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Effect of Sago Fine Waste as Replacement on Cements Bricks Properties

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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 common materials used in construction projects and building 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. The objective is to determine the compression strength, density and initial rate absorption of cement bricks containing Sago Fine Waste in accordance with standard of bricks and to obtain optimum percentage Sago Fine Waste used in bricks as partial replacement materials for cement. The overall results revealed that both density and compressive strength are decreasing as the percentages of SFW increase. Meanwhile, 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 Sago Fine Waste 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. According to the results of this study, it was discovered that the cement bricks' density, strength, and IRA performance are significantly impacted by the replacement of cement with partial SFW.

Keywords: Brick, Sago Fine Waste, Environmental

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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 issues [1]. Bricks are a widely used building and construction material worldwide. Brick is one of the most essential raw materials used in Malaysian construction projects to fulfil their daily 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. There are several differences between cement bricks and red bricks. Cement bricks can now be found practically anywhere, particularly in new structures. Their designs are simple and straightforward. They are also less expensive than red bricks. Cement bricks have a larger compressive strength than red bricks. This is mostly due to the method by which concrete bricks are formed and the materials utilised. Cement bricks are quite waterproof. This is especially useful when the work is taking place in a wet and muddy environment. As a result, most constructors choose to use concrete bricks. Aside from that, cement bricks are considered more environmentally friendly because most cement bricks are now constructed from waste materials rather than stone aggregates. 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, nitrogen oxide, and carbon monoxide, all of which are linked 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. In other cases, sago is a popular traditional food that is widely recognized as a basic ingredient in the preparation of local cuisine. 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]. Along with expanding sago starch demand, the sago starch sector is currently dealing with waste management issues, which have resulted in pollution and health risks. 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. As an alternative, this study is being carried out to evaluate the availability of SFW as a replacement for cement in brick, hence decreasing pollution.

At the end, the goal of this research is to identify SFW materials, that can potentially serve as a substitute for natural cement in brick manufacturing as a means of producing eco-friendly and sustainable construction materials. Furthermore, the purpose of this research is to conserve resources and encourage sustainable building design in the construction industry. In addition, this study uses an experimental method to evaluate the qualities of brick incorporating SFW as partial cement replacement materials. The first objective is to determine the compression strength, density and initial rate absorption of cement bricks containing Sago Fine Waste as partially replacement for cements in accordance with standard of bricks. The second objective is to obtain optimum percentage Sago Fine Waste used in bricks as partial replacement materials for cement.

2. Literature Review

The background of the sago fine waste was further discussed in this section. Apart from that, some literature regarding the optimum sago fine waste been studied and the related information or testing been listed. Comparison between each existing research also be made.

2.1 Sago Fine Waste (SFW)

In South East Sulawesi, Indonesia, sago is well known as a basic ingredient in the preparation of a popular traditional cuisine known as Sinonggi [3]. Sarawak has the most sago palm planting areas in Malaysia, especially in the Mukah division. SFW or sago fine waste, is produced during the extraction process after most of the starch has been taken from the rasped pith of the sago palm. One tonne of SFW was produced for every tonne of sago starch produced. Figure 1 depicts a simplified steps for extracting sago starch process [4].

Figure 1: Simplified Flow for Extracting Sago Starch Process [4]

2.2 Previous Study of Bricks Produced with Sago Waste

Several researchers have investigated the use of sago waste or sago husk in the production of bricks. Table 1 summaries prior work done by utilizing sago waste as a replacement for natural material in concrete. For overall, existing sago as material replacement in manufacturing brick will decrease the strength and density but increase the water absorption of bricks. From this, the selection of percentage SFW replacement chosen for this study are 0%, 1%, 3%, 5%, 7%, and 9% which this percentage not more than 10% to meet the requirements of standard bricks. In addition, water content 0.5 and below is better for replacing sand that using wastes such as RCA, PET recycled plastic bottles or high-density polyethylene (HDPE). But for this study, the selection of water cement ratio for additive SFW is 0.6 because this water content is better in this case due to the properties of sago fine waste that the water absorption is high to replace cement in manufacturing cement bricks.

Table 1: Summary of Previous Work of Sago Waste in Bricks

Author	Volume of sago waste %	W/C ratio %	Test involved	Results
Ornam et al., 2017	1.3, 1.7, 2, 2.3, 2.6, 2.9, 3.1, 3.3	12-15%, 20-30%, 7-10%	Density, compressive strength, initial rate of absorption (IRA)	Diminishes the strength of the brick but still meet requirements, met the ASTM density requirements and IRA value met the ASTM C67-14 requirement on average
I Hadi Izaan et al, 2022	0, 5, 10, 15, 20, 25	50%, 60%	Density, water absorption, compressive strength	Both density and compressive strength decrease but percentage of water absorption of brick increased

Ornam et al., 2019	1.1, 2.2, 2.5	Not mentioned	Density, IRA and salt content, compressive strength, water absorption	Provide greater performance in terms of strength and construction weight.

