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ASSESSMENT OF THE CONTENT OF STONE FINE POWDER AND RAW RICE HUSK IN HIGH-PERFORMANCE LIGHTWEIGHT RICE HUSK CONCRETE BLOCKS

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ABSTRACT: Stone fine powder (SFP) as a solid by-product of the stone-cutting industry and raw rice husk (RRH) as a large-tonnage waste left from rice production often cause land pollution in the surrounding areas. This research aims to investigate the optimal use of SFP and RRH as raw materials in the manufacturing of lightweight material of SFP-based rice husk concrete blocks (RHCBs) associated with the different performances of RHCBs. The RHCBs were composed of three materials: cement (binder), SFP, and RRH. To assess their performances, samples were grouped into three batches of binder-RRH ratios and in each batch, there were six binder-SFP ratios, resulting in a total of 18 concrete mixes. The results have revealed that the increase of the SFP content in concrete mixture significantly enhances the density and compressive strength of SFP-based RHCBs, due to their denser structure. This best synergetic ratio in a lightweight concrete mixture of SFP-based RHCB is 1 binder : 1 SFP : 3 RRH, with a density of around 1,345.27 kg/m^3 and a compressive strength of approximately 2.80 MPa. The findings will contribute to the forthcoming paradigm shift of using SFP and RH in concrete, which will decrease the environmental impacts.

Keywords: Stone Fine Powder, Raw Rice Husk, Concrete Blocks, Density, Compressive Strength

1. INTRODUCTION

Indonesia is well known for its several active volcanoes with frequent eruptions, spouting large amounts of sand and stone. These materials are typically used as construction materials for several applications, such as floor tiles and garden decorations. For example, among the four regencies surrounded by Mount Merapi on Java Island, Sleman Regency currently has more than 17 companies specializing in stone cutting [1].

However, the stone-cutting industry generates large quantities of solid wastes such as stone fine powder (SFP), a by-product generated during the manufacturing stage including sawing, cutting, polishing, and finally finishing processes. SFP was left in the form of sludge waste (fine powder mixed with water in a semi-liquid state) and dried out during the dry season. SFP is a non-biodegradable waste and one of the main sources of solid waste in the stone-cutting industry. Approximately 170 tonnes of SFP are generated every month in the Sleman Regency. The accumulation of SFP triggers land and air pollution in the surrounding areas, posing risks to people and vegetation.

In fact, the demand for natural sand to be used as fine aggregates in construction applications is rapidly increasing. Therefore, utilizing SFP can alter as partial replacements for natural sand in these applications and also can reduce the over-exploitation of natural river sand. Previous studies [2-5] have revealed SFP can perform as fine aggregates made of natural stones. They are regarded as chemically inactive and are primarily used in concrete mixtures to increase the proportion of fine cement matrix and enhance workability [4]. Besides the SFP, Indonesia, as an agricultural-producing country, generates large amounts of agricultural waste such as raw rice husks (RRH). Rice husks are the hard protective coverings of rice grains that are removed during milling. As a result of such wastes, some Indonesian communities have experienced environmental degradation seriously. In order to overcome this situation, currently, the synergetic effects of SFP and RRH as waste materials are attracting a great deal of interest as a more sustainable, less expensive solution for numerous applications.

Producing concrete from waste materials appears to be a viable partial solution for mitigating the impact of this environmental problem. Numerous researchers have utilized waste materials in concrete mostly as partial replacements for fine aggregate. Here, a few of the research examining the mechanical properties of the produced concrete will be examined, but the major focus will be on the studies examining the applications of concrete incorporating waste elements. At last, the scope of the paper focuses on using SFP and RRH wastes as an alternative to natural river sand in green concrete.

Researchers have used SFP as an alternative fine aggregate to produce conventional concrete [5], self-compacting concrete [6], lightweight hollow concrete blocks [7], lightweight solid concrete blocks [8], cemented paste backfill [3], and foamed concrete [9]. Other scholars have utilized granite waste for high-strength refractory concrete [10] and limestone powder for fly ash concrete [11]. Several researchers have developed green concrete based on agricultural wastes, including RRH [2, 4, 8], bagasse fibers [13], coconut fiber [14], sawdust [15], and hemp [16]. Agricultural waste is a remarkable material for concrete mixtures because of its lightweight and the interconnected networks that create porosity among its ingredients. Lightweight materials have significant advantages, such as dead-load reduction [17], fast construction [18], low installation cost, good acoustic, and thermal insulation properties, making them suitable for walling materials in sky scraper buildings [19]. Recycled plastic has also been studied for lightweight aggregates in concrete production [7, 20].

