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Research Article

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

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Structural performance evaluation of composite concrete slabs that were constructed using partially precast concreting system which utilized Hybrid Fiber-Reinforced Lightweight Aggregate Concrete (HyFRLWAC) as stay in-place formwork and self-compacting concrete (SCC) as topping layer was 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 bisurface shear test, and dual L-shaped shear test was 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 acting 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 acting perpendicularly on the concrete interface area. Proposed formulation for bond strength prediction between HyFRLWAC as substrate and SCC as topping layer is also presented in this paper.

1. Introduction

1.1. Background. Nowadays, composite concrete structures are widely implemented for construction works in accordance with the rapid development of concrete construction industry. 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 construction can be found in application of partial depth precast concrete construction, in which the precast concrete is used as stay in-place formwork while cast in-place concrete is used for topping layer. The expected benefits from the application of partially precast concrete systems include saving cost component for formwork and scaffolding as well as labor costs, better quality control, faster construction period, and minimizing the weather constraints during the implementation of construction works.

Partially precast concrete applications utilizing Hybrid Fiber-Reinforced Lightweight Aggregate Concrete (HyFRLWAC) are expected to provide more significant benefits as it has lower self-weight when compared to normal weight concrete. Therefore, the installation process becomes easier and faster, and the dead-load acting on the structural system can be reduced. In this research, pumice breccia which can be found abundantly in Indonesia is proposed to be utilized as lightweight coarse aggregate to produce a lighter stay in-place formwork. Pumice breccia is a type of coarse grained pyroclastic sedimentary rock which has a relatively low density and low mechanical strength. Crushed pumice breccia has a dry-loose bulk density of less than 1000 kg/m^3; therefore, it 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 ranges between 55% and 75% to the total volume of aggregate [1].

Fibers addition into concrete mixture is mainly aimed at increasing 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 which are added to the concrete by combining different types of fibers using polypropylene (PPF) and steel fibers (SF) are expected to provide better performance of concrete to resist the micro- and macrocrack caused by the shrinkage of concrete and also by the action of mechanical load. Moreover, the existence of microfiber is expected to increase the pull-out strength of the macrofiber. The compressive strength of lightweight concrete can be improved proportionally up to 22% when the hybrid polypropylene-steel fiber is added with the combination of 0.1% PPF and 1.0% SF which 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% when the hybrid polypropylene-steel fiber is added with the combination of 0.1% PPF and 1.5% SF which 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 it will be suitable to be used for the topping layer of composite flooring system which is relatively thin. SCC is also highly pumpable (easily pumped to reach casting location) so as to facilitate and speed up the construction work, as well as minimizing labor requirements. The use of normal vibrated concrete in thin layers of topping 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 act 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 another special concrete (e.g., high strength concrete, lightweight concrete, fiber-reinforced concrete, and 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 composed of 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 be influenced by several factors, that is, the cleanliness of the surface of the substrate from contaminating substances 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, 7].

The interfacial bond strength is closely related to the compressive strength of concrete overlay. Previous researcher verified significant indications that silica fume addition to the mixture of concrete overlay can improve the bond strength of the concrete interface [8]. The bond strength also tends to increase in accordance with the increasing compressive strength of concrete overlay. The ratio between the interfacial bond strength to the compressive strength of concrete overlay is approximately 0.05 to 0.10. The ratio tends to decrease when compressive strength of concrete overlay was increased [9].

Several other researchers have focused on investigating the contribution of shear connector to the interfacial 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 component that may contribute to the bond strength of concrete interface, for both high strength concrete [10] and normal concrete for the construction of precast concrete [11].

This research was conducted to provide recommendation 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 conditions 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 acts 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 the requirements in the Indonesian National Standards of SNI 0302:2014 [12]. The chemical compounds of the pozzolanic Portland cement are presented in Table 1.

