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Mechanical Properties of Bricks Containing Sago Fine Waste as Cement Replacement Material

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ABSTRACT

Due to the country's expanding population and the resulting growth of the building industry, brick is one of the most crucial materials used in construction projects in Malaysia. Producing large amounts of bricks requires a lot of cement yet this method has environmental consequences due to increasing carbon emissions into the atmosphere. Therefore, this study aims to use partial Sago Fine Waste (SFW) to replace the cement. About 60 tonnes of sago trash are dumped into the closest river every day during the production of sago starch. To protect the environment and contributing to sustainable development, this study has been conducted on the production of bricks from waste materials. For this study, the brick specimens were prepared using 0%, 1%, 3%, 5%, 7% and 9% of SFW with a water-cement ratio of 0.6 fixed at 1:3 sand cement ratio. The total specimens that were produced for testing are 72 bricks. The water curing for concrete has been conducted at 7 and 28 days. The overall results revealed that both density and compressive strength are decreases as the percentages of SFW increases. The initial rate of absorption increases due to the increasing percentage of SFW. However, all the results obtained are still met the requirements. Based on the findings, the optimum percentage SFW are SFW1W0.6 with strength 5.18 MPa. The optimum brick properties of SFW1W0.6 is normal weight with density 2092.86 kg/m^3 and lowest initial rate absorption with 0.91 kg/m^3.min.

1. Introduction

The ever-increasing population and urbanization in Malaysia have led to the growing demand for construction materials. More manufacturing generates more waste, and more waste raises environmental concerns about harmful threats. Recycling the waste materials can save the natural resources, reduces solid waste, reduces air and water pollutants, and reduces other environmental

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issues [1,18]. Bricks are a popular construction and building material all over the world. Brick is one of the most important raw materials used in construction projects in Malaysia to fulfil their living needs due to the increasing population of people, which has led to the rise of the construction industry in Malaysia. Cement is one of the important raw materials in manufactured of brick. As a result, cement brick is commonly used in building construction in Malaysia.

There is a problem with brick production, as excessive cement consumption has a negative influence on the environment. Emissions from cement manufacturing processes impair air quality and pollute the environment. Cement facilities, for example, are a substantial producer of Sulphur Dioxide (SO_2), Nitrogen Oxide (NO_2), and Carbon Monoxide (CO) [17], all of which are led to health issues and environmental harm. Huge amounts of cement are necessary to make large quantities of cement bricks, yet this method has environmental consequences due to increasing carbon emissions into the atmosphere. Many studies are now focusing on the use of waste material in the manufacture of brick concrete. It is necessary to seek ecologically friendly new materials and technologies to replace building materials, allowing for a reduction in environmental effect in terms of waste material incorporation.

Sago is a popular traditional food that is widely recognized as a basic ingredient in the preparation of local cuisine [20]. This is due that sago is processed in a highly traditional process and prolonged period. It is carried out in several locations along the riverbank where palm trees exist for each processing phase. During processing, a large amount of leftover solid waste, such as bark and *hampas*, is generated which is generally burned or washed into adjacent streams [2-4,16]. The sago husk, also known as a waste of the sago processing, is dumped in the riverbank and in certain cases, in the river stream [3,19]. On the other hand, the increasing demand of sago starch also lead into the sago starch sector currently dealing with waste management issues, which have resulted in pollution and health risks.

As an alternative to reduce the waste and carbon emission, this study is being carried out which has replaced the cement in brick concrete with Sago Fine Waste (SFW). The aim of this study is to identify the SFW properties, that can be potentially used as a replacement material. This as a means of producing eco-friendly and sustainable construction materials. On the other hand, the purpose of this study is also to promoted on using of waste material in the construction industry.

This study identifies the performance of concrete bricks using SFW as cement replacement in term of density, compressive strength and absorption and proposes the optimum percentages of SFW replacement as cement replacement material.

2. Methodology

2.1 Materials

In this investigation, the materials that had been used for the production of cement brick are Ordinary Portland Cement (OPC), sand, water, and Sago Fine Waste (SFW). SFW is used as a replacement material for cement.