The mixture of SFP and RRH can be used as alternatives to natural river sand in green concrete material, such as lightweight concrete blocks. Typically, concrete blocks are made of cement, aggregate, and water. By substituting natural aggregate with a mixture of SFP and RRH as lightweight materials, lightweight concrete blocks can be manufactured, available in solid and hollow forms.

Lightweight hollow concrete blocks based on a mixture of Portland cement (binder), RRH, and SFP have been manufactured using mechanical vibrations [7], in which their maximum compression strength was only 1.94 MPa. Achieving a better quality blocks have been done by fabricating lightweight solid concrete blocks using manual casting [8], based on a volumetric ratio of 1.25 binder : 2.75 SFP : 8.50 RRH. Its compression strength was approximately 2.66 MPa, and its density was about 1,536.73 kg/m^3. According to SNI-03-0349-1989 (an Indonesian standard for the concrete blocks used in wall materials), the minimum compression strength should be 2.5 MPa, and according to SNI-03-3449-2002 (an Indonesian standard for the manufacturing procedure of lightweight concrete), the density of concrete blocks should be less than 1,400 kg/m^3. Indeed, the previous findings [8] has achieved the minimum strength standard but failed to meet the maximum dry density of lightweight concrete. Therefore, the content of SFP and RRH should be further studied to accomplish the standard for lightweight rice husk concrete blocks (RHCBs). Moreover, as manual casting provides a slow process, the production process of concrete blocks should involve a vibration machine to improve the production speed.

Using a synergetic mixture both SFP and RRH as alternative raw materials in the production of SFP-based RHCB is an ideal route towards green material from waste. This study investigates experimentally the optimal amount of SFP and RRH required for the fabrication of solid lightweight concrete blocks of SFP-based RHCB that meets the strength and density standards. The effectiveness of using synergetic and different amounts of SFP and RRH on the performance of SFP-based RHCB was also investigated. Moreover, these research findings have been compared with other respective ones of conventional lightweight concrete blocks which are readily available in the marketplace, in making a positive identification of this research findings.

2. RESEARCH SIGNIFICANCE

As Indonesia has many stone-cutting industries and is an agricultural country, so there are many SFP and raw rice husks that can be used for construction materials. This paper includes advanced experimental techniques for cement-based composites by investigating the optimum content of stone fine powder (SFP) dan raw rice husk (RRH) in the production of SFP-based Rice Husk Concrete Block (RHCB). This is significant because the results can contribute to green economic development through reducing waste disposal, converting waste materials into resources, and conserving natural resources. Moreover, this lightweight concrete block can contribute positively, particularly for building dead-load reduction, fast construction, and low installation cost. The RHCB can be replicated in other communities that have similar conditions towards green concrete based on agricultural wastes.

3. MATERIALS

Three materials were used in this study, i.e., cement, SFP, and RRH. The type of cement used here as a binder (B) was ordinary Portland cement (OPC) or Type-I in accordance to the SNI 15-2049-2004 standard for Portland cement in Indonesia. All materials were collected from the Sleman Regency: SFP was obtained from the andesite-stone-cutting industries, RRH wastes were collected from the agriculture wastes, and conventional lightweight concrete blocks as comparative samples were procured from the marketplace. The conventional lightweight concrete blocks are made from cement, quartz sand, and gypsum, which are mixed with aluminum paste to produce a material that is light but solid [21].

According to SFP originated from Mount Merapi, Sulistyani et.al. [22] mentioned that most of the materials (sand, gravel, stone, and boulder) erupted from Mount Merapi were classified as andesite materials, in which the highest minerals contained were silica (~50%), aluminum (~17%), and iron (~14%). Engin [23] also discovered Afyon andesite stone with similar results. Previous study has revealed that Merapi andesite sand was observed chemically inactive [24] in which the use of andesite sand that had higher content of silica for concrete mixture did not give a significant improvement in concrete's strength. Musil et al. [4] also confirmed that the fillers made of natural stones contained a significant quantity of SiO_2, were chemically inactive, and had no effect on the concrete's performance. Therefore, the strength based-approach of concrete mixture with additional SFP as fillers based on previous studies suggests that SFP fills the void among particles, creates the denser structure of the composite, and thus increases the concrete's strength. The size distribution and chemical composition of SFP will be examined.

