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FLEXURAL BEHAVIOR OF COMPOSITE CONCRETE SLABS USING HYBRID FIBER REINFORCED LIGHTWEIGHT CONCRETE SUBSTRATE AND SELF-COMPACTING CONCRETE TOPPING

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ABSTRACT

This research is aimed to observe and analyze the flexural behavior of composite concrete slab that constructed using Hybrid Fiber Reinforced Lightweight Concrete (HyFRLWC) for stay in-place (SIP) formwork then overlaid with self-compacting concrete (SCC) for topping layer. The study was focused to observe and evaluate the constructed one-way slabs whether its failure mainly caused by bending moment or interface failure between the two layer of concrete materials (HyFRLWC as the substrate layer with SCC topping) without any shear connector. The experiment was carried out with full-scale testing of the six composite concrete slabs. The slabs prepared in smooth substrate surface conditions (as-placed) and roughened in longitudinal direction and the bending test using two points loading was carried out on three full scale slabs for each variant. All slabs were made with dimensions of 800 mm in width, 3200 mm in length and 120 mm in thickness. Physical model tests and the stress analysis results showed the failure mainly caused by bending failure, and none of the specimens collapsed due to interface failure. SCC that casted as topping layer can adhere well to the HyFRLWC substrate and the composite slab is capable to act monolithically in dealing with flexural loads.

Key words: Composite concrete slab, Flexural behavior, Hybrid fiber-reinforced lightweight concrete, Self-compacting concrete.

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1. INTRODUCTION

Composite structures are widely applied to construction work. This condition is corresponding with the rapidly growing concrete construction industry that mainly used to support infrastructure development in recent decades. This kind of structure uses at least two types of concrete which possesses different physical and/or mechanical characteristics so that the cross-sectional area composed by two or more concrete layers. Composite concrete can be easily identified in the partially precast construction, where precast concrete is installed for stay-in-place (SIP) formwork while cast in-place concrete is utilized for topping layer. Significant advantages that can be expected from partially precast concrete structures include: reduction of formwork and scaffolding installation cost that directly imply to the labor cost efficiency, ease the quality control in the site, site management becomes more simple, shorter construction period, and delay time of the construction due to weather conditions can be avoided [1-2].

In this research, Hybrid Fiber Reinforced Lightweight Concrete (HyFRLWC) is tested and utilized as lightweight SIP formwork to generate more significant advantages because it has lower self-weight when compared with normal weight concrete. The transportation, handling and installation process can be expected to becomes easier and faster, and the dead-load that supported by the lower structural elements can be reduced when lightweight SIP formwork used for construction of partially precast concrete structures. In order to produce lightweight SIP formwork, pumice breccia which is widely available in Indonesia is evaluated and adopted as an alternative of lightweight aggregate then utilized for structural lightweight concrete. Pumice breccia can be defined as a kind of coarse grained pyroclastic sedimentary rock that possesses low density and also low mechanical strength. It has a dry-loose bulk density which is less than 1000 kg/m^3 thus allows it to be categorized as lightweight aggregate. Structural lightweight concrete requirements can be met when the mixture utilizes crushed pumice breccia for the coarse aggregate with its volume fraction is between 55% up to 75% of the total aggregate volume [3].

HyFRLWC was utilized as SIP formwork to achieve better performance of lightweight concrete. Fibers addition are mainly intended to inhibit the emergence of cracks that is possible to occur in concrete during construction stages and its service life [4-5]. The existence of fibers in concrete mixture may also provide better bond performance between the reinforcing bar with its surrounding lightweight concrete [6]. Hybrid fibers addition which is applied in concrete mixtures by combining different kinds of fibers that utilizing polypropylene fibers (PPF) and steel fibers (SF) are intended to improve the concrete performance when resisting micro and macro-crack that caused by shrinkage and stresses due to applied mechanical load. Moreover, the existence of micro-fiber is aimed to enhance the pull-out strength of the macro-fiber. The compressive strength of pumice breccia lightweight concrete could be increased up to 22% when added with hybrid polypropylene-steel fiber. It is proportional to the dosage of fiber addition until an optimum proportion of 0.1% PPF and 1.0% SF but it then tends to decline but remain showing better performance compared with non-fiber lightweight concrete. The flexural strength of fiber-reinforced lightweight concrete can also achieve a significant improvement up to 187% in case of hybrid polypropylene and steel fiber is added in a combination of 0.1% PPF mixed with 1.5% SF [7].