2.1.1 Sago Fine Waste (SFW)

The sago fine waste that has been used for this study was obtained from supplier of a sago mill in Mukah, Sarawak. Sago waste had been collected from the River Link Sago Resources Sdn Bhd factory in Kampung Dalat, Mukah, as well as from small-scale sago farmers in Kampung Tellian Hulu, Mukah, Sarawak. Fresh sago waste was damp, greyish, and light brown, and turned to brownish after drying. Before these materials may be reused, the moisture level of sago waste must be reduced. In terms of SFW treatment, raw sago waste from the factory had been dried under sunlight for at least 18 hours before being processed into a fine powder using a grinder machine as in Figure 1. The replacement volume of SFW that been used in this study are 0%, 1%, 3%, 5%, 7%, and 9%. Figure 2 shows the SFW that have been used in this study.

Fig. 1. Raw sago waste ground using grinder machine

Fig. 2. Sago fine waste that has been processed

2.1.2 Ordinary portland cement

The cement that had been used in this study is an Ordinary Portland Cement (OPC). The cement was obtained locally at Concrete Laboratory at Universiti Tun Hussein Onn Malaysia (UTHM). The cement been kept in an airtight container in the laboratory, kept dry and away from any damp conditions to avoid being exposed to moisture and hardening before use.

2.1.3 Sand

The fine aggregate used in this study was natural sand. Sand with a maximum particle size of 5 mm was used to produce bricks. Sand been kept dry in the provided storage until it is time to use it.

2.1.4 Water

In this study, the tap water has been used.

2.2 Methods

Several methods have been involved for conducting this study. It includes brick sample preparation, testing materials and laboratory testing to achieve the goal for this study.

2.2.1 Brick samples

The total samples produced for this study are 72 samples. These samples are produced for density test, compressive strength test and initial rate of absorption test (IRA). The volume replacement material that been used to produce cement bricks are 0%, 1%, 3%, 5%, 7% and 9% of SFW. The bricks were moulded with a 215 mm length, 102.5 mm width, and 65 mm depth in accordance with the scale specified in MS 76 (1972) [5] and BS 3921 (1985) [6]. The sand cement ratio of composite brick was 1:3.

2.2.2 Material testing

Sieve analysis test, specific gravity test and bulk density test have been conducted before laboratory testing is proceed.

2.2.2.1 Sieve analysis

The sand and SFW sieved to produce fine aggregates that meet the particle sizes specified by the British Standards Institution in 1985. The particle size distribution in sieve analysis is characterized by the mass or volume of the particles. The fine aggregate grading size is less than 5mm, which is normally required to be within the limits specified in BS 882. (1983) [7]. In general, the sieve sizes used for fine aggregate particle size distribution were 10 mm, 5 mm, 2.36 mm, 1.18 mm, 600 µm, 300 µm, 150 µm and pan µm. 1kg of sand was weighted to determine the grain size distribution of the fine aggregate. Then, this test was repeated with 500g of SFW. The number of particles retained on each sieve was used to grade the aggregate.

2.2.2.2 Specific gravity

The fine aggregate specific gravity test determines the specific gravity of a fine aggregate sample by calculating the weight of a given volume of aggregate divided by the weight of an equal volume of water. This test was taken approximately three days (from sample preparation to final dry weight determination). The specific gravity of fine aggregate was measured in line with ASTM C128 [8], using the Eq. (1).

$$\text{Bulk Specific Gravity} = A/(B+500-C) \tag{1}$$

where
A = mass of oven-dry specimen in air (g),
B = mass of pycnometer filled with water (g),

C = mass of pycnometer with specimen and water to calibration mark (g).

2.2.2.3 Bulk density

Bulk density, also known as unit weight, is the weight per unit volume (mass per unit volume or density). Bulk density is determined by the density with which the aggregate is packed. It is also affected by the particle's size, distribution, and shape. Sand, cement and SFW are the materials been tested for bulk density test. Standard test methods BS 812-2, 1995 are used to determine the bulk density of fine aggregate [9]. The bulk density was calculated as in Eq. (2).

Bulk Density =(weight cylinder +Fine aggregate -Empty weight cylinder (kg)/(volume of cylinder (m^3)) (2)

2.2.3 Laboratory testing

In this study, testing such as density, compressive strength, and initial rate of absorption were conducted to obtain the physical and mechanical properties of cement brick produced.

2.2.3.1 Density test

Density of brick was calculated after a curing period of 7 and 28 days. This test has been carried out according to BS 6073: Part 1:1981 [10]. Brick density was calculated using Eq. (3).