4. EXPERIMENTAL METHODOLOGY

First of all, it was important to examine the size distribution and chemical composition of SFP. The bulk densities of the materials were considered as well. According to the concrete mixture, three batches were investigated based on three different volumetric ratios of binder-RRH and six different volumetric ratios of binder-SFP for each batch, as presented in Table 1.

Table 1 Mix details of the SFP-based RHCBs.

#Samples	Mix Designation	The amount of SFP to B
Batch-I (200% RRH)		
I-1	1 B : 0.25 SFP : 2 RRH	25%
I-2	1 B : 0.50 SFP : 2 RRH	50%
I-3	1 B : 0.75 SFP : 2 RRH	75%
I-4	1 B : 1.00 SFP : 2 RRH	100%
I-5	1 B : 1.25 SFP : 2 RRH	125%
I-6	1 B : 1.50 SFP : 2 RRH	150%
Batch-II (300% RRH)		
II-1	1 B : 0.25 SFP : 3 RRH	25%
II-2	1 B : 0.50 SFP : 3 RRH	50%
II-3	1 B : 0.75 SFP : 3 RRH	75%
II-4	1 B : 1.00 SFP : 3 RRH	100%
II-5	1 B : 1.25 SFP : 3 RRH	125%
II-6	1 B : 1.50 SFP : 3 RRH	150%
Batch-III (400% RRH)		
III-1	1 B : 0.25 SFP : 4 RRH	25%
III-2	1 B : 0.50 SFP : 4 RRH	50%
III-3	1 B : 0.75 SFP : 4 RRH	75%
III-4	1 B : 1.00 SFP : 4 RRH	100%
III-5	1 B : 1.25 SFP : 4 RRH	125%
III-6	1 B : 1.50 SFP : 4 RRH	150%

The amount of water added to each batch was based on a maximum slump value of 25 mm (i.e., a very dry mix). Indonesian standard used in this matter is SNI-03-0349-1989 for concrete blocks used in wall material and SNI-03-3449-2002 for the manufacturing procedure of lightweight concrete. Five samples of conventional lightweight concrete blocks were also tested to be used as a comparison of the performance of SFP-based RHCB.

5. MANUFACTURING PROCESS

First, the three materials, i.e., binder (B), SFP, and RRH, were thoroughly dry mixed using a concrete mixer to obtain a homogenous mixture. Water was gradually added to the mixtures until they converted into stiff, very dry mixes, through consecutive operation. The workability of the mixture was assessed using a slump test, lower than 25 mm. Next, the homogenous and stiff mixture was poured and casted into a mold (12 cm × 22 cm × 40 cm) attached to a high-powered vibration machine. When the mold was completely filled, the concrete was further compacted by vibration as well as the weight of the upper mold head pressing down on the mold cavity. Then, the compacted block was forced out of the mold onto a wood pallet. This made an extremely dry mixes, stiff mixture, that retains its shape when the block mold was removed. Finally, the pallet and block were pushed out from the machine and placed them in curing rack, a shaded and rain-protected space. The RHCB samples were then tested in a laboratory after the age of 28 days. Previous studies have utilized concrete blocks with similar manufacturing process [25-27]. Fig. 1 illustrates the manufacturing process of RHCBs.

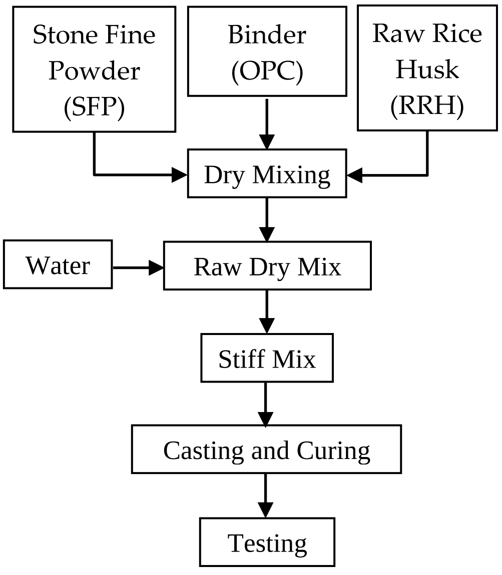

Fig.1 The manufacturing process of RHCB.

