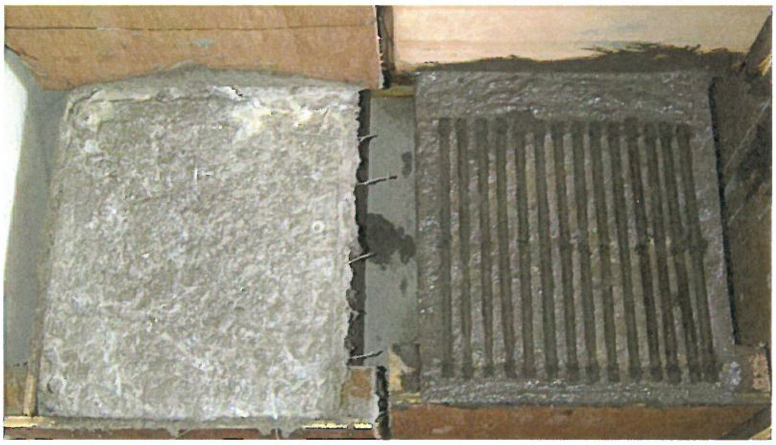


FIGURE 1: Difference of substrate surface conditions between as-placed and grooved with 6 mm of roughness amplitude

Topping layer was casted onto the substrate after 28 days. Variation of compressive strength and composition of the self-compacting concrete (SCC) that used in this test can be seen in Table 3.

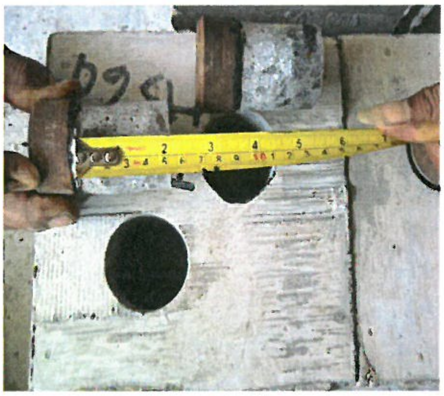
TABLE 3: Mixtures proportion of SCC as topping layer

Material		Concrete Topping Variants				
		T30	T35	T40	T50	T60
Water	(kg)	178.50	175.00	171.50	168.50	164.50
Portland cement	(kg)	255.00	318.20	398.80	481.40	498.50
Limestone powder	(kg)	229.80	188.20	133.10	79.20	80.30
Coarse aggregate (crushed stone)	(kg)	806.00	806.00	806.00	806.00	806.00
Fine aggregate (sand)	(kg)	769.70	766.80	762.80	755.00	750.50
Viscoflow	(kg)	1.50	1.90	2.40	2.90	3.00
Plastiment VZ	(kg)	0.40	0.50	0.60	0,70	0,70
Average compressive strength	(MPa)	31.30	34.51	42.99	51.66	61.85

2.2. Tests Set-up

The tensile strength between HyFRLWAC with SCC was tested using pull-off test method based on (ASTM 1583). The specimen variations were prepared for two different surface conditions that is as-placed and grooved substrate surfaces, and then five different SCC mixtures casted on the top of substrate layers, thus there are 10 variants tested for the tensile strength of concrete interface. Each variant represented by three specimens, therefore the total specimen number was 30 samples which were used for direct pull-off test. The test set-up was documented in Figure 2.

a)