In this research, the coarse aggregate for HyFRLWAC mixture utilizes 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

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

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 aggregate (sand)	538.52
Viscoflow	4.70
Plastiment VZ	0.70
Polypropylene	0.90
Steel fiber	67.00

density of 1620 kg/m^3 satisfying the technical specification of lightweight aggregate in ASTM C330 [13]. The coarse aggregates with maximum size of 20 mm were prewetted and submerged in water for 24 hours and then air-dried to be in saturated surface dry condition before the mixing process. Well-graded natural sand with specific gravity of 2.65 kg/dm^3 was employed as the fine aggregate. Silica fume and naphthalene formaldehyde sulfonate based high range water reducer (HRWR) which complies with ASTM C494-92 Type F were also utilized as concrete admixture, respectively.

HyFRLWAC mixture was prepared by combining 0.1% volume fraction of polypropylene fiber (PPF) and 1.0% of steel fiber (SF). In this research, a monofilament type of polypropylene with 18 μm diameter, 12 mm length, and 0.91 g/cm^3 density was used. Polypropylene was chosen due to its inexpensive, inert high pH cementitious environment and also because it is easy to disperse. Steel fiber was chosen as the macrofiber based on its proven ability on the energy absorbing mechanism (bridging action) and its ease to be found in the construction market. The steel fiber that was added to the lightweight concrete mixture was a type of hooked-end steel fiber with 60 mm length and 0.75 mm diameter. HyFRLWAC was cast as substrate layer which will be overlaid with SCC as topping layer.

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

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, that is, as-placed and grooved, in both the longitudinal and transverse directions. Resulted surface condition of substrate layers can be observed in Figure 1.

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

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

2.2. Tests Set-Up. The tensile strength between HyFRLWAC and SCC was tested using pull-off test method based on ASTM C1583 [14]. The specimens were prepared for two different surface conditions that were as-placed and grooved substrate surfaces, and then five different SCC mixtures were cast on the top of substrate layers; thus, there were 10 variants tested for the tensile strength of concrete interface. Each variant was represented by three specimens; therefore, the total specimens number was 30 which were used for direct pull-off test. The concrete layer was partially drilled with 50 mm of diameter through the overlay layer and approximately 20 mm into the substrate concrete. The surface of overlay layer was bond with metal disc using-rapid set epoxy, and the pull-off device was applied at a constant rate so that the tensile stress increases at a rate of 35 ± 15 kPa/s (5 ± 2 psi/s). Finally, the failure load and the failure mode were recorded. The test set-up was documented in Figure 2.

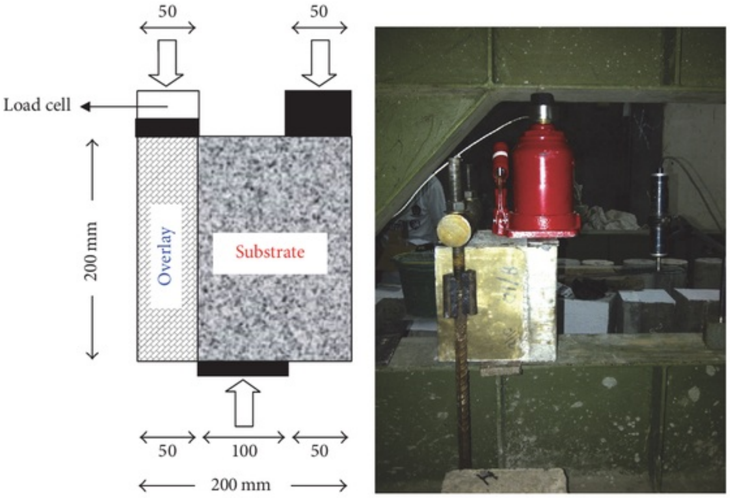
The cohesion on interfacial bond between substrate and overlay concrete was evaluated using modified bisurface shear test that was developed based on the bisurface shear method which was proposed by Momayez et al. in 2005 [8]. Modified bisurface shear strength was conducted on 15 variants. The condition of the substrate surface was prepared in a smooth condition (as-placed) and grooved in longitudinal and transverse direction. The overlay concrete constitutes one-fourth of the specimen. In other words, using 200 mm cube forms, prisms with a base size of 150 × 200 mm and a height of 200 mm were cast as substrate concrete; the overlay concrete was cast in prisms with a base of 200 × 50 mm and a height of 200 mm and bonded to the concrete substrate. The loading on these specimens causes a shear failure. The concrete was manufactured in the laboratory using concrete mixer and was cast in lubricated steel forms. When necessary, Styrofoam was used to form the blockouts and preparing space for overlay concrete layer. Substrate specimens were removed from the forms 24 hours after casting and they were cleaned from any extra dust or particles. The substrate concrete specimens were submerged in water until the age of 28 days. The contact surface of specimens was recleaned using a wire brush and high-pressure air a few hours before casting the overlay concrete using SCC with five different compressive strength values as the topping layer. In total, there were 45 specimens assessed using modified bisurface shear test since each variant was represented by three specimens. Details of specimens and test set-up can be observed in Figure 3.

