Estimation of the Content of Stone Fine Powder in High-Performance Lightweight Rice Husk Concrete Blocks

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Abstract

Stone fine powder (SFP) is a solid by-product of the stone-cutting industry, which causes land and air pollution in the surrounding areas. In this study, SFP was used as a raw material in the manufacturing of lightweight material of SFP-based rice husk concrete blocks (RHCBs), and its optimal content to meet the performance of Indonesian standards was determined. The RHCBs studied here were composed of three materials: cement (binder), SFP, and raw rice husk (RRH). Samples were grouped into three batches: Batch-I, Batch-II, and Batch-III with binder-RRH ratios of 1:2, 1:3, and 1:4 respectively. Moreover, six binder-SFP ratios were tested in each batch, i.e., 1:0.25, 1:0.50 1:0.75, 1:1, 1:1.25, and 1:1.50. Thus, 18 mixes were cast to assess the performance of the SFP-based RHCBs. The results 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. The SiO$_2$ as the majority component of SFP does not have an impact on improving RHCB strength because it is chemically inactive. SFP-based RHCB with 300% RRH and the ratio of SFP to binder = 92.82–105.49% is the optimal choice. For practical purposes, it can be regarded as 100% SFP. This synergetic application of binder:SFP:RRH = 1:1:3 in a concrete mixture will generate the best SFP-based RHCB, with a density of around 1,345.22 kg/m$^3$ and a compressive strength of approximately 2.80 MPa.

1. Introduction

Indonesia is well known for its several active volcanoes with frequent eruptions. Large amounts of sand and stone surround the volcano areas. These materials are typically used as construction materials for several applications, such as floor tiles and garden decorations, which increased the demand in the stone-cutting industry. For example, among the four regencies surrounded by Mount Merapi in Java Island, Sleman Regency currently contains more than 17 companies specializing in stone cutting (BPS-Statistics, 2022), see Fig. 1.

However, the stone-cutting industry generates large quantities of solid wastes such as stone fine powder (SFP). SFP is 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 tons of SFP are generated every month in the Sleman Regency. The accumulation of SFP triggers land and air pollution in the surrounding area, posing risks to people and vegetation. This waste has been increasing annually at an alarming rate and is expected to further increase with the increase in the demand for stone floor tiles and home ornaments.

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, which has a negative impact on the environment. Previous research has revealed SFP can perform as fillers made of natural stones.
They are regarded chemically inactive and are primarily used to concrete mixtures to increase the proportion of fine cement matrix and enhance workability (Musil et al., 2020). Besides the solid waste of SFP, as an agricultural producing country, Indonesia 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 waste, some Indonesian communities have experienced environmental degradation which may be caused by a number of factors, including technological developments, agricultural intensification, and population growth. 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 or coarse aggregate, depending on the type or size of waste material used. 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, this interesting research work focuses on using SFP and RRH wastes as alternative to natural river sand in concrete material manufacturing.

Researchers have used SFP as an alternative fine aggregate to produce conventional concrete (Rashwan et al., 2020), self-compacting concrete (Rashwan et al., 2022; Basu et al., 2021), lightweight hollow concrete blocks (Winarno, 2019), lightweight solid concrete blocks (Winarno, 2021), cemented paste backfill (Zhang et al., 2021), and foamed concrete (Ahmadi et al., 2022). Other scholars have utilized granite waste for high-strength refractory concrete (Shirani et al., 2021) and lime stone powder for fly ash concrete (Jung et al., 2018). Several researchers have developed green concrete based on agricultural wastes. Examples of agricultural wastes investigated for green concrete, include RRH (Winarno, 2019; Winarno, 2021; Tayeh et al., 2021), bagasse bers (Bilba & Arsene, 2008), coconut ber (Tawasil et al., 2021), sawdust (Dias et al., 2022), and hemp (Marianne et al., 2009). Agricultural waste is a remarkable material for concrete mixtures because of its lightweight, which is due to the interconnected networks that create porosity among its ingredients. Lightweight materials have significant advantages, such as dead-load reduction (Winarno et al., 2010), fast construction (Winarno et al., 2008), low installation cost, good acoustic, and thermal insulation properties, making them suitable for walling materials in sky scraper buildings (Koksal et al., 2020).