Brick density (kg/m^3) = (weight of sample (kg)/(volume of brick (m^3) (3)

2.2.3.2 Compressive strength test

The test was carried out in referring to BS 3921 (1985), which specifies the testing of bricks [11]. The tests been performed after 7 and 28 days of curing. Compressive testing was performed with three specimens for each mix. Eq. (4) was used to compute the compressive strength of the cubes.

$$\sigma=F/A \quad (4)$$

where;
σ = Compressive strength (kN/mm^2),
F = Ultimate compressive load of concrete (kN),
A = Cube surface area (mm^2).

2.2.3.3 Initial rate of absorption (IRA)

The amount of water absorbed in one minute through the bed face of the brick is known as the Initial Rate of Absorption (IRA). The initial rate of absorption of 36 sample bricks was tested at the age of 7 days and 28 days. ASTM C67-14 is the standard that been used as reference for IRA results [12].

3. Results and Discussion

This section presents the results of each experiment that were conducted according to the methods. The data obtained throughout the experiments and testing were discussed, analyzed and interpreted.

3.1 Material Testing
3.1.1 Sieve analysis

From the data in Figure 3, it shows that the fine aggregates obtained fine modulus of 2.82 while SFW 2.65, respectively. Since the fine's modulus for SFW and fine aggregates are almost similar, thus SFW have the potential as replacement material for producing cement bricks. The results of fineness modulus for both fine aggregates and SFW obtained from this study similar to a preliminary study conducted by Hadi Izaan *et.,*[4]. They reported that the SFW has potential to be a replacement material in production of bricks.

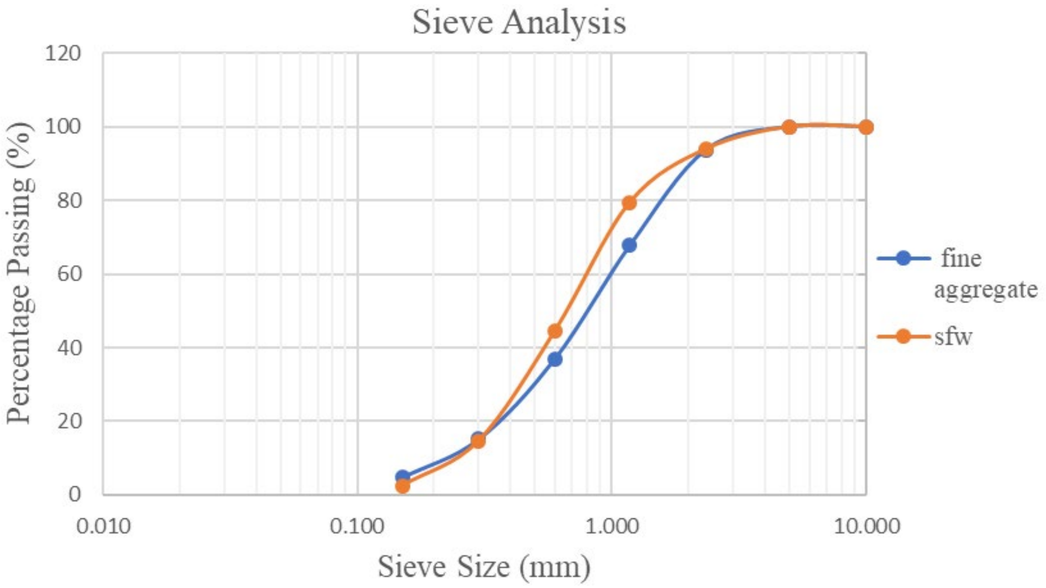

Fig. 3. Grading curve of fine aggregates and SFW

3.1.2 Specific gravity

According to the results obtained in this study, the specific gravity of sand is substantially higher than that of waste materials such as SFW. Table 1 shows the sand and SFW specific gravity values were 2.683 and 0.75, respectively. As a result, the density of materials containing SFW is lower compared to sand. In addition, the lower value of specific gravity of SFW shows that this fine aggregates as replacement materials are lighter compared to the natural fine aggregates. Hence, Abd Wahab *et al.,* [13] found that the specific gravity of SFW is about 0.45 which was similar to the data obtained from this study which is 0.75. The results for current study is similar to physical properties of SFW which has been conducted by Abd Wahab et. al [13]. They reported that the specific gravity of sand is higher than SFW.