Application of self-compacting concrete (SCC) may offer some significant benefits due to its highly flow-able and self-compactable characteristic in fresh state, thus it requires no compaction in concreting works [8-9], and therefore it will be ideal to be applied as topping layer in composite concrete floors which is relatively thin. SCC is also highly pump-able (easily pumped to the casting location) that will facilitate and accelerate the construction stages, as well as to reduce the needs of manpower. Utilization of normal vibrated concrete as a thin layer concrete topping may cause difficulties in pumping and compaction of fresh concrete and later on lead to high risk of cavity that may occur in the interface area.

In general, structural systems are expected to work monolithically. Therefore, the bond between two layers of concrete that are used will be a very decisive factor. In composite concrete structures, the emergence of early cracks and delamination on interface concrete area should be avoided. Once the structure is utilized, the effects of structural loads that can cause separation between two layers of concrete in the composite concrete structures are mainly consist of the shear and tensile force which acts along the interface. Therefore, it should be well analyzed and anticipated [10-11].

The rapid development of current technology allows consultants and contractors to construct composite concrete that combines normal concrete with any kind of special concrete type, 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 achieve better structural performance. Utilization of different concrete types may lead to different results of bond strength between the two layers of composite concrete. The load transfer mechanisms that may occur at the concrete interface are consist of cohesion, friction, and dowel action. Tests result which is related to the interface bond strength between HyFRLWC and SCC has been reported in a previously published research paper. Interface bond strength between its topping and substrate layer with no shear connector can be calculated by analyzing its cohesion and friction based on the circumstances of 1) roughness condition of substrate layer; 2) compressive strength of its concrete topping; 3) normal stresses whether compressive or tensile which may occur and acts in the interface [12].

This research is aimed to observe and evaluate the structural performance of proposed composite flooring system that using two layers of special concrete with different ages (HyFRLWC as substrate and SCC as topping layer), with different conditions of the substrate surface (smooth/as-placed and roughened/grooved in longitudinal direction). It expected to be developed further and implemented for partially precast flooring slabs. In this stage, the experiments are focused on: (1) examining failure mode of the proposed slab system and (2) evaluating whether the failure mainly caused by bending failure or interface failure between the two types of special concrete materials (HyFRLWC as the substrate layer with SCC topping) without any shear connector.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

2.1. Materials

The concrete mixtures in this research were prepared using Portland Pozzolana Cement (PPC) which meets the requirements in the Indonesian National Standards of SNI 0302:2014 [15]. PPC was chosen because it helps to produce more cohesive concrete and is less prone to segregation and bleeding. The composition of chemical compounds in the PPC that used in this research are explained in Table 1.

Table 1 Chemical composition of Portland Pozzolana Cement (PPC)

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 that used for HyFRLWC mixture was a crushed pumice breccia that continuously graded with the maximum aggregate size of 20 mm and taken from Bawuran area, Pleret district, Bantul regency that is located in the Special Region of Yogyakarta, a southern part of the island of Java. It is one of the largest quarry areas of pumice breccia that can be found Indonesia. This aggregate has a dry-loose bulk density of 760 kg/m^3 and particle density of 1620 kg/m^3 which is met to the technical requirements of lightweight aggregate based on ASTM C330 [16]. This coarse aggregate that having 10.23% of water absorption was then pre-wetted by submerged it into a soaking tub for at least 24 hours and then air-dried to achieved a saturated surface dry condition before the mixing process started. Well-graded natural sand with a specific gravity of 2.65 kg/dm^3 and 2.04% water absorption was used as the fine aggregate. Silica fume that complies to ASTM C-1240 with 94.7% content of silicon dioxide, and naphthalene formaldehyde sulfonate-based superplasticizer which complies ASTM C494-92 Type F were also utilized as the concrete admixture.