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. They are usually rectangular, utilized in the construction of wall structures, and also are 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 (Winarno, 2019), in which their maximum compression
strength is only 1.94 MPa. In order to make a better quality blocks, following studies have been done by fabricating lightweight solid concrete block using manual casting (Winarno, 2021). This study was based on a binder:SFP:RRH ratio of 1.25:2.75:8.50 in volumetric ratios. 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, these studied lightweight solid concrete blocks have achieved the minimum strength standard but failed to meet the maximum dry density of lightweight concrete. Therefore, the content of SFP should be further studied to accomplish the standard for lightweight rice husk concrete blocks (RHCBs). Further, as manual casting provides a slow process, the production process of concrete blocks should involve a vibration machine to improve the production speed.

Using 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 also can contribute to the green economic development through reducing waste disposal, converting waste materials into resources, and conserving natural resources. This study investigates the optimal amount of SFP 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 findings will be compared with other respective ones of conventional lightweight concrete blocks which are readily available in the marketplace. These comparison samples could be very important in making a positive identification of RHCB.

2. 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, with specific gravity of 3.15. SFP was obtained from the andesite-stone-cutting industries in the Sleman Regency, in which andesite stone is abundant materials in the Mount Merapi located near the Sleman Regency. RRH wastes were collected from the agriculture wastes generated in the Sleman Regency where the RRH was an abundantly available waste material in this rice producing regency. Conventional lightweight concrete blocks as comparative samples were procured from the marketplace in the Sleman Regency also. The 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 (Blesscon (Lightweight Concrete Block): Right Choice and Quick Build, 2022).

3. Experimental Methodology

In this study, three batches were tested based on three different volumetric ratios of binder-RRH. The volumetric ratio was chosen to facilitate the simple measurements during the sample production. The
volumetric binder-RRH ratios in Batch-I (200% RRH), Batch-II (300% RRH), and Batch-III (400% RRH) were 1:2, 1:3, and 1:4, respectively. The amount of water added to each batch was based on a maximum slump value of 25 mm (i.e., a very dry mix).

The effect of different amounts of SFP on the performance of the SFP-based RHCB was investigated. Six different volumetric binder-SFP ratios (1:0.25, 1:0.50, 1:0.75, 1:1, 1:1.25, and 1:1.50) were used for each batch. Thus, 18 mixes were cast to evaluate the performance of SFP-based RHCB and the mix details of the batches are listed in Table 1.
Table 1
Mix details of the SFP-based RHCBs