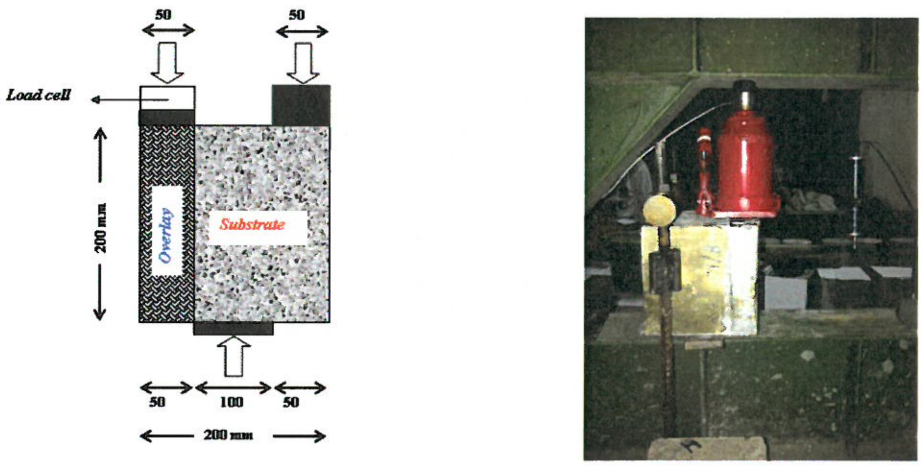


b)

FIGURE 2: a) Direct pull-off test setting, b) typical failure on concrete interface

Modified bi-surface shear strength was conducted on 15 variants for the cohesion investigation. The condition of the substrate surfaces were prepared in a smooth condition (as-placed), and grooved in longitudinal and transverse direction. After 28 days, on the top of the substrate were casted with five variations of SCC compressive strength as the topping layer. In total, there were

45 specimens assessed using modified bi-surface shear test since each variant represented by three specimens. Details of specimens and test set-up can be observed in Figure 3.



a) b)

FIGURE 3: a) Dimensions of specimens, b) modified bi-surface shear test

The next test was conducted to determine the effect of normal force on the shear strength of the interface. Tests conducted on 54 test specimens of double L-shaped shear test, which consists of 18 variants (three substrate surface variation with six variations of the magnitude of normal force). Figure 4 shows the detailed dimensions of the specimen while Figure 5 shows the test set-up.

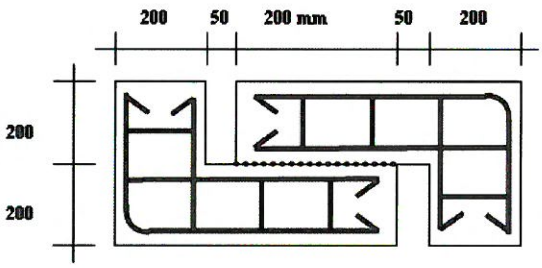


FIGURE 4: Detailed dimensions of specimens for double L-shaped shear test

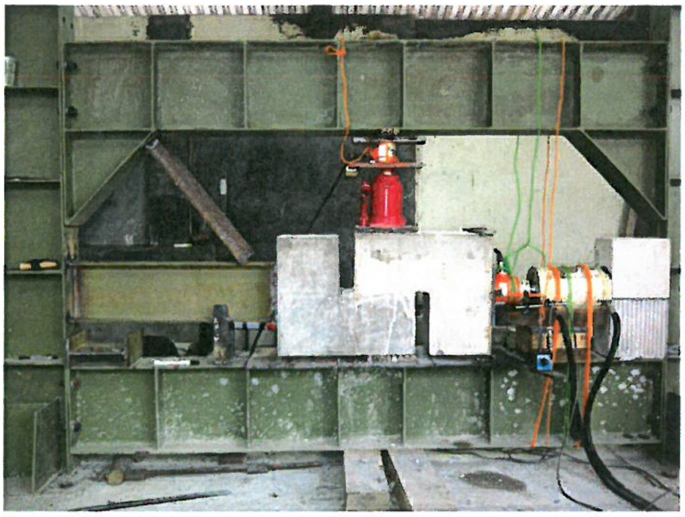
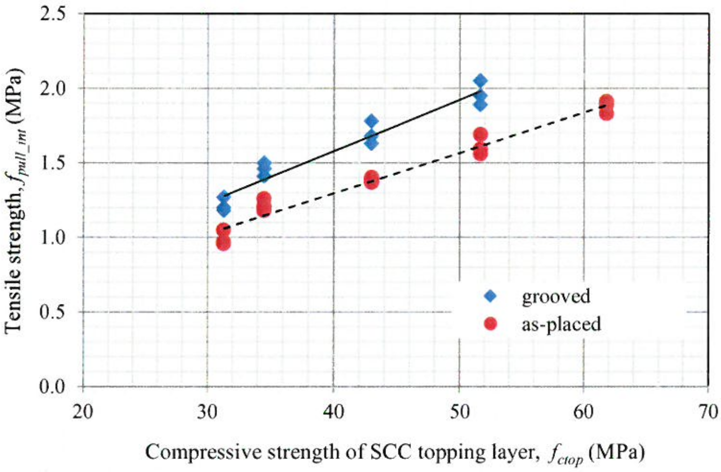