HyFRLWC for substrate layer was a structural lightweight concrete that is added with hybrid fiber in a combination of 0.1% volume fraction of PPF and 1.0% of SF. Polypropylene monofilament fiber type with 0.91 g/cm^3 of density, 12 mm length and 18 µm diameter were used as the micro fiber. Polypropylene was chosen based on the reasons that it is available in affordable price, inert in high pH cementitious environment, and its ease to disperse. Steel fiber was used as the macro fiber due to its proven ability in improving the mechanism of energy absorbance (bridging action), and widely available in the construction market. The macro fiber that was added into the lightweight concrete mixture was a hooked-end type of steel fibers which have a measurement of 60 mm in length and 0.75 mm of diameter. HyFRLWC then used as SIP formwork and overlaid with SCC after 28 days.

Mixtures composition of HyFRLWC were calculated and obtained based on the previous research works [7, 13-14]. Details of its mixture proportion that prepared in saturated surface dry (SSD) condition of aggregates and resulting 20.14 MPa of average compressive strength with 1874 kg/m^3 of density can be observed in the following Table 2.

Table 2 Mixture proportion of HyFRLWC 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

After the process of mixing, fresh concrete casted into the formwork and the surface was prepared based on the experimental design to obtain representative test variants, i.e. as-placed, and longitudinally roughened. The surface appearance and condition of the substrate layers can be observed in Figure 1.

Figure 1. Difference of substrate surface conditions between as-placed and longitudinally roughened with 6 mm of roughness amplitude

Topping concrete was casted onto the substrate layer after 28 days. Normal weight self-compacting concrete (SCC) was utilized as the topping layer. The mixture was prepared based on proposed method which is capable for proportioning SCC mixtures to meet specified compressive strength [9]. The SCC topping has a compressive strength of 43 MPa and 2287 kg/m^3 density, produced with a water/cement (W/C) ratio of 0.43, and having average slump flow of 560 mm. Composition of the normal weight self-compacting concrete (SCC) with SSD aggregates that was used in this test can be seen in Table 3.

Table 3. Mixtures proportions of SCC as topping layer

Material		(kg/m^3)
Water	(kg)	171.50
Portland cement	(kg)	398.80
Limestone powder	(kg)	133.10
Coarse aggregate (crushed stone)	(kg)	806.00
Fine aggregate (sand)	(kg)	762.80
Viscoflow	(kg)	2.40
Plastiment VZ	(kg)	0.60
Average compressive strength	(MPa)	42.99
w/c ratio		0.43

2.2. Tests Set-up

Full-scale tests were implemented on one-way slabs of composite concrete to observe and collect data that related to the investigation of the cracking moment, maximum moment, deflection, and crack pattern or failure mode of the slabs. This test is focused on the examination of the failure mechanism of the concrete slabs whether the damage is caused by the bending load that preceded by the occurrence of slip on the interface between those two concrete layers, or it is mainly caused by bending failure. Stress analysis with numerical model was also done based on the physical model test data as a comparison to the criteria of interface bond strength resulted from the previous research stage. Set up of full-scale one-way slabs test using a two points loading test method can be observed in **Figure 2** and **3** as follows.