<table>
<thead>
<tr>
<th>#Samples</th>
<th>Mix Designation</th>
<th>Volumetric percentage of SFP-to-B</th>
<th>Maximum slump value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch-I</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(200% RRH)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-1</td>
<td>1 B : 0.25 SFP : 2 RRH</td>
<td>25%</td>
<td>25 mm</td>
</tr>
<tr>
<td>I-2</td>
<td>1 B : 0.50 SFP : 2 RRH</td>
<td>50%</td>
<td>25 mm</td>
</tr>
<tr>
<td>I-3</td>
<td>1 B : 0.75 SFP : 2 RRH</td>
<td>75%</td>
<td>25 mm</td>
</tr>
<tr>
<td>I-4</td>
<td>1 B : 1.00 SFP : 2 RRH</td>
<td>100%</td>
<td>25 mm</td>
</tr>
<tr>
<td>I-5</td>
<td>1 B : 1.25 SFP : 2 RRH</td>
<td>125%</td>
<td>25 mm</td>
</tr>
<tr>
<td>I-6</td>
<td>1 B : 1.50 SFP : 2 RRH</td>
<td>150%</td>
<td>25 mm</td>
</tr>
<tr>
<td>Batch-II</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(300% RRH)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>II-1</td>
<td>1 B : 0.25 SFP : 3 RRH</td>
<td>25%</td>
<td>25 mm</td>
</tr>
<tr>
<td>II-2</td>
<td>1 B : 0.50 SFP : 3 RRH</td>
<td>50%</td>
<td>25 mm</td>
</tr>
<tr>
<td>II-3</td>
<td>1 B : 0.75 SFP : 3 RRH</td>
<td>75%</td>
<td>25 mm</td>
</tr>
<tr>
<td>II-4</td>
<td>1 B : 1.00 SFP : 3 RRH</td>
<td>100%</td>
<td>25 mm</td>
</tr>
<tr>
<td>II-5</td>
<td>1 B : 1.25 SFP : 3 RRH</td>
<td>125%</td>
<td>25 mm</td>
</tr>
<tr>
<td>II-6</td>
<td>1 B : 1.50 SFP : 3 RRH</td>
<td>150%</td>
<td>25 mm</td>
</tr>
<tr>
<td>Batch-III</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(400% RRH)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>III-1</td>
<td>1 B : 0.25 SFP : 4 RRH</td>
<td>25%</td>
<td>25 mm</td>
</tr>
<tr>
<td>III-2</td>
<td>1 B : 0.50 SFP : 4 RRH</td>
<td>50%</td>
<td>25 mm</td>
</tr>
<tr>
<td>III-3</td>
<td>1 B : 0.75 SFP : 4 RRH</td>
<td>75%</td>
<td>25 mm</td>
</tr>
<tr>
<td>III-4</td>
<td>1 B : 1.00 SFP : 4 RRH</td>
<td>100%</td>
<td>25 mm</td>
</tr>
<tr>
<td>III-5</td>
<td>1 B : 1.25 SFP : 4 RRH</td>
<td>125%</td>
<td>25 mm</td>
</tr>
<tr>
<td>III-6</td>
<td>1 B : 1.50 SFP : 4 RRH</td>
<td>150%</td>
<td>25 mm</td>
</tr>
</tbody>
</table>

The compressive strength of each mix at the age of 28 days was assessed in accordance with the Indonesian standard of SNI-03-0349-1989 for concrete blocks used in wall material. Moreover, the dry density of each mix at the age of 28 days was evaluated to comply with the SNI-03-3449-2002, the
Indonesian standard for the manufacturing procedure of lightweight concrete. The standard values for lightweight concrete blocks are a minimum compressive strength of 2.5 MPa and a maximum dry density of 1,400 kg/m$^3$. Five samples of conventional lightweight concrete blocks were also tested to be used as a comparison of the performance of SFP-based RHCB.

4. Manufacturing Process Of Rhcbs

First, the three materials, i.e., binder (B), SFP, and RRH, were thoroughly dry mixed using a concrete mixer to obtain a homogenous mixture. Moreover, 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, in which the slump value was very low (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 is completely filled, the concrete is further compacted by vibration as well as the weight of the upper mold head pressing down on the mold cavity. Then, the compacted block is forced out of the mold onto a wood pallet. This makes an extremely dry mixes, stiff mixture, that retains its shape when the block mold is removed. Finally, the pallet and block are pushed out from the machine and places them in curing rack, a shaded and rain-protected space. The RHCB samples were then tested in a laboratory when their age reached 28 days. Figure 2 illustrates the manufacturing process of RHCBs.

5. Results And Discussion

5.1 Material Characterization

RHCB is made of three different materials, i.e., a cement/binder, RRH, and SFP. The visual appearance of binder and SFP is shown in Fig. 3. Binder and SFP 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 GFP is described in Fig. 4 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 and overall, 78.57% of SFP particles size were between 0.075 mm and 0.010 mm. SFP was considerable stickiness under wet conditions. These results are similar with the granite fine powder particle size (Kumar G & Mishra, 2021).