FIGURE 5: Double L-shaped shear test

3. Results and Discussion

Test results that indicate the effect of SCC topping layer on interface pull-off strength, both for as-placed and grooved surface condition with 6 mm (1/4 inch) of roughness amplitude of substrate layer can be observed in Figure 6.

(5) $f_{pull\ out} \approx 0{,}03 \cdot f_{ctop}$



(9) Where occurred the failures?

FIGURE 6: Interface tensile strength with different substrate surface conditions and different compressive strength of SCC topping layer

Figure 7 shows the relation between the compressive strength of SCC topping layer and its interface tensile strength when SCC casted on the top of fiber-reinforced lightweight aggregate concrete substrate.

was

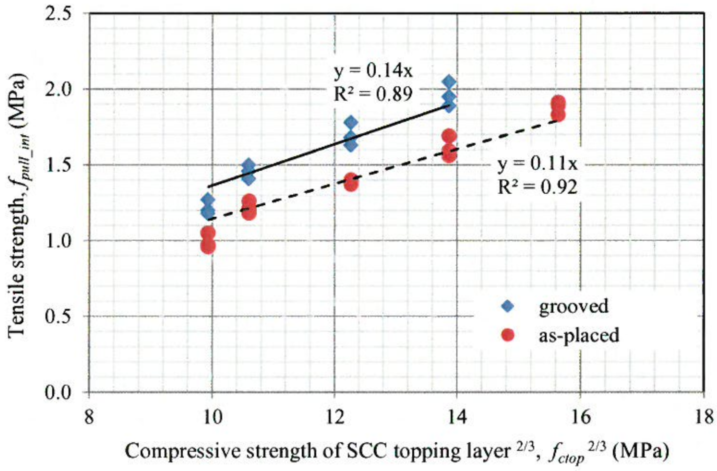


FIGURE 7: Prediction of interface tensile strength based on average compressive strength of SCC topping layer with different substrate surface conditions

Based on the results of the pull-off test, it can be obtained the formulation to predict maximum tensile strength of interface between fiber-reinforced lightweight aggregate concrete as substrate layer and SCC as a topping layer. Prediction of the tensile strength between old and new concrete interface that use SCC as a topping layer that possesses compressive strength in the range between 30 MPa to 60 MPa can be expressed in the following Equation 1, for the as-placed surface condition of the substrate layer.

$$f_{pull\_as\text{-}placed} = 0{,}11.\left(f_{c_{top}}\right)^{2/3} \quad (1)$$

When the surface of substrate layer prepared in grooved condition with 6 mm (1/4 inch) of roughness amplitude, the tensile strength between old and new concrete interface that use SCC as a topping layer that possesses compressive strength in the range between 30 MPa to 50 MPa can be expressed in the following Equation 2.

$$f_{pull\_grooved} = 0{,}14.\left(f_{c_{top}}\right)^{2/3} \quad (2)$$

with:

$f_{pull\_as\text{-}placed}$: interface tensile strength with as-placed surface condition of substrate (MPa)
$f_{pull\_grooved}$: interface tensile strength with grooved surface condition of substrate (MPa)
$f_{c_{top}}$: average compressive strength of SCC topping layer (MPa)

The effect of SCC topping layer on the cohesion between HyFRLWAC substrate and SCC topping, for as-placed and grooved surface, both in longitudinal and transverse direction can be observed in Figure 8. Figure 9 shows the relation between SCC topping layer and cohesion between HyFRLWAC substrate and SCC topping, for as-placed and grooved surface, both in longitudinal and transverse direction.