Table 1
Specific gravity

Materials	Specific gravity
Sand	2.683
SFW	0.75

3.1.3 Bulk density

To a certain extent, particles of the similar size can be packed together, but as smaller particles are added, the voids are filled with them, then the bulk density is increases. The bulk density obtained from the testing conducted in this study for sand, SFW and cement were 2237 kg/m^3, 1270 kg/m^3 and 1938 kg/m^3, respectively.

3.2 Experimental Testing
3.2.1 Density test

The densities of all the samples drop as the percentage SFW content in the sample increases as shown in Figure 4. Brick SFW9 had the lowest density of 1607.14 kg/m3 at 7 days curing, which was 30.12% less than the control brick but then increases as much 26.98% compared to control brick after 28 days with density 1642.86 kg/m3. The density of the control brick is highest at 2300.00 kg/m3 at 7 days and dropped to 2250.00 kg/m3 after 28 days when compared with other samples containing various percentage of SFW. Furthermore, the number of air voids in SFW bricks reduced density when compared to control brick. This is due to the increases in SFW replacement that reduce the density of bricks. The SFW content in SFW1 resulted higher in density compared to other bricks samples that containing SFW. This is occurred due to SFW has low specific gravity. Then, other results showed that the density of bricks decreases with increases of curing age. It demonstrates that samples of SFW3 and SFW5, the densities obtained at 28 days were lower than that those obtained at 7 days. This resulted from the samples' water evaporating during the curing process. When the curing time is extended, this result shows in a reduction in brick density.

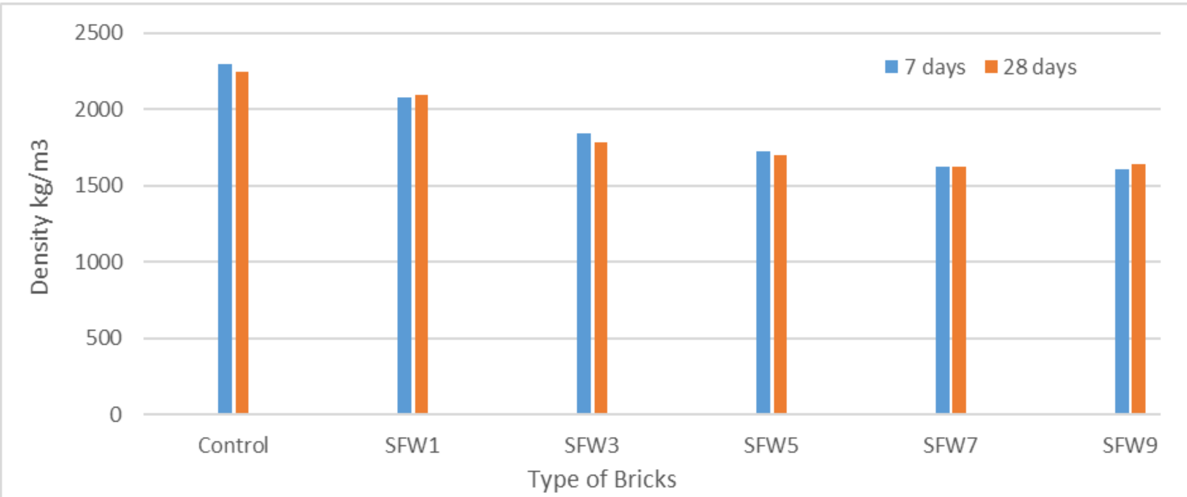

Fig. 4. Density of cement bricks for 7 and 28 days

For overall, the higher the percentage of SFW replacement, the lower the density value. This has shown the contribution of SFW affecting the reduction of brick density. This can be stated that increasing SFW content in cement bricks will be a potential material to produce lightweight brick. On the other hand, lightweight bricks have numerous advantages, such as reduced structural dead load, easy to handle, lower transport costs, and lower thermal conductivity. The drastic reduction of density is similar to a preliminary study that has been conducted by I Hadi Izaan *et al.,* [4] who reported that the replacement percentage of SFW reduced the density of the sample bricks significantly.