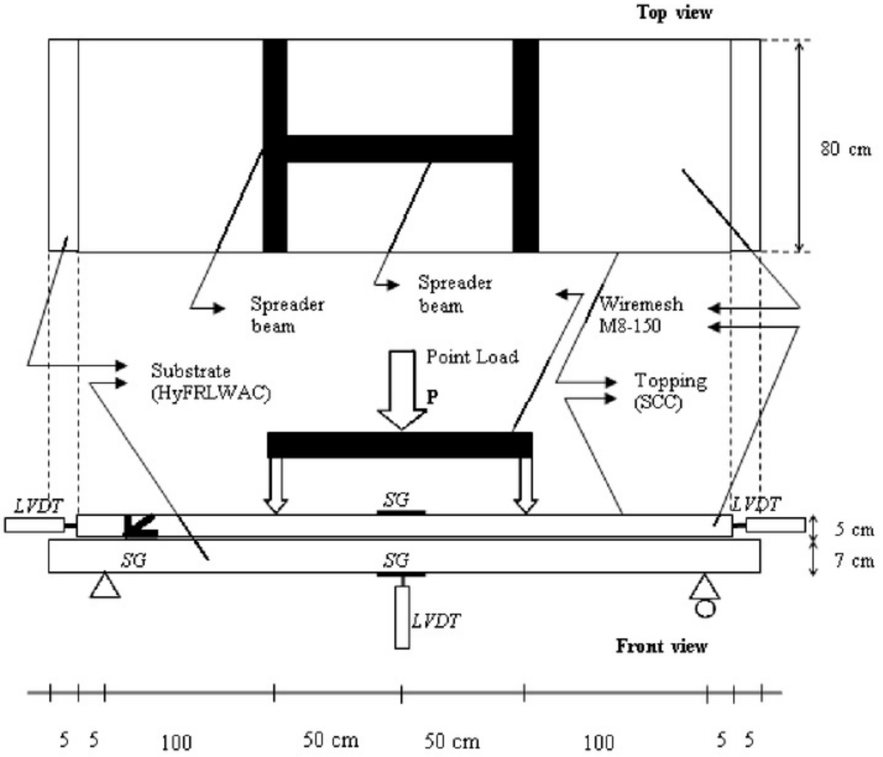

Figure 2 Setting of instrumentations in full scale two points loading test

Figure 3 Flexural test setup of the composite concrete slab

3. RESULTS AND DISCUSSION

The summary and detail results of flexural test on the concrete composite slabs which have been conducted based on two-point loading method are shown in Table 4, Figure 4, 5, 6, and 7 respectively.

Table 4 Summary of flexural test results on the concrete composite slab

Specimen Code	**First-crack load**	**Max Load**	**Weight of instruments**	**Self-weight**	**First-crack moment**	**Max moment**	**Failure mode**
	(kN)	*(kN)*	*(kN)*	*(kN/m)*	*(kN.m)*	*(kN.m)*	
S1	10.044	11.664	0.700	2.010	7.633	8.443	Bending, no slip
S2	9.820	12.150	0.700	2.010	7.521	8.686	Bending, no slip
S3	10.044	11.826	0.700	2.010	7.633	8.524	Bending, no slip
LR1	9.820	12.150	0.700	2.010	7.521	8.686	Bending, no slip
LR2	10.692	12.312	0.700	2.010	7.957	8.767	Bending, no slip
LR3	10.530	11.502	0.700	2.010	7.876	8.362	Bending, no slip

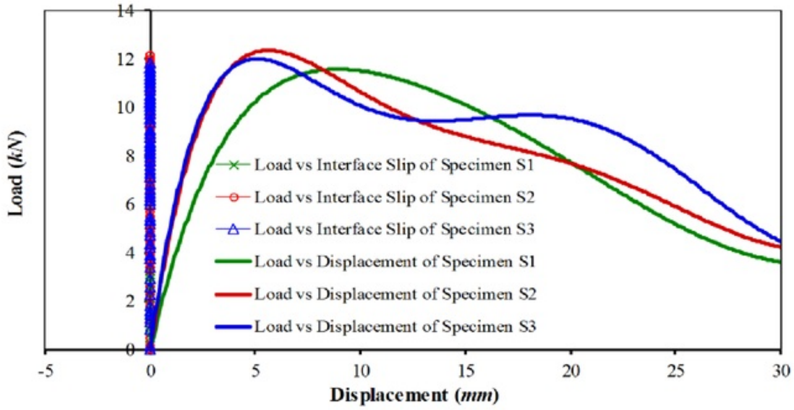

Figure 4. Relations of load-deflection, and load-interface slip of composite concrete slab that using substrate with as-placed surfaces