The effect of SCC topping layer on interface cohesion (shear strength without any influence of normal stress), both for as-placed, longitudinally grooved, and transversally grooved surface condition with 6 mm (1/4 inch) of roughness amplitude of substrate layer can be observed in Figure 8.

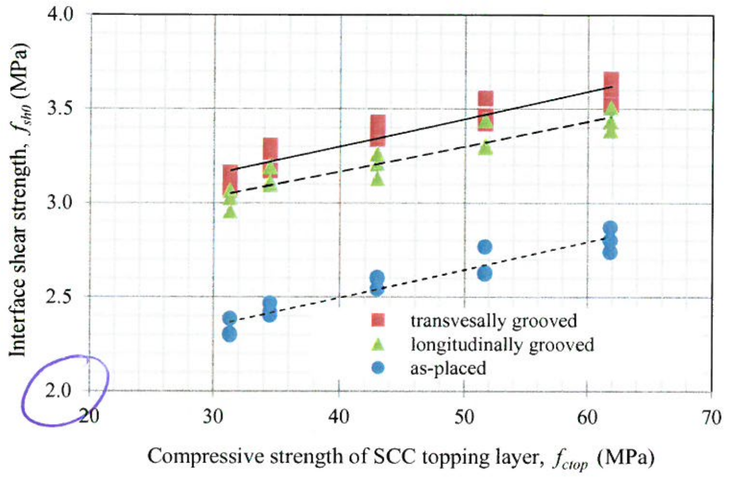


FIGURE 8: Effect of SCC topping layer compressive strength on the cohesion of interface with different substrate surface conditions

Figure 9 shows the relation between compressive strength of SCC topping layer, and its interface cohesion when SCC casted on the top of fiber-reinforced lightweight aggregate concrete substrate.

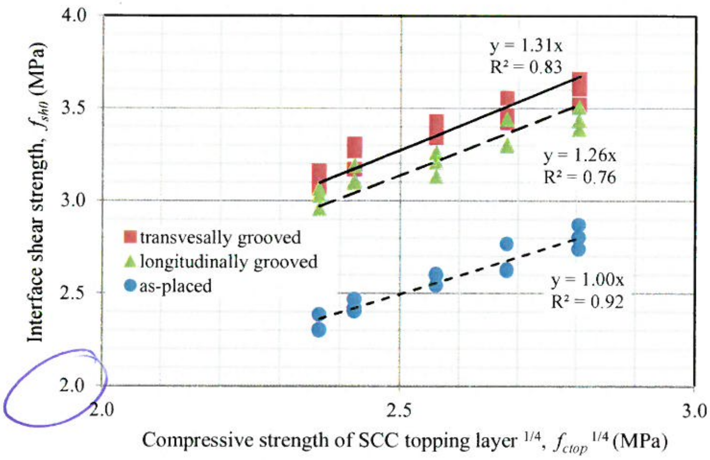


FIGURE 9: Prediction of interface cohesion based on average compressive strength of SCC topping layer with different substrate surface conditions

Considering the results of cohesion (shear strength without any influence of normal stress) test, it can be obtained the formulation to predict cohesion of interface between fiber-reinforced lightweight aggregate concrete as substrate layer and SCC as a topping layer. Prediction of cohesion between old and new concrete interface that use SCC as a topping layer with the range of compressive strength in between 30 MPa to 60 MPa can be expressed in the following Equation 3, for the as-placed surface condition of the substrate layer.

$$f_{sh_0} = 1{,}00.\left(f_{c_{top}}\right)^{1/4} \quad (3)$$

When the surface of substrate layer prepared in grooved condition with 6 mm (1/4 inch) of roughness amplitude, the tensile strength between old and new concrete interface that use SCC as a topping layer that possesses compressive strength in the range between 30 MPa to 60 MPa can be expressed in the following Equation 4 for longitudinally grooved substrate, and Equation 5 for transversally grooved substrate.