TABLE 3: Mixtures proportions 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
w/c ratio		0.70	0.55	0.43	0.35	0.33


(a) (b)

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



(a) (b)

FIGURE 3: (a) Dimensions of specimens and (b) modified bisurface shear test.

Table 4: Pull-off test results.

Average compressive strength of SCC topping (MPa)	Tensile bond strength of as-placed substrate surface (MPa)	Failure location	Tensile bond strength of grooved substrate surface (MPa)	Failure location
31.30	1.05	Interface	1.20	Interface
	0.96	Interface	1.18	Interface
	0.97	Interface	1.27	Interface
34.51	1.26	Interface	1.46	Interface
	1.21	Interface	1.50	Interface
	1.18	Interface	1.41	Interface
42.99	1.39	Interface	1.68	Interface
	1.37	Interface	1.63	Interface
	1.40	Interface	1.78	Interface
51.66	1.69	Interface	1.89	Interface
	1.56	Interface	1.95	Interface
	1.59	Interface	2.05	Interface
61.85	1.89	Interface	2.13	Substrate
	1.91	Interface	2.17	Substrate
	1.83	Interface	2.08	Substrate

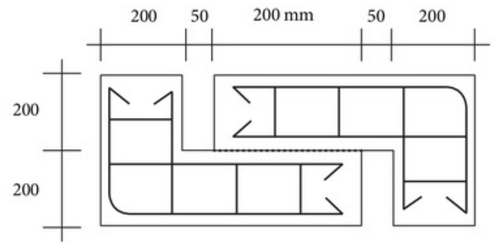


Figure 4: Detailed dimensions of specimens for double L-shaped shear test.

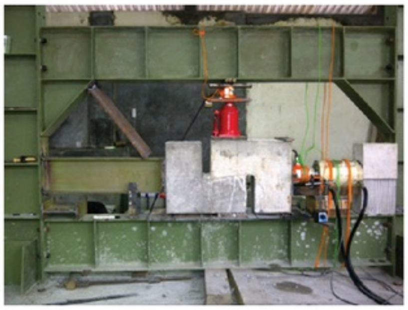


Figure 5: Double L-shaped shear test.

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 variations with six variations of the magnitude of normal force). Each substrate surface condition, as-placed, longitudinally grooved, and transversally grooved surfaces, was examined using 18 specimens which consist of 12 specimens that were used for examination of the combination between shear and compression stresses; three specimens for pure shear stress evaluation and another three specimens were tested for tensile and shear stresses combination that were applied on the interfacial surface. Two L-shaped pieces of concrete (one representing the substrate concrete and the other one representing the overlay) are bonded together as shown in Figure 4. The first segment receives a proper cure along with surface preparation before placing the second L-shaped segment. The two segments must be cast such that the interface is within the plane of the applied load. As part of testing, slip at the interface is measured through a pair of displacement transducers. The measured load-slip relationship is used to ensure that the specimen is loaded concentrically. The bond strength is obtained by dividing the ultimate load by the bonded area. The load is applied at 1.35 kN per minute. Figure 4 shows the detailed dimensions of the specimen while Figure 5 shows the test set-up.

3. Results and Discussion

Test results indicate that the compressive strength of SCC that was used as topping layer on the lightweight aggregate concrete type of substrate layer will affect the interfacial tensile strength. Tensile strength of concrete interface that was examined using pull-off test method, for both as-placed and grooved surface conditions, is presented in Table 4.