3.2.2 Compressive strength test

The result of compressive strength of the samples is as shown in Figure 5. It clearly can be seen that the value of strength decreases due to the increasing percentage of SFW content in cement bricks after curing periods at 7 and 28 days. All brick samples containing SFW has lower strength value compared to the control brick as at 7 and 28 days, which are 15.50 MPa and 18.34 MPa, respectively. The strength was decreases as for replacing 1% of SFW which the maximum strength obtained is at 13.80 MPa after curing at 7 days and 15.13 MPa after curing for 28 days. The strength of bricks starts to decreases for SFW1 followed with other samples containing SFW due to the increasing percentage of SFW replacements in the brick. The samples SFW9has lowest strength which is 3.88 MPa and 4.15 MPa after 7 and 28 days with percentage different compared to control brick as much 74.97% and 74.32%, respectively. The inclusion of SFW implies defects in the internal structure of the brick which leads to a reduction in strength. However, the samples SFW1 still obtained the highest compressive strength compared to the other samples containing SFW which are samples SFW3, SFW5, SFW7 and SFW9.

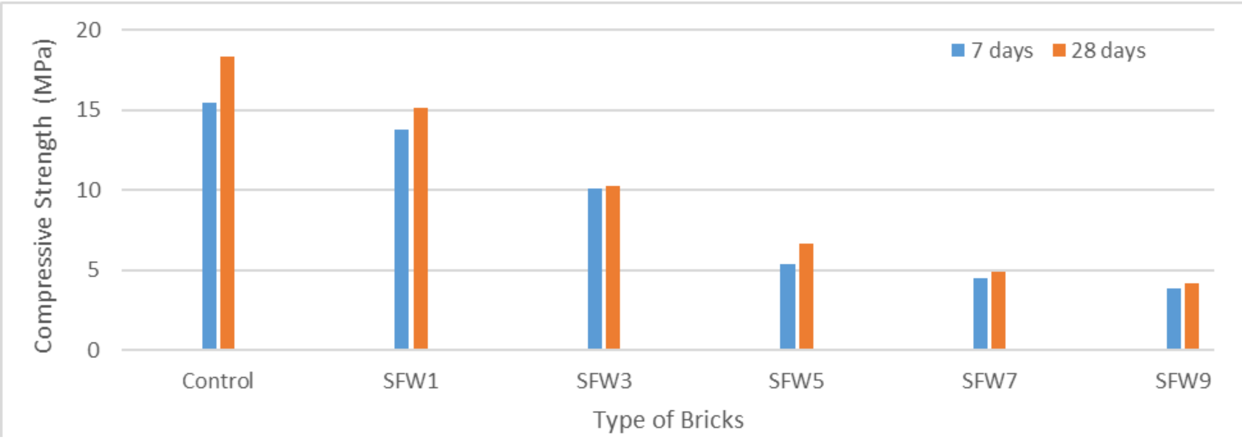

Fig. 5. The compressive strength of cement bricks for 7 and 28 days

In addition, it was observed that the compressive strength increases with the increasing percentage of SFW for all samples as the curing time which has been increased from 7 to 28 days. It can be shown that the increasing period time of curing, the strength of brick samples also increases. It is due to the moisture content is at the optimum level and under proper curing method. The drastic reduction of strength shown above similar to a preliminary study that has been conducted by Hadi Izaan *et al.,* [4] who reported that the replacement levels of 5% of SFW and above reduced the compressive strength of the specimens significantly. Ornam *et al.,* [3] also reported that additional sago has reduces the strength of brick. The great reduction in strength was due to the characteristic of SFW with its low in strength and higher amount average of water absorption percentage [12].

3.2.3 Initial rate of absorption test

Initial Rate Absorption (IRA) results for 7 and 28 days are presented as in Figure 6. The data of IRA obtained in Figure 6 are meet the requirement. This is due to the good rate of initial absorption is between 0.25 kg/m^2.min to 2.00 kg/m2.min. This value can be referred to evaluate the performance of initial rate absorption on certain bricks [14,15]. Figure 6 shows a percentage graph of initial rate of absorption at curing 7 and 28 days. The initial rate of absorption, as can be seen on Figure 6, hit the lowest value which is 0.45 kg/m^2.min for control bricks at both curing 7 ad 28 days. The data also reached the highest value is at 1.82 kg/m^2.min for samples SFW3 and SFW7 after 28 days curing and for the samples SFW9 for both curing at 7 and 28 days. On the 28 days, the initial rate of absorption recorded for samples SFW3 and SFW7 are higher than their 7 days. But for control bricks, samples SFW1, SFW5 and SFW9 shows the similar IRA for both curing at 7 and 28 days. If the rate of water absorption is high, it may affect the hydration and result in poor bonding of bricks. In overall, the IRA value obtained still met the requirement from the ASTM C67-14. The graph shows that all samples bricks do not exceed the values of 2.00 kg/m^2.min.