6. RESULTS AND DISCUSSION

6.1 Material Characterization

RHCB was made of three separate materials: cement/binder, RRH, and SFP. The visual appearance of binder and SFP is exhibited a light gray color and dark gray color respectively. The morphology of SFP is irregular-shape and has rough surface texture as inferred from Fig. 2. The size distribution of SFP is described in Fig. 3 and however, the gradation of SFP followed the uniform well graded pattern. The SFP particles size were very fine, and 94% of the SFP exhibited a diameter of 0.075 mm or smaller. These results are similar with the granite fine powder particle size [9].

Fig.2 Binder and stone fine powder (SFP).

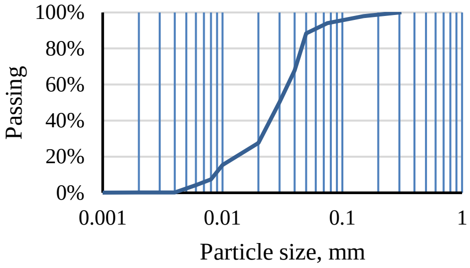

Fig.3 Size distribution of SFP.

Table 2 provides the chemical composition of SFP in comparison to Merapi sand and Afyon andesite stone. As mentioned by previous findings [22], the majority of natural mountainous materials were classified as andesite material, with silica, aluminum, and iron as the most abundant minerals.

Table 2 Chemical composition of SFP, Merapi andesite sand, and Afyon andesite stone.

	Percentage		
	SFP	Merapi andesite sand [22]	Afyon andesite stone [23]
SiO_2	49.23	48.13	59.85
Al_2O_3	17.33	16.87	13.68
Fe_2O	13.00	14.28	4.96
CaO	10.90	11.54	4.92
K_2O	2.15	2.17	5.86
MgO	3.39	3.55	2.84
MnO	0.33	0.36	0.53
Na_2O	0.93	-	2.49
P_2O_5	0.64	0.75	0.99
TiO_2	1.35	1.32	1.06

According to Table 2, the chemical composition of SFP closely resembles that of Merapi andesite sand and Afyon andesite stone, with SiO_2, Al_2O_3, and Fe_2O being the three most abundant elements. This means that the characteristics of SFP are the same as the type of andesite stone from which they originate. Although the materials like SFP contain a large amount of SiO_2, they do not have a significant effect on reaction in concrete mixture because the pozzolanic activity is negative [4]. The chemical composition could be activated by heat treatment to make the pozzolanic activity positive. Therefore, the chemical composition of SFP is not further elaborated in this paper. Another research has mentioned that the higher concrete strength characteristics were a result of the denser structure of the cement composite [4].

Besides SFP, there is raw rice husk (RRH) for RHCB production. RRH is the outmost layer of protection encasing a rice grain with convex shape (curved contour) and yellowish color, as visual appearance presented in Fig. 4. The length of a rice husk, which refers to grain length, is about 9 mm. The length, thickness, and weight vary with the variety of rice husk.

Fig.4 Raw rice husk (RRH).

As a result that the higher strength of concrete is because of the denser structure of the cement composite, it is urgent to investigate the material density. Density is a physical parameter that if the mass of two substances of the same volume is compared, the substance with the higher weight has the higher density. Thus, the definition of density is mass per unit volume. Test result of the bulk densities of the binder, SFP, and RRH are listed in Table 3, in which the RRH is approximately seven times lighter than the binder or SFP.

Table 3 Test results of the bulk density (kg/m^3) of the materials.

#Sample	Binder	SFP	RRH
1	1.032	0.989	0.138
2	1.024	0.978	0.136
3	1.075	0.969	0.145
4	1.077	0.963	0.141
5	1.082	0.973	0.132
Average	*1.058*	*0.974*	*0.138*

6.2 Manufacturing of the Blocks

Concrete blocks are made in numerous sizes and shapes depend on the mold used. However, the fundamental principle regulating their production remains the same: (1) preparation of the mixture and (2) manufacturing of the blocks. The composition of three different materials of RHCB i.e., a binder, SFP, and RRH is based on volumetric ratio.

After the preparation, all materials were mixed together by adding water gradually. A relatively dry combination of binder, SFP, RRH, and water was compacted under pressure in a block press. The samples were kept moist during curing and not allowed to dry in accordance with normal practice. This full concrete blocks were 12 cm wide, 22 cm high, and 40 cm long. After completing this procedure, the blocks were ready for laboratory testing after the age of 28 days.