Interfacial tensile strength, for both as-placed and grooved surface conditions, with 6 mm (1/4 inch) of roughness amplitude of substrate layer with different compressive strength of SCC that was cast on the top of fiber-reinforced lightweight aggregate concrete substrate can be observed in Figure 6.

Based on the results of the pull-off test, the maximum tensile strength of interface between fiber-reinforced lightweight

TABLE 5: Test results on interfacial cohesion with different substrate surface condition.

Average compressive strength of SCC topping (MPa)	Substrate surface condition					
	As-placed		Longitudinally grooved		Transversally grooved	
	Shear force (kN)	Interfacial shear strength (MPa)	Shear force (kN)	Interfacial shear strength (MPa)	Shear force (kN)	Interfacial shear strength (MPa)
31.300	95.40	2.39	118.20	2.96	122.90	3.07
	92.20	2.31	121.10	3.03	126.40	3.16
	91.90	2.30	122.60	3.07	125.10	3.13
34.505	98.70	2.47	123.80	3.10	126.80	3.17
	96.10	2.40	127.60	3.19	132.20	3.31
	96.80	2.42	124.30	3.11	130.70	3.27
42.990	101.70	2.54	125.20	3.13	133.60	3.34
	104.20	2.61	130.40	3.26	137.10	3.43
	103.90	2.60	128.30	3.21	135.40	3.39
51.663	110.70	2.77	137.60	3.44	142.20	3.56
	105.20	2.63	132.10	3.30	138.50	3.46
	104.90	2.62	131.80	3.30	136.90	3.42
61.845	114.80	2.87	135.40	3.39	140.80	3.52
	112.10	2.80	140.20	3.51	146.30	3.66
	109.60	2.74	137.30	3.43	144.20	3.61

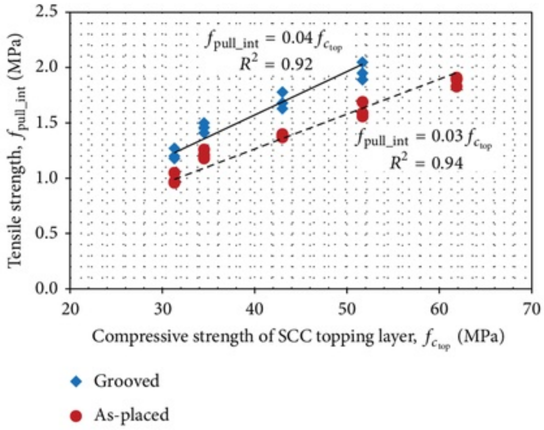


FIGURE 6: Interfacial tensile strength with different substrate surface conditions and different compressive strength of SCC topping layer.

aggregate concrete as substrate layer and SCC as a topping layer can be determined. The maximum interfacial tensile strength between lightweight concrete substrate and overlay concrete which utilize SCC that possesses compressive strength in the range between 30 MPa and 60 MPa as a topping layer can be expressed in (1), for the as-placed surface condition of the substrate layer.

$$f_{\text{pull\_as-placed}} = 0.03 f_{c_{\text{top}}}. \quad (1)$$

When the surface of substrate layer is prepared in grooved condition with 6 mm (1/4 inch) of roughness amplitude, the tensile strength between substrate and overlay concrete interfaces that utilize lightweight concrete as substrate layer and SCC that possesses compressive strength in the range between 30 MPa and 60 MPa as a topping layer can be expressed in

$$f_{\text{pull\_grooved}} = 0.04 f_{c_{\text{top}}}, \quad (2)$$

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

Cohesion of concrete interfaces that were examined using various compressive strengths of SCC which were cast as topping layer, for both as-placed and grooved surface conditions, is presented in Table 5.

The effect of SCC topping layer on the cohesion (shear strength without any influence of normal stress) of concrete interface between HyFRLWAC substrate and SCC topping, for as-placed, longitudinally grooved, and transversally grooved surface conditions, with 6 mm (1/4 inch) of roughness amplitude of substrate layer can be observed in Figure 7. Furthermore, the relationship between compressive strength of SCC topping layer and its interfacial cohesion when SCC is cast on the top of fiber-reinforced lightweight concrete substrate can be introduced in Figure 7, for both as-placed and grooved surfaces, in both longitudinal and transverse directions.