$$f_{sh_0} = 1{,}26.\left(f_{c_{top}}\right)^{1/4} \quad (4)$$

$$f_{sh_0} = 1{,}31.\left(f_{c_{top}}\right)^{1/4} \quad (5)$$

with:

f_{sh_0} : interface cohesion i.e. shear strength without any influence of normal stress (MPa)
$f_{c_{top}}$: average compressive strength of SCC topping layer (MPa)

The effect compressive normal force which is acting perpendicularly to the interface area on the shear strength, both for as-placed, longitudinally grooved, and transversally grooved surface condition with 6 mm (1/4 inch) of roughness amplitude of substrate layer can be observed in Figure 10.

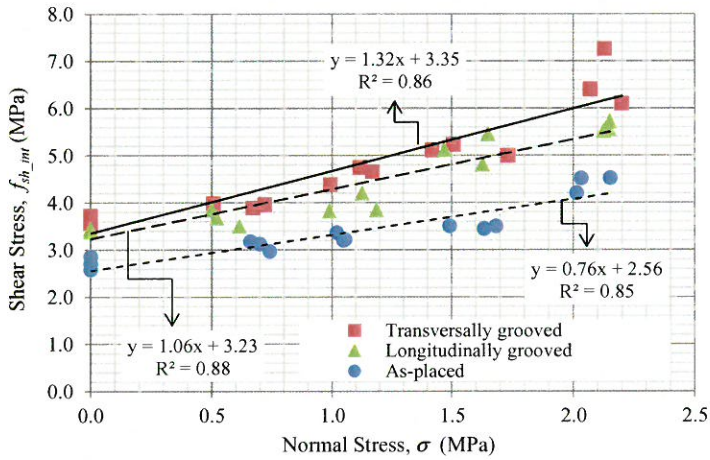


FIGURE 10: Effect of compressive normal force on the shear strength of interface with different substrate surface conditions

Figure 11 shows the relation between normal force which is acting perpendicularly to the interface area, and the interface bond strength when SCC casted on the top of fiber-reinforced lightweight aggregate concrete substrate.

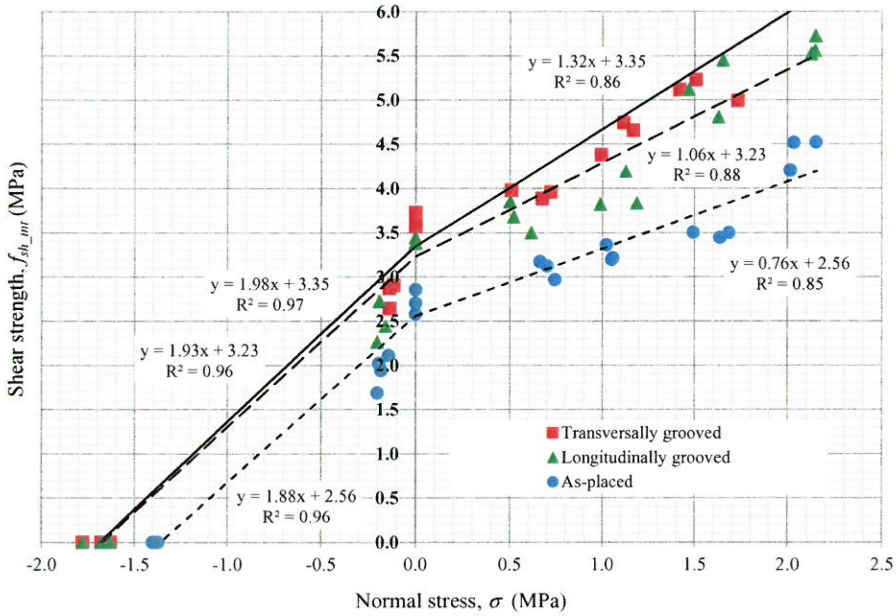


FIGURE 11: Prediction of interface bond strength based on different normal stress that acting perpendicularly to the interface area