6.3 Hardened Density and Compressive Strength

The hardened density and compressive strength of 18 samples at the age of 28 days were tested. The density of concrete block is a measure of the mass per unit volume and expressed in kg/m^3. The compressive strength of these concrete blocks is necessary for determining their suitability for use in wall building.

The compressive strength testing machine consists of two steel bearing blocks, one of which is in a fixed position on which the concrete block unit is mounted, and the other of which is mobile and transmits the applied load to the concrete block unit. The load must be gradually added at a rate of 140 kg/cm^2 per minute until the specimen fails. Compressive strength of concrete is equal to the failure load divided by the specimen's area.

These samples were categorized into three batches (Batch-I, Batch-II, and Batch-III) with different amount of RRH to binder (i.e., 200%, 300%, and 400%, respectively). Six different amount of SFP to binder (25%, 50%, 75%, 100%, 125%, and 150%) were used for each batch The laboratory test results for density and compressive strength of RHCB and conventional lightweight concrete blocks are listed in Table 4.

According to the data in Table 4, the average density for the RHCB batches of 200%, 300%, and 400% are decreasing, i.e., 1,481.45, 1,272.77, and 1,167.79 kg/cm^3, respectively. This decreased density is relevant with the bulk density of the RRH, as shown in Table 3. Also, this increase in the RRH content decreases the average compressive strength of the RHBCs, i.e., 4.99 MPa, 2.43 MPa, and 1.80 MPa, respectively. Thus, the increase of density of the RHCBs significantly increases with the compressive strength. The hardened density and compressive strength of RHCB significantly decreased with the increase in RRH and increased with the increase in SFP.

These findings that addition of SFP can increase the strength are a result of the denser structure of the concrete blocks, and this is the same outcomes with previous studies [4] that SiO_2 was the majority SFP constituents, it was chemically inactive and its negative pozzolanic activity prevented it from influencing the reaction in concrete mixture. Therefore, the increase of SFP in the concrete material converts RHCB into a denser, more solid, and compact unit and causes the increment of both density and strength. On the other hand, the test results of the conventional lightweight concrete block have shown that surprisingly, the density is only 742.42 kg/m^3, however, the strength can reach up to 2.7 MPa. This conventional lightweight concrete test of density result cannot be achieved by all RHCB batches. This is due to the fact that the material composition, method of manufacture, and curing method are totally different between these two materials.

Fig. 5-7 illustrates that the compressive strength of RHCB significantly increased with the additional of the SFP because the RHCB becomes heavier and more dense. The strength characteristics of the SFP-based RHCB are controlled by their densities.

Table 4 Laboratory test results of SFP-based RHCB and conventional lightweight blocks.

Block samples	Batch-I (200% RRH)		Batch-II (300% RRH)		Batch-III (400% RRH)	
	Density (kg/m^3)	Strength (MPa)	Density (kg/m^3)	Strength (MPa)	Density (kg/m^3)	Strength (MPa)
1. SFP-based RHCB						
5% SFP	1,056.82	0.95	811.21	0.51	660.23	0.29
50% SFP	1,197.27	2.27	934.72	1.05	847.29	0.89
75% SFP	1,319.58	3.99	1,059.43	1.76	1,039.83	1.43
100% SFP	1,588.21	5.80	1,345.27	2.80	1,236.41	2.09
125% SFP	1,769.34	7.58	1,594.33	3.85	1,502.47	2.79
150% SFP	1,957.47	9.33	1,891.68	4.60	1,720.53	3.29
Average	*1,481.45*	*4.99*	*1,272.77*	*2.43*	*1,167.79*	*1.80*
2. Conventional lightweight blocks						
Average	*742.42*	*2.70*				

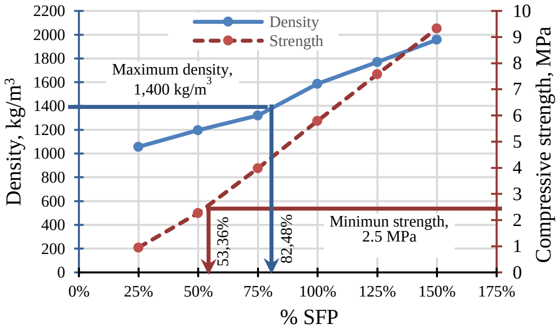

Fig.5 The increase in the density and compressive strength with the increase in the SFP content on Batch-I (200% RRH).