After determining the size distribution, it is important to recognize about chemical composition of SFP, solid waste of Merapi andesite stone-cutting industry. As mentioned by Sulistyani (Sulistyani et al., 2015), most of the materials (sand, gravel, stone, and boulder) erupted from Mount Merapi were classified as andesite material, in which the highest minerals contained were silica (~ 50%), aluminum (~ 17%), and iron (~ 14%). Engin (Engin, 2013) also discovered Afyon andesite stone with similar results. Chemical composition of SFP, Merapi sand, and Afyon andesite stone is given in Table 4.
According to Table 4, the chemical composition of SFP closely resembles that of Merapi andesite sand and Afyon andesite stone, with SiO₂, Al₂O₃, and Fe₂O 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 fillers like SFP contain a large amount of SiO₂, they do not have a significant effect on reaction in concrete mixture because the pozzolanic activity is negative (Musil et al., 2020). The chemical composition could be activated by heat treatment to make the pozzolanic activity positive.

The findings that Merapi andesite sand was observed chemically inactive have been described also by Nadia and Fauzi (Nadia & Fauzi, 2011). These showed that the use of andesite sand with higher content of SiO₂ for concrete mixture does not give a significant improvement in concrete strength. Another research has mentioned that the higher concrete strength characteristics are a result of the denser structure of the cement composite (Musil et al., 2020).

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. 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. Figure 5 presents visual appearance of 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 offers

### Table 4

<table>
<thead>
<tr>
<th>Percentage</th>
<th>SFP</th>
<th>Merapi andesite sand (Sulistyani et al., 2015)</th>
<th>Afyon andesite stone (Engin, 2013)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>49.23</td>
<td>48.13</td>
<td>59.85</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>17.33</td>
<td>16.87</td>
<td>13.68</td>
</tr>
<tr>
<td>Fe₂O</td>
<td>13.00</td>
<td>14.28</td>
<td>4.96</td>
</tr>
<tr>
<td>CaO</td>
<td>10.90</td>
<td>11.54</td>
<td>4.92</td>
</tr>
<tr>
<td>K₂O</td>
<td>2.15</td>
<td>2.17</td>
<td>5.86</td>
</tr>
<tr>
<td>MgO</td>
<td>3.39</td>
<td>3.55</td>
<td>2.84</td>
</tr>
<tr>
<td>MnO</td>
<td>0.33</td>
<td>0.36</td>
<td>0.53</td>
</tr>
<tr>
<td>Na₂O</td>
<td>0.93</td>
<td>-</td>
<td>2.49</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>0.64</td>
<td>0.75</td>
<td>0.99</td>
</tr>
<tr>
<td>TiO₂</td>
<td>1.35</td>
<td>1.32</td>
<td>1.06</td>
</tr>
</tbody>
</table>
information on how heavy a substance is. 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>
<thead>
<tr>
<th>Sample</th>
<th>Binder (kg/m$^3$)</th>
<th>SFP (kg/m$^3$)</th>
<th>RRH (kg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.032</td>
<td>0.989</td>
<td>0.138</td>
</tr>
<tr>
<td>2</td>
<td>1.024</td>
<td>0.978</td>
<td>0.136</td>
</tr>
<tr>
<td>3</td>
<td>1.075</td>
<td>0.969</td>
<td>0.145</td>
</tr>
<tr>
<td>4</td>
<td>1.077</td>
<td>0.963</td>
<td>0.141</td>
</tr>
<tr>
<td>5</td>
<td>1.082</td>
<td>0.973</td>
<td>0.132</td>
</tr>
<tr>
<td>Average</td>
<td>1.058</td>
<td>0.974</td>
<td>0.138</td>
</tr>
</tbody>
</table>

**5.2 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. The example preparation of the mixture is presented in Fig. 6. After the preparation, all materials are mixed together by adding water gradually. A relatively dry combination of binder, SFP, RRH, and water is compacted under pressure in a block press, and then allowed to harden and dry. This full concrete blocks are 12 cm wide, 22 cm high, and 40 cm long. After completing this procedure, the block is ready for laboratory testing. Figure 7 mentions the manufacturing of the blocks.