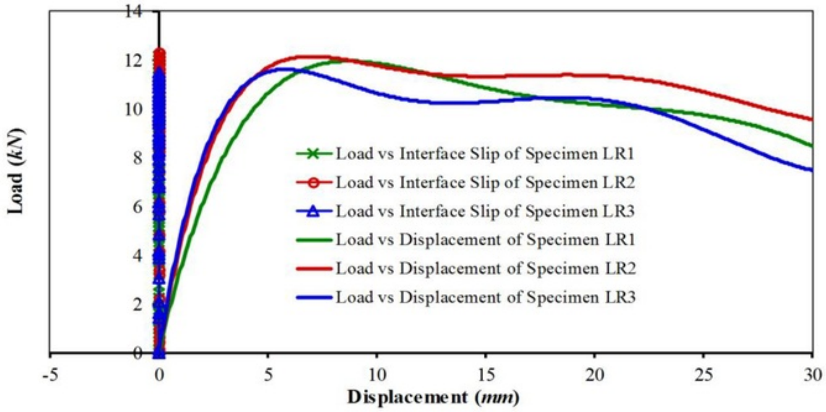

Figure 5. Relations of load-deflection, and load-interface slip of composite concrete slab that using substrate with longitudinally roughened surfaces

Figure 6. Crack pattern of composite concrete slab that using substrate with as-placed surfaces

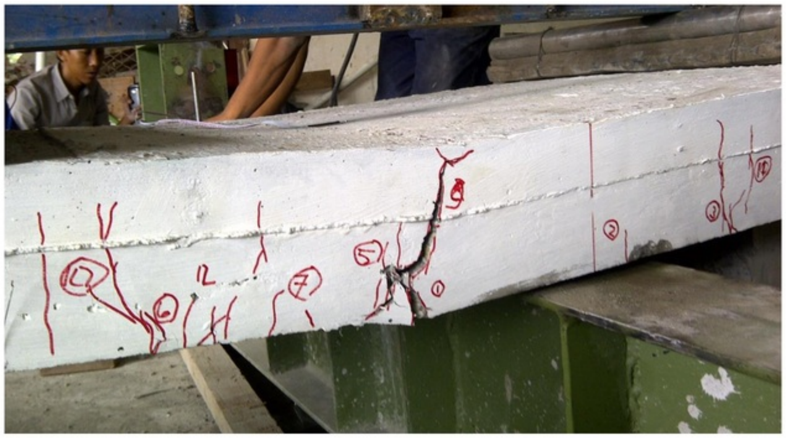

Figure 7. Crack pattern of composite concrete slab that using substrate with longitudinally roughened surfaces

Based on the observed experimental results, the failure that occurred on the six composite one-way slab test specimens shows that bending failure occurs in the mid-span area which is in line to the initial prediction in the research design. The pattern of cracks that occurred showed no damage occurred in the composite concrete interface area. The cracks begin from the lower side of the composite slab and then spread vertically from the substrate layer through the continuous interface area to the topping layer without any propagation in the horizontal direction in the interface area. This condition indicates that on composite slab test specimens shows its ability to withstand the designed load when constructed with two different types of special concrete and poured over a 28-day interval, and the composite concrete slabs did not suffer any damage in the interface area.