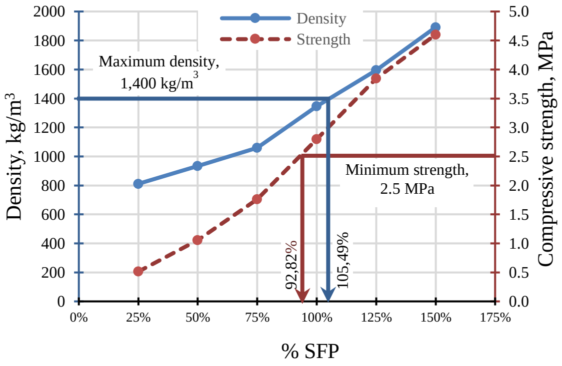

Fig.6 The increase in the density and compressive strength with the increase in the SFP content on Batch-II (300% RRH).

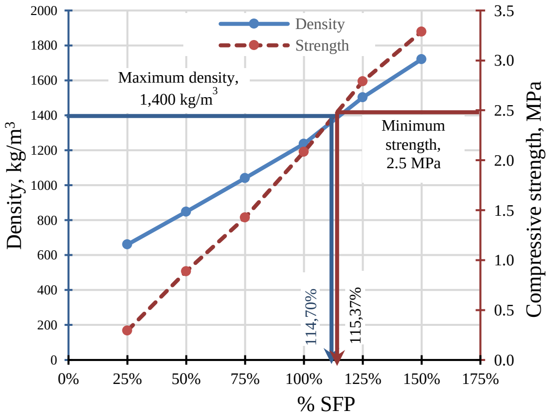

Fig.7 The increase in the density and compressive strength with the increase in the SFP content on Batch-III (400% RRH).

The increase in the SFP from 25% to 150% causes a significant increase in the hardened density of Batches I, II, and III; from 1,056.82 to 1,957.47 kg/m^3, from 811.21 to 1,891.68 kg/m^3, and from 660.23 to 1,720.53 kg/m^3, respectively. The hardened densities of all the RHCB batches considerably increased with the increase in the SFP. The higher the density of the concrete block, the higher the strength of the concrete block generally, as described in Fig. 8. Fig. 9 also describes that the higher composition of SFP, the lower water absorption, and all samples fulfil the standard of water absorption (SNI-03-0349-1989).

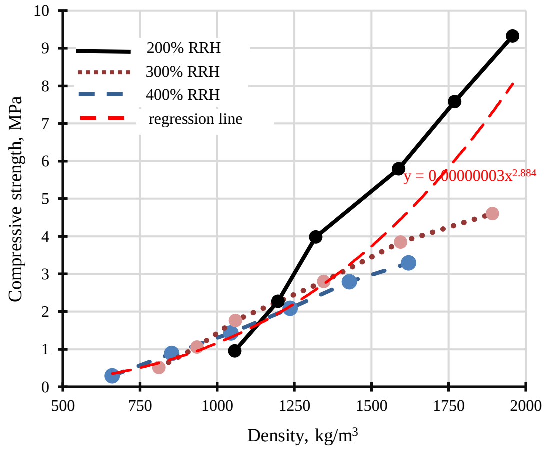

Fig.8 Density and compression strength of the SFP-based RHCBs.

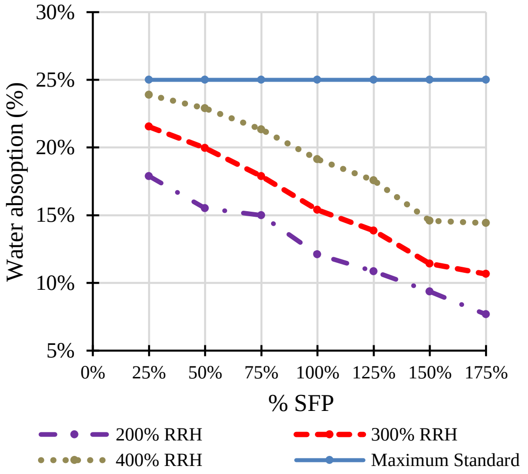

Fig.9 Water absorption of the SFP-based RHCBs.

6.4 Optimum SFP and RRH Contents

As a minimum compressive strength of 2.5 MPa and a maximum dry density of 1,400 kg/m^3, Fig. 5 and 6 indicate that the feasible SFP contents in the 200%-RRH and 300%-RRH batches are in the ranges of 53.36%–82.48% and 92.82%–105.49%, respectively. However, Fig. 7 reveals that there is no feasible SFP content in the 400%-RRH batch for the fabrication of lightweight RHCBs. This means that it is impossible to produce standardized lightweight RHCB at 400%-RRH or higher.