**5.3 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 is 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. Figure 8 describes the compression test of the blocks.
These samples were categorized into three batches (Batch-I, Batch-II, and Batch-III) with different volumetric binder-RRH ratios (i.e., 200%, 300%, and 400%, respectively). The laboratory test results for density and compressive strength of RHCB and conventional lightweight concrete blocks are listed in Table 4.

<table>
<thead>
<tr>
<th>SFP-based RHCB</th>
<th>Density (kg/m³)</th>
<th>Strength (MPa)</th>
<th>Density (kg/m³)</th>
<th>Strength (MPa)</th>
<th>Density (kg/m³)</th>
<th>Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Batch-I (RRH 200%)</td>
<td>1,056.82</td>
<td>0.95</td>
<td>811.21</td>
<td>0.51</td>
<td>660.23</td>
<td>0.29</td>
</tr>
<tr>
<td>Batch-II (RRH 300%)</td>
<td>1,197.27</td>
<td>2.27</td>
<td>934.72</td>
<td>1.05</td>
<td>847.29</td>
<td>0.89</td>
</tr>
<tr>
<td>Batch-III (RRH 400%)</td>
<td>1,319.58</td>
<td>3.99</td>
<td>1,059.43</td>
<td>1.76</td>
<td>1,039.83</td>
<td>1.43</td>
</tr>
<tr>
<td>SFP 25%</td>
<td>1,588.21</td>
<td>5.80</td>
<td>1,345.27</td>
<td>2.80</td>
<td>1,236.41</td>
<td>2.09</td>
</tr>
<tr>
<td>SFP 50%</td>
<td>1,769.34</td>
<td>7.58</td>
<td>1,594.33</td>
<td>3.85</td>
<td>1,502.47</td>
<td>2.79</td>
</tr>
<tr>
<td>SFP 75%</td>
<td>1,957.47</td>
<td>9.33</td>
<td>1,891.68</td>
<td>4.60</td>
<td>1,720.53</td>
<td>3.29</td>
</tr>
<tr>
<td>Average</td>
<td>1,481.45</td>
<td>4.99</td>
<td>1,272.77</td>
<td>2.43</td>
<td>1,167.79</td>
<td>1.80</td>
</tr>
<tr>
<td>Conventional lightweight concrete blocks</td>
<td>742.42</td>
<td>2.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Based on 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/cm³, 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, 2.43, 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 (Musil et al., 2020). SiO₂ as the majority SFP constituents is chemically inactive. Although SFP contains a substantial amount of SiO₂, its negative pozzolanic activity prevents it from influencing the reaction in concrete mixture. 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.

Figure 9–11 illustrates the increase in the density and compressive strength with the increase in the SFP content.

Based on Fig. 9–11, in contrast, the compressive strength of RHCB significantly increased with the increase in the SFP because the RHCB is heavier and more compact. The strength characteristics of the SFP-based RHCB is controlled by their density. The increase in the SFP from 25–150% 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. Higher the density of the concrete block, the higher the strength of the concrete block generally, as described in Fig. 12.

### 5.4 Optimum SFP Content

As a minimum compressive strength of 2.5 MPa and a maximum dry density of 1,400 kg/m$^3$, Figs. 9 and 10 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. 11 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 an RRH 400% or higher.

Figure 12 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%). The production of RHCBs at an binder-RRH ratio of 1:3 requires less binder. 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 optimal binder-RRH ratio is 1:3 with the optimal volume of SFP to binder is $= 92.82–105.49\%$. This can be considered 100% SFP (binder:SFP = 1:1) for practicality.