Considering the results of cohesion test (shear strength without any influence of normal stress), it can be determined the relation between compressive strength of SCC which was utilized as topping layer with the cohesion of fiber-reinforced lightweight aggregate concrete as substrate layer and SCC as a topping layer. Cohesion of interface between old concrete and new concrete that use SCC as a topping layer with the range

Table 6: Test results on interfacial shear bond strength with different substrate surface condition and various normal force which is acting perpendicularly to the interface area.

As-placed Stress (MPa)		Longitudinally grooved Stress (MPa)		Transversally grooved Stress (MPa)		Remarks
Normal	Shear	Normal	Shear	Normal	Shear	
0.00	2.58	0.00	3.39	0.00	3.57	—
0.00	2.71	0.00	3.44	0.00	3.73	—
0.00	2.86	0.00	3.38	0.00	3.59	—
0.66	3.17	0.62	3.50	0.67	3.89	Compression
0.74	2.97	0.52	3.68	0.72	3.96	Compression
0.70	3.12	0.50	3.85	0.51	3.98	Compression
1.02	3.36	1.19	3.84	0.99	4.38	Compression
1.06	3.21	0.99	3.82	1.12	4.74	Compression
1.05	3.20	1.13	4.20	1.17	4.66	Compression
1.68	3.50	1.47	5.12	1.73	4.99	Compression
1.64	3.44	1.63	4.81	1.51	5.23	Compression
1.49	3.50	1.65	5.45	1.42	5.12	Compression
2.02	4.20	2.15	5.72	2.07	6.40	Compression
2.03	4.52	2.15	5.56	2.20	6.10	Compression
2.15	4.52	2.13	5.52	2.13	7.25	Compression
0.14	2.11	0.19	2.72	0.14	2.87	Tension
0.18	1.94	0.16	2.44	0.12	2.90	Tension
0.20	1.69	0.20	2.26	0.14	2.65	Tension

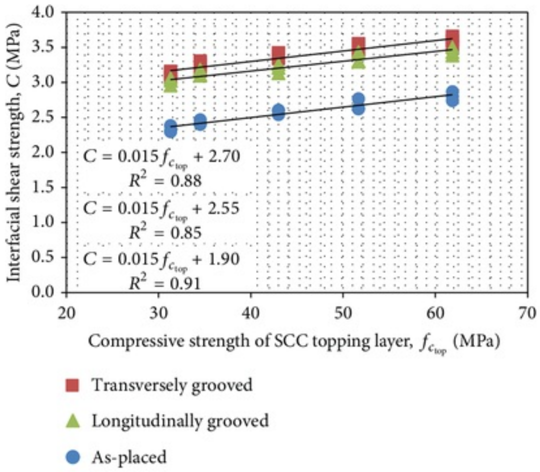


Figure 7: Effect of SCC topping layer compressive strength on the cohesion of interface with different substrate surface conditions.

of compressive strength between 30 MPa and 60 MPa can be expressed in (3), for the cases of as-placed surface condition of the substrate layer.

$$C = 0.015 f_{c_{\text{top}}} + 1.90. \tag{3}$$

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

$$C = 0.015 f_{c_{\text{top}}} + 2.55 \tag{4}$$

$$C = 0.015 f_{c_{\text{top}}} + 2.70, \tag{5}$$

where C is interface cohesion, that is, shear strength without any influence of normal stress (MPa), and $f_{c_{\text{top}}}$ is average compressive strength of SCC topping layer (MPa).

The effect of compressive normal force which acts perpendicularly to the interface area on the shear strength, for as-placed, longitudinally grooved, and transversally grooved surface conditions, with 6 mm (1/4 inch) of roughness amplitude of substrate layer can be observed in Figure 8.

Details of the test results on interfacial shear bond strength with different substrate surface condition and various normal forces which are acting perpendicularly to the interface area are presented in Table 6.

Figure 9 shows the relationship between normal force (compression and tension) which is acting perpendicularly to the interface area and the interfacial bond strength when SCC is cast on the top of fiber-reinforced lightweight aggregate concrete substrate.