Fig. 8 shows a summary of the three variables, i.e., SFP content, density, and strength, in which the increase in SFP creates a heavier and stronger RHCBs. Thus, the relationship between the density and compressive strength is given by: $Y = 0.00000003x^{2.884}$, where Y is the compressive strength and x is the density.

According to the feasible SFP contents in the 200%-RRH and 300%-RRH batches, the amount of binder required for the RHCB production at a binder-RRH ratio of 1:3 (or 300%) is 33.33% smaller than that of the RHCB fabricated at a ratio of 1:2 (or 200%). Indeed, the production of RHCBs at an binder-RRH ratio of 1:3 requires less binder than that of 1:2. At the same time, binder is the primary component and the most expensive material for the RHCB production, and hence, RHCB with 300%-RRH is significantly cheaper than that produced using the 200%-RRH. Moreover, the 300%-RRH is better from a lightweight technical point of view, based on their density. Therefore, the optimum amount of RRH is 300% to binder and the optimum amount of SFP is 92.82%–105.49% to binder. This can be considered 100% SFP (binder:SFP = 1:1) for practicality.

7. CONCLUSIONS

The feasibility of using SFP and RRH for the fabrication of lightweight solid concrete blocks has been thoroughly investigated. The experimental results reveal that the increase of the SFP content in concrete mixture significantly enhances the performance (both density and compressive strength) of SFP-based RHCBs, due to their denser structure. In contrast, the increase in the RRH content substantially decreases the quality of the RHCBs. Fortunately, the RRH content of both 200% and 300% to binder in the mixture satisfies the standards and provides the feasible SFP contents for RHCBs. Conversely, an SFP-based RHCB with the amount of 400%-RRH or higher to binder could not meet the standard requirements for lightweight concrete blocks. The synergetic use of 100% SFP and 300% RRH in concrete mixture will produce the best product of SFP-based RHCB with density of about 1,345.27 kg/m^3 and compressive strength of about 2.80 MPa.

8. ACKNOWLEDGEMENTS

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9. REFERENCES

[1] BPS-Statistics, Sleman Regency in Figures 2022. Sleman: BPS-Statistics of Sleman Regency, 2022.

[2] Tayeh, B. A., Alyousef, R., Alabduljabbar, H., and Alaskar, A., Recycling of Rice Husk Waste for a Sustainable Concrete: A critical Review, J. Clean. Prod., Vol.312, May 2021, pp.127734.

[3] Rashwan, M. A., Al_Basiony, T. M., Mashaly, A. O., and Khalil, M. M., Behaviour of Fresh and Hardened Concrete Incorporating Marble and Granite Sludge as Cement Replacement, J. Build. Eng., Vol.32, August 2020, pp.101697.

[4] Winarno, S., Preliminary Study on Hand-cast Lightweight Concrete Block using Raw Rice Husk as Aggregate, IOP Conf. Ser. Earth Environ. Sci., Vol.933, 2021, pp. 102-120.

[5] Zhang, S., Ren, F., Zhao, Y., Qiu, J., and Guo, Z., The Effect of Stone Waste on the Properties of Cemented Paste Backfill using Alkali-Activated Slag as Binder, Constr. Build. Mater., Vol.283, 2021, pp.122686.

[6] Musil, L., Cibulka, T., Vodicka, J., and Chylik, R., Characterization of Fillers Made of Natural Stones as a Cement Substitute, International Conference Building Materials, Products and Technologies, Telč, Czech Republic, 2nd-4th June 2020, pp. 189-199.

[7] Eua-apiwatch, S. and Kanjanakijkasem, W., Laboratory Study of Physical and Thermal Properties of Concrete Mixed with Bakelite Int. J. GEOMATE, Vol.24, No.102, 2023, pp. 109–116.

[8] Winarno, S., Comparative Strength and Cost of Rice Husk Concrete Block, MATEC Web Conf., Vol.280, 2019, pp.04002.

[9] Ahmadi, S. F., Reisi, M., and Amiri, M. C., Reusing Granite Waste in Eco-friendly Foamed Concrete as Aggregat, J. Build. Eng., Vol.46, October 2021, pp.103566.