### 6. Conclusions

The use of SFP as an alternative source of raw material for manufacturing building products is crucial for increasing sustainable values today, due to the social and ecological difficulties linked with the scarcity
of natural raw materials and the disposal of SFP. The feasibility of using SFP for the fabrication of lightweight solid concrete blocks has been thoroughly investigated. Therefore, the purpose of this study was to determine the best quantity of SFP required for the production of lightweight concrete blocks. The objective of the work was to study the synergetic effects of SFP and RRH on the performance of SFP-based RHCB that meets the standards of lightweight concrete block, i.e., a minimum compressive strength of 2.5 MPa and a maximum density of 1,400 kg/m$^3$. The followings are the inferences and conclusions gained from this study.

- The increase of the SFP content in concrete mixture significantly enhances the performance (both density and compressive strength) of SFP-based RHCBs. This is due to their denser structure, consistent with the findings of prior investigations. SiO$_2$, the predominant component of SFP, is chemically inactive. Despite the fact that SFP includes a significant amount of SiO$_2$; their negative pozzolanic activity and also their inactive chemical characteristic prevent SFP from impacting the reaction in concrete mixture. The rise in SFP content in the concrete material only leads RHCB to become denser, more solid, and more compact, resulting in an increase in density and strength. In general, the higher the density of the SFP-based RHCB causes considerably the higher its strength, as expressed by exponential regression line: $Y = 0.00000003x^{2.884}$, where $Y$ is the compressive strength and $x$ is the density.

- In contrast, the increase in the RRH content substantially decreases the quality of the RHCBs. Fortunately, the RRH content of both 200% and 300% in the mixture satisfies the standards and provides the feasible SFP contents for RHCBs, i.e., range 53.36–82.48% SFP for 200%-RRH and 92.82–105.49% SFP for 300%-RRH. Conversely, an SFP-based RHCB with 400%-RRH or higher could not meet the standard requirements for lightweight concrete blocks.

- Since (1) the production of RHCBs with 300% RRH requires less binder that that of 200% RRH, (2) binder (cement) is the most expensive material for the RHCB production, and (3) the content of 300%-RRH is better from a lightweight technical point of view, RHCB with 300% RRH is the best choice.

- At last, SFP-based RHCB with 300% RRH will be optimum if the volume of SFP to binder is $= 92.82–105.49\%$, which can be regarded as 100% SFP (binder:SFP = 1:1) for practicality. This 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 (as mentioned in Table 4).

- The remarkable density of conventional lightweight concrete block is just 742.42 kg/m$^3$, yet its strength can reach up to 2.7 MPa, according to test data. This conventional block density test result cannot be attained by all RHCB batches. This is due to the fact that the composition, manufacturing process, and curing procedure of these two materials are entirely distinct.

**Abbreviations**
Declarations

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Authors’ contributions

S.W.: conceptualization, research methodology, laboratory test, funding acquisition, and writing—original draft. H.: review, editing, and validating. A.M.A.: validation and writing—review, and editing. This published version of the manuscript have been read and agreed by all authors.

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Availability of data and materials

Some or all data or code that support the findings of this study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.
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References


**Figures**

![Image](image-url)

**Figure 1**

The local stone-cutting industry in Sleman Regency
Figure 2

The manufacturing process of RHCB

Figure 3

binder (ordinary Portland cement)  stone fine powder (SFP)
Binder and stone fine powder (SFP)

Figure 4

Size distribution of SFP
Figure 5

Raw rice husk (RRH)

Figure 6

- **binder**
  (ordinary portland cement)
- **stone fine powder**
  (SFP)
- **raw rice husk**
  (RRH)
An example of preparation of the mixture (1B:1SFP:3RRH)

Figure 7

The manufacturing of the blocks: (a) mixing, (b) compacting, and (c) fresh solid concrete blocks

Figure 8

The compression test of the block and its specimen failure
Figure 9

The increase in the density and compressive strength with the increase in the SFP content on Batch-I (200% RRH)
Figure 10

The increase in the density and compressive strength with the increase in the SFP content on Batch-II (300% RRH)
Figure 11

The increase in the density and compressive strength with the increase in the SFP content on Batch-III (400% RRH)
Figure 12

Density and compression strength of the SFP-based RHCBs