Numerical modelling that aimed to analyze the stress distribution on the concrete interface layer is also done as a comparison against the experimental test results that have been completed on the physical models. The result of the stress analysis shows that there are no stresses in the interface of concrete composite slabs exceed the limit of the interface bond strength. The numerical model and results are shown in following Figure 8 and 9.

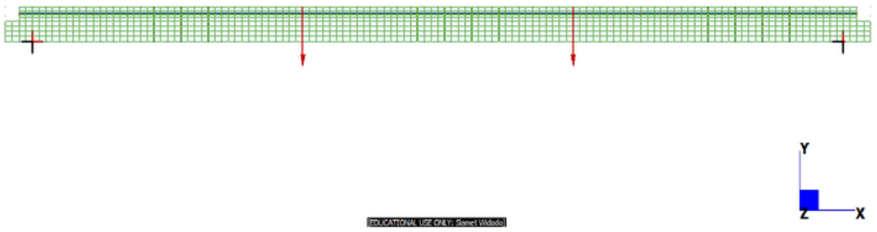

Figure 8. Finite element model of composite concrete slab using Strand7 software

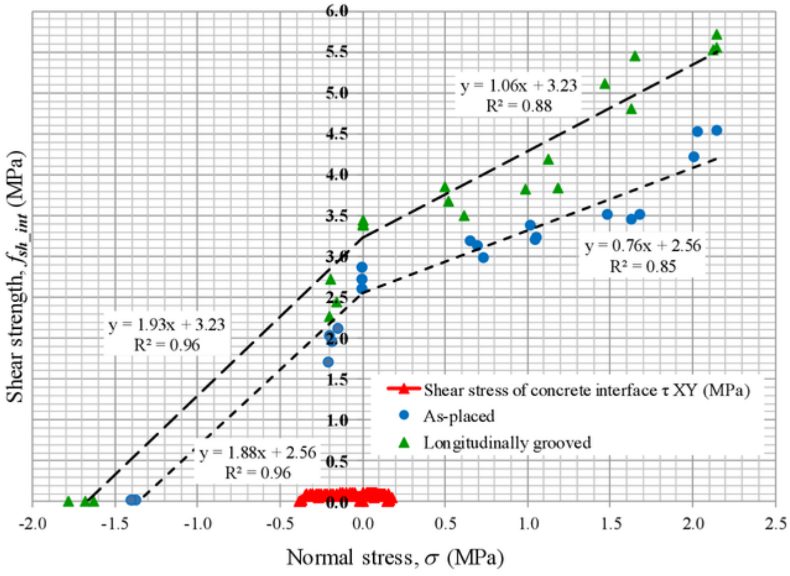

Figure 9. Stress distribution in the interface area compared to the limit of interface bond strength

Based on above results, it can be concluded that there is no slip on the interface of composite concrete slabs. The result of the stress analysis also indicates that there are no composite concrete slabs subjected to any combination between shear and normal stresses that exceed the limit of the interface bond strength. These results are in line with a previous study that reported when the bending test was carried on composite slabs that using normal concrete for substrate and steel fiber reinforced concrete for its topping, it showed that interface slippage can be observed in all of the specimens; however, none failed at the interface [17]. The experimental results on composite concrete slabs in this research that utilized HyFRLWC for substrate layer and SCC as its topping shows there was no slip between the substrate and its topping. The composite slabs show monolithic action when dealing with applied flexural loads, better interface bond strength can be observed due to the fresh state of SCC that possess high flowability, high segregation resistance, nearly self-leveling and consolidate by its own self-weight.

4. CONCLUSIONS

The result of stress analysis is in line with the results from the physical model test of the full scale composite concrete slabs in investigating the bending failure on the six test specimens of composite concrete slabs. Both physical and numerical model indicates that there is no occurrence of slip on the interface of two-layer concrete with different ages. Based on the results of experimental works and stress analysis that been completed, it can be concluded that SCC was able to adhere well in the substrate layer of composite concrete.

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