[10] Shirani, K., Reisi, M., and Savadkoohi, M. S., Eco-friendly High-Strength Refractory Concrete Containing Calcium Alumina Cement by Reusing Granite Waste as Aggregate, Int. J. Concr. Struct. Mater., Vol.15, No.1, 2021, pp. 78-88.

[11] Jung, S. H., Saraswathy, V., Karthick, S., Kathirvel, P., and Kwon, S. J., Microstructure Characteristics of Fly Ash Concrete with Rice Husk Ash and Lime Stone Powder, Int. J. Concr. Struct. Mater., Vol.12, No. 1, 2018, pp.98-111.

[12] Lawal, A. Q. T., Effect of Unburnt Rice Husk on the Properties of Concrete, Procedia Manuf., Vol. 35, 2019, pp.635–640.

[13] Bilba, K. and Arsene, M., Silane Treatment of Bagasse Fiber for Reinforcement of Cementitious Composites, Compos. Part A Appl. Sci. Manuf., Vol.39, 2008, pp.1488–1495.

[14] Tawasil, D. N. B. et al., Coconut Fibre and Sawdust as Green Building Materials: A Laboratory Assessment on Physical and Mechanical Properties of Particleboards, Buildings, Vol.11, No.6, 2021, pp. 678-691.

[15] Dias, S. et al., Physical, Mechanical, and Durability Properties of Concrete Containing Wood Chips and Sawdust: An Experimental Approach, Buildings, Vol.12, No.8, 2022, pp.1277.

[16] Marianne, L. T., Claire S, P., Agnès, S., and Thierry, C., Influence of Various Chemical Treatments on the Interactions between Hemp Fibres and a Lime Matrix, J. Eur. Ceram. Soc., Vol.29, 2009, pp.1861–1868.

[17] Winarno, S., Griffith, A., and Stephenson, P., Reducing Earthquake Risk to Non-engineered Buildings: A Study of Design and Construction Practices in Indonesia, Int. J. Constr. Manag., Vol.10, No.1, 2010, pp.154-171.

[18] Winarno, S., Griffith, A., and Stephenson, P., Earthquake Risk Reduction to Non-engineered Buildings: A Study of Practice in Indonesia, in Association of Researchers in Construction Management, ARCOM 2008 - Proceedings of the 24th Annual Conference, 2008, pp.623-634.

[19] Koksal, F., Mutluay, E., and Gencel, O., Characteristics of Isolation Mortars Produced with Expanded Vermiculite and Waste Expanded Polystyrene, Constr. Build. Mater., Vol.236, 2020, pp.117789.

[20] Alqahtani, F. K., Sherif, M. A., Ghanem, A. M., and Abotaleb, I. S., Assessment of Sustainable Green Lightweight Concrete Incorporated in New Construction Technologies, KSCE J. Civ. Eng., Vol.26, 2022, pp.4942–4959.

[21] Blesscon (Lightweight Concrete Block): Right Choice and Quick Build. 2022. Available: https://blessconbataringan.com/

[22] Sulistyani, Priyambodo, E., and Yogantari, L., Mineral Content Analysis of Merapi Volcanic Sand and Its Potential Application, in Proceeding of International Conference on Research, Implementation, and Education of Mathematics and Science, Yogyakarta State University, 2015, pp.115–124.

[23] Engin, I. C., Investigation on the Usage of Different Rock Aggregates as Abrasive Materials in Natural Stone Aging Process, Arab. J. Geosci., Vol.6, 2013, pp.5043–5054.

[24] Nadia and Fauzi, A., Effect of Silica Content on Fine Aggregate in Concrete Mixture toward Increasing of Compressive Strength, Konstruksia, Vol.3, No.1, 2011, pp.35–43.

[25] Mohamad, H. M. et al., “Manufacture of Concrete Paver Block using Waste Materials and By-products: A Review,” Int. J. GEOMATE, Vol. 22, No. 93, 2022, pp. 9–19.

[26] Buyung, N. R., Ghani, A. N. A., and Abdullah, N. H., “Properties of Porous Paver Concrete Blocks and Their Overall Infiltration Rate in Pavement Formation,” Int. J. GEOMATE, Vol. 21, No. 86, 2021, pp. 32–39.

[27] Teguh, M. and Rahmayanti, N., “Flexural Behaviour of Confined Masonry Walls using Interlocking Concrete Blocks Subjected to Out-of-Plane Loads,” Int. J. GEOMATE, Vol. 20, No. 81, 2021, pp. 179–184.