Based on Figure 9, it can be identified that the increase of compressive normal force will lead to 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 9 also shows that the conditions of substrate surface and roughness direction also give effect to the interface strength. In accordance

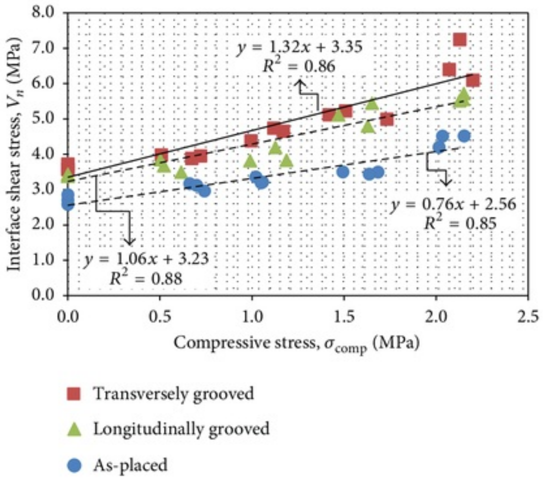


Figure 8: Effect of compressive stress on the shear strength of interface with different substrate surface conditions.

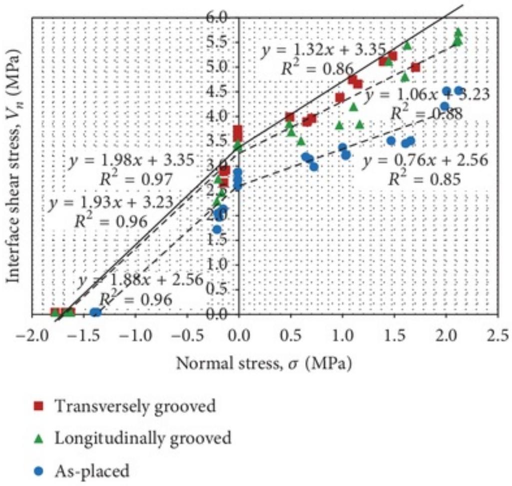


Figure 9: Effect of different normal (compression and tension) stress on the bond strength of interface between lightweight concrete substrate and SCC topping.

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 was 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

$$\mu = \frac{v_u - C}{\sigma_n}. \tag{6}$$

Based on test results and analysis, a formula can be proposed 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 composed of cohesion and friction between two layers of concrete can be expressed in (7) when the interface is subjected to compression stress which is acting perpendicularly to the interface area.

$$V_n = C + \mu\sigma_{\text{comp}}, \tag{7}$$

where V_n is interface shear strength (MPa); C is interface cohesion (MPa) which is equal to $0.015 f_{c_{\text{top}}} + 1.90$ for as-placed HyFRLWAC substrate surface, $0.015 f_{c_{\text{top}}} + 2.55$ for longitudinally grooved HyFRLWAC substrate surface, and $0.015 f_{c_{\text{top}}} + 2.70$ for transversally grooved HyFRLWAC substrate surface; μ is coefficient of friction which is equal to 0.72 for as-placed HyFRLWAC substrate surface, 0.95 for longitudinally grooved HyFRLWAC substrate surface, and 1.16 for transversally grooved HyFRLWAC substrate surface; and σ_{comp} is compressive stress (MPa).

Experimental results indicate that the existence of compressive stress which acts perpendicularly on the interface area tends to increase the interfacial bond strength, for both as-placed and grooved surfaces of substrate layer. The test results are in line with the proposed formula which is expressed in (7). On the other hand, (8) can be applied to predict the interfacial bond strength when there is tensile stress presence on the interface area.

$$V_n = C - k\sigma_{\text{tens}}, \tag{8}$$

where V_n is interface shear strength (MPa); C is interface cohesion (MPa) which is equal to $0.015 f_{c_{\text{top}}} + 1.90$ for as-placed HyFRLWAC substrate surface, $0.015 f_{c_{\text{top}}} + 2.55$ for longitudinally grooved HyFRLWAC substrate surface, and $0.015 f_{c_{\text{top}}} + 2.70$ for transversally grooved HyFRLWAC substrate surface; $f_{c_{\text{top}}}$ is average compressive strength of SCC topping layer (MPa); k is coefficient of friction which is equal to 3.42 for as-placed HyFRLWAC substrate surface, 4.12 for longitudinally grooved HyFRLWAC substrate surface, and 4.17 for transversally grooved HyFRLWAC substrate surface; and σ_{tens} is tensile stress (MPa).