Based on Figure 11, it can be identified that the increase of compressive normal force will lead higher shear strength of the interface between the two layers of different concrete. On the other hand, the higher tensile force on the interface will weaken the concrete interface strength. Figure 11 also shows that the conditions of substrate surface and roughness direction also give effect to the interface strength. In accordance with the results of cohesion test, the interface friction testing also showed that the surface of the substrate with a roughness that is created in the direction perpendicular to the direction of shear force will provide the highest interface shear strength contributed by interlocking during shear load. The surface of the substrate with a roughness that prepared in the same direction with the shear force will provide the interface shear strength higher than smooth (as-placed) substrate surface. Based on the above test results, further calculation of the cohesion coefficient and friction coefficient can be derived based on the following Equation 6 and Equation 7.

$$c = \frac{v_u}{{f_{c_{top}}}^{x}} \tag{6}$$

$$\mu = \frac{v_u - c.{f_{c_{top}}}^{x}}{\sigma_n} \tag{7}$$

Based on test results and analysis has been done it can be proposed a formula for calculating the shear strength of interface between two layers of concrete with different ages, especially for partially precast construction utilizing HyFRLWAC as substrate and SCC as topping layer. Proposed formulation for prediction of interface shear strength which is contributed by cohesion and friction between two layers of concrete can be expressed in Equation 8 when the interface influenced by compression stress which acting perpendicularly on the interface area.

$$V_n = c\, {f_{c_{top}}}^{1/4} + \mu\, \sigma_{comp} \tag{8}$$

with:

c : coefficient of cohesion
= 1.00 for as-placed HyFRLWAC substrate surface
= 1.26 for longitudinally grooved HyFRLWAC substrate surface
= 1.31 for transversally grooved HyFRLWAC substrate surface

$f_{c_{top}}$: average compressive strength of SCC topping layer (MPa)
μ : coefficient of friction
= 0.72 for as-placed HyFRLWAC substrate surface
= 0.95 for longitudinally grooved HyFRLWAC substrate surface
= 1.16 for transversally grooved HyFRLWAC substrate surface
σ_{comp} : compressive stress (MPa)

Equation 9 can be applied to predict the interface bond strength when there are tensile stress presence on the interface area.

$$V_n = c\, f_{c_{top}}{}^{1/4} - k\, \sigma_{tens} \tag{9}$$

with:
c : coefficient of cohesion
= 1.00 for as-placed HyFRLWAC substrate surface
= 1.26 for longitudinally grooved HyFRLWAC substrate surface
= 1.31 for transversally grooved HyFRLWAC substrate surface

$f_{c_{top}}$: average compressive strength of SCC topping layer (MPa)
μ : coefficient of friction
= 3.42 for as-placed HyFRLWAC substrate surface
= 4.12 for longitudinally grooved HyFRLWAC substrate surface
= 4.17 for transversally grooved HyFRLWAC substrate surface
σ_{tens} : tensile stress (MPa)

4. Conclusions

Based on the test results in this research, it can be concluded that the surface roughness of the concrete substrate and compressive strength of topping concrete layer lead significant effect to the tensile strength of concrete interface. The cohesion of interface between HyFRLWAC substrate and SCC topping layer also affected by these two variables.

The surface roughness of the concrete substrate and normal stresses that acting perpendicularly to the interface area causing significant influences on friction between two different concrete layers. Compressive stress lead to improvement of friction resistance between interface while tensile stress prompting reduction to the friction resistance of concrete interface.

More accurate prediction of concrete interfaces bond strength are proposed in Equation 8 and 9 which can be obtained by calculating its cohesion and friction based on the consideration of: 1) roughness condition of substrate surface; 2) the compressive strength of concrete overlay; 3) normal stresses that may occur, both compression and tensile which is acting perpendicularly to the interface due to external loading should also be considered.