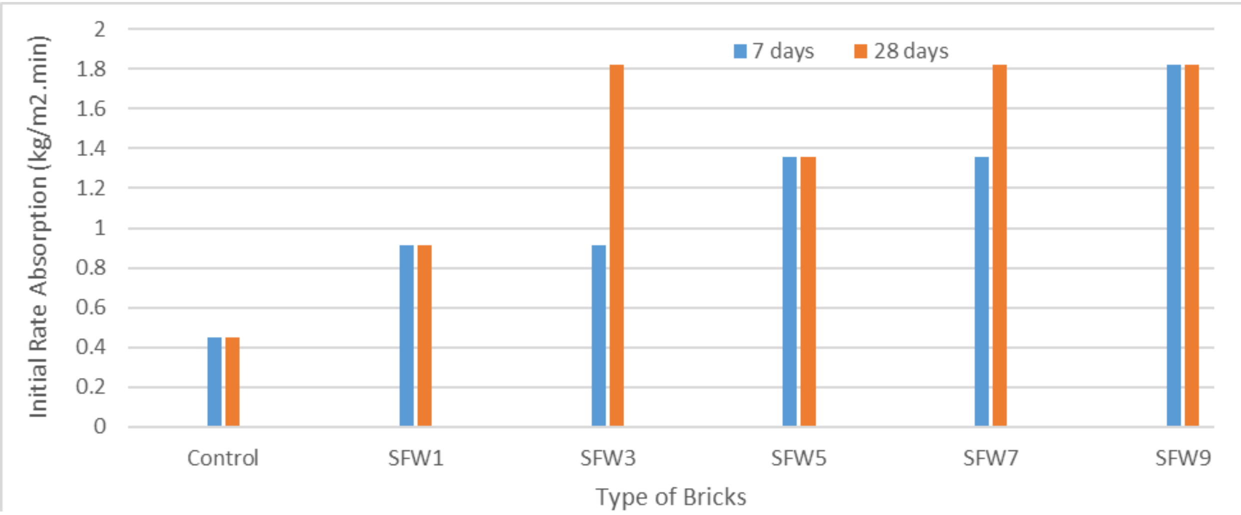

Fig. 6. Initial rate of absorption of cement bricks for 7 and 28 days

3.3 Optimum Percentage of SFW for Cement Bricks

The overall findings and data obtained from this study help to identified the optimum percentages of SFW for cement bricks. From the results of the density, compressive strength and initial rate of absorption test, it can be concluded that SFW1 was the optimum percentage. The density test showed that SFW1 can be classified as a normal weight brick. Regarding the data, SFW1W0.6 obtained the highest value of strength overall regarding control bricks with 15.13 MPa at 28 days curing. The initial rate of absorption test for SFW1 also showed the lowest value which is 0.91 kg/m^2.min compared to other samples and since it fulfilled the requirement which is less than 2.00 kg/m^2.min.

4. Conclusions

For the conclusion on this study, it can be identifying the performance of brick containing SFW in term of density, compression strength and initial rate absorption. The results for density indicated that the average density of brick is lower compared to the control bricks. This can be stated that increasing of SFW content in cement bricks has a potential to produce a lightweight brick. Then, the result on the compressive strength of cement bricks decreases when the percentage of SFW is increases. The inclusion of SFW implies defects in the internal structure of the brick which leads to a reduction in strength. It also can be concluded that the value of initial rate of absorption increases when the value of percentage SFW increase. However, all the results obtained are still met the requirements.

From this study, it was found that the partially replacement of cement by SFW give a significant impact on density, strength and initial rate of absorption performance on cement bricks. On the other hand, the optimum percentage of SFW as cement replacement material is SFW1.

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