The proposed formula reflects the experimental results which show that the influence of tensile stress perpendicularly to the interface will decrease the interfacial bond strength. For grooved surface, the degradation of the bond strength seems to be worse compared to as-placed surface.

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 significantly affect the tensile strength of concrete interface. The cohesion of interface between HyFRLWAC substrate and SCC topping layer is also affected by these two variables.

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

More accurate predictions of bond strength are proposed in (7) and (8) 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 tension acting perpendicularly to the interface.

Competing Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

References

[1] S. Widodo, I. Satyarno, and S. Tudjono, "Experimental study on the potential use of pumice breccia as coarse aggregate in structural lightweight concrete," *International Journal of Sustainable Construction Engineering and Technology*, vol. 5, no. 1, pp. 1–8, 2014.

[2] S. Widodo, I. Satyarno, and S. Tudjono, "Effects of hybrid polypropylene-steel fiber addition on some hardened properties of lightweight concrete with pumice breccia aggregate," *ISRN Civil Engineering*, vol. 2012, Article ID 475751, 8 pages, 2012.

[3] J. Silfwerbrand, "Shear bond strength in repaired concrete structures," *Materials and Structures*, vol. 36, no. 260, pp. 419–424, 2003.

[4] P. M. D. Santos and E. N. B. S. Júlio, "Interface shear transfer on composite concrete members," *ACI Structural Journal*, vol. 111, no. 1, pp. 113–121, 2014.

[5] Fédération internationale du béton (fib), fib Model code for concrete structures 2010, 2013, http://www.fib-international.org/fib-model-code-2010.

[6] M. E. Mohamad, I. S. Ibrahim, R. Abdullah, A. B. A. Rahman, A. B. H. Kueh, and J. Usman, "Friction and cohesion coefficients of composite concrete-to-concrete bond," *Cement and Concrete Composites*, vol. 56, pp. 1–14, 2015.

[7] H. Aysha, K. R. Ramsundar, M. Arun, and G. Velrajkumar, "An overview of interface behavior between concrete to concrete," *International Journal of Advanced Structures and Geotechnical Engineering*, vol. 3, no. 2, pp. 110–114, 2014.

[8] A. Momayez, M. R. Ehsani, A. A. Ramezanianpour, and H. Rajaie, "Comparison of methods for evaluating bond strength between concrete substrate and repair materials," *Cement and Concrete Research*, vol. 35, no. 4, pp. 748–757, 2005.

[9] H. Beushausen and M. G. Alexander, "Bond strength development between concretes of different ages," *Magazine of Concrete Research*, vol. 60, no. 1, pp. 65–74, 2008.

[10] L. F. Kahn and A. D. Mitchell, "Shear friction tests with high-strength concrete," *ACI Structural Journal*, vol. 99, no. 1, pp. 98–103, 2002.

[11] I. A. E. M. Shehata, L. C. D. Shehata, and E. C. G. De Mendonça, "Strength of shear keys used in pre-cast prestressed composite beams," *Materials and Structures/Materiaux et Constructions*, vol. 43, no. 5, pp. 675–685, 2010.

[12] SNI, "Semen portland pozolan," SNI 0302:2014, Badan Standarisasi Nasional, 2014 (Indonesian).

[13] ASTM C330/C330M-14, *Standard Specification for Lightweight Aggregates for Structural Concrete*, ASTM International, West Conshohocken, Pa, USA, 2014 https://www.astm.org/.

[14] ASTM, "Standard test method for tensile strength of concrete surfaces and the bond strength or tensile strength of concrete repair and overlay materials by direct tension (Pull-off Method)," ASTM C1583/C1583M-13, ASTM International, West Conshohocken, Pa, USA, 2013.

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