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7015254: Minor Revision Required

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Togay Ozbakkaloglu <ace@hindawi.com> 26 Desember 2016 18.39
Balas Ke: moaz.abdulrahman@hindawi.com
Kepada: swidodo@uny.ac.id
Cc: togay.ozbakkaloglu@adelaide.edu.au

Dear Dr. Widodo,

Following the review of your Research Article titled "Bond Strength between Hybrid Fiber Reinforced Lightweight Aggregate Concrete Substrate and Self-Compacting Concrete as Topping Layer," by Slamet Widodo, I recommend that it should be revised taking into account the changes requested by the reviewer(s). Please login to the Manuscript Tracking System to read the submitted review report(s) and submit the revised version of your manuscript not later than Monday, January 09, 2017.

To submit your revised manuscript, please access "Current Manuscripts" in your account and upload the PDF file of your revised manuscript. You are also asked to submit your replies to the reviewer(s) comments as an additional PDF file.

Best regards,

Togay Ozbakkaloglu
togay.ozbakkaloglu@adelaide.edu.au

Moaz Abdulrahman <moaz.abdulrahman@hindawi.com> 27 Desember 2016 18.42
Kepada: swidodo@uny.ac.id

Dear Dr. Widodo,

With reference to the email below, I know that the deadline of receiving the revised version of manuscript 7015254 is January 09, 2017. However, it would be appreciated if you could submit it within the coming 5 days in order to be able to accelerate its review process as much as possible to avoid any delay.

Your prompt action would be appreciated.

Best regards,

Moaz

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Moaz Abdulrahman
Editorial Office
Hindawi Publishing Corporation
http://www.hindawi.com/
****

[Kutipan teks disembunyikan]

Hindawi

7015254.v2 (Research Article)

Title	Bond Strength between Hybrid Fiber Reinforced Lightweight Aggregate Concrete Substrate and Self-Compacting Concrete as Topping Layer
Journal	Advances in Civil Engineering
Issue	Regular
Manuscript Number	7015254 (Research Article)
Resubmitted On	2016-12-06
Author(s)	**Slamet Widodo**
Editor	Togay Ozbakkaloglu
Status	Minor Revision Required

No.	Review Report
3	Read
4	Read

Manuscript Versions

View Version 3
View Version 2
View Version 1

UNIVERSITAS NEGERI YOGYAKARTA

- swidodo <swidodo@uny.ac.id>

7015254: Your manuscript has been accepted

1 pesan

Togay Ozbakkaloglu <ace@hindawi.com> 4 Januari 2017 21.23
Balas Ke: moaz.abdulrahman@hindawi.com
Kepada: swidodo@uny.ac.id
Cc: togay.ozbakkaloglu@adelaide.edu.au

Dear Dr. Widodo,

The review process of Research Article 7015254 titled "Bond Strength between Hybrid Fiber Reinforced Lightweight Aggregate Concrete Substrate and Self-Compacting Concrete as Topping Layer" by Slamet Widodo submitted to Advances in Civil Engineering has been completed. I am pleased to inform you that your manuscript has now been accepted for publication in the journal.

The publication process of your manuscript will be initiated upon the receipt of electronic files. Please log in to the Manuscript Tracking System at the link below using your username and password, and upload the electronic files of your final accepted version within the next 2-3 days.

http://mts.hindawi.com/author/7015254/upload.files/

The electronic files should include the following:

1- Source file of the final accepted manuscript (Word or TeX/LaTeX).
2- PDF file of the final accepted manuscript.
3- Editable figure files (each figure in a separate EPS/PostScript/Word file) if any, taking into consideration that TIFF, JPG, JPEG, BMP formats are not editable.

Thank you again for submitting your manuscript to Advances in Civil Engineering.

Best regards,

Togay Ozbakkaloglu
togay.ozbakkaloglu@adelaide.edu.au

7015254.v3 (Research Article)

Title	Bond Strength between Hybrid Fiber Reinforced Lightweight Aggregate Concrete Substrate and Self-Compacting Concrete as Topping Layer
Journal	Advances in Civil Engineering
Issue	Regular
Manuscript Number	7015254 (Research Article)
Resubmitted On	2017-01-02
Author(s)	**Slamet Widodo**
Editor	Togay Ozbakkaloglu
Status	Published

Manuscript History

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View Version 1