3. Materials and Methods

The materials and methods are necessary in conducting the study until the end to obtain the results of the study. All the materials, sample preparation, methods and test techniques that involved in this study are described in this section.

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 for cement.

2.1.1 Sago Fine Waste (SFW)

The sago fine waste that 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 2. The replacement volume of SFW that been used is 0%, 1%, 3%, 5%, 7%, and 9%. Figure 3 shows the SFW that used in this study.

Figure 2: Raw sago waste ground using grinder machine.

Figure 3: Sago fine waste that has been processed.

2.1.2 Ordinary Portland Cement

There are various types of cement used in the construction sector. Cement is a cover substance that bonds aggregates and reinforcing elements. In composite brick, cement acts as a binder for the materials. The cement that had been used in this study is ordinary Portland cement, which is primarily composed of lime, silica, alumina, and iron oxide. The cement was obtained locally at laboratory of 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

Sand is the majority ingredient in making all bricks. The fine aggregate in this study was natural white sand. Sand with a maximum particle size of 5 mm was used to make bricks. The sand had been collected locally at the UTHM laboratory. Sand been kept dry in the provided storage until it is time to use it.

2.1.4 Water

Water is the important material in manufacturing the cement bricks. The use of tap water as a binder for sand and other materials improves the performance of cement. Only clean, transparent, drinkable water should be used in the production of the bricks. The tap water used in this study will be purified and supplied by Malaysia's Syarikat Air Johor.

2.2 Methods

Several methods involved to conduct this study until the end. It includes brick sample preparation, testing materials and laboratory testing to achieve the objectives of this study.

2.2.1 Brick Sample Preparation of Mixtures

The test that involved were 36 specimens for compressive strength and density, and 36 for initial rate of absorption test with the overall total is 72 specimens. The control brick was used to begin the production of brick samples. The volume replacement material that been used to produce cement bricks are 0%, 1%, 3%, 5%, 7% and 9% of SFW. The name for SFW1 is mean by SFW 1%, SFW3 for SFW 3%, SFW5 for SFW 5%, SFW7 for SFW 7% and SFW9 for SFW 9% while W0.6 means the water cement ratio is 0.6. 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. The works involved in brick preparation was mixtures preparation, where the mixtures been prepared by hand mixing the brick. All ingredients been measured and weighted in accordance with the mix's design as in Table 2. The mixtures will then be used to cast a total of 72 bricks. The bricks been stored in the open air for 14 days at room temperature (dry curing) for set 2 sample and immersed in water (wet curing) for set 1 sample. Then allowed to cure for 7 days and 28 days before being used in this study. After curing, samples are going to be prepared for laboratory testing. The number of specimens that been conducted is shown in Table 3.

Table 2: Calculation Material with Water Cement Ratio 1:3

Mix Designation	Sand (kg)	Cement (kg)	SFW (kg)	Water (kg)
Control	2.68	0.74	0	0.44
SFW1W0.6	2.68	0.73	0.015	0.44
SFW3W0.6	2.68	0.71	0.046	0.43
SFW5W0.6	2.68	0.70	0.076	0.42
SFW7W0.6	2.68	0.68	0.107	0.41
SFW9W0.6	2.68	0.67	0.137	0.40

Table 3: Number of Brick Samples for ρ & σ and IRA

Mix Designation	Number of Days	ρ & σ (Set 1 Sample)	IRA (Set 2 Sample)
Control	7	3	3
	28	3	3
SFW1W0.6	7	3	3
	28	3	3
SFW3W0.6	7	3	3
	28	3	3
SFW5W0.6	7	3	3
	28	3	3
SFW7W0.6	7	3	3
	28	3	3
SFW9W0.6	7	3	3
	28	3	3
Total		36	36

* density (ρ), initial rate of absorption (IRA) and compressive strength (σ)

2.2.2 Material Testing

Sieve analysis test, specific gravity test and bulk density test were the material testing that has been conducted for this study before proceed to the further laboratory testing.

- 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.

- 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.

$$Bulk\ Specific\ Gravity = A/(B + 500 - C) \qquad Eq. 1$$

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).

- 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.

$$Bulk\ Density\ = \frac{weight\ cylinder\ + Fine\ aggregate\ - Empty\ weight\ cylinder\ (kg)}{volume\ of\ cylinder\ (m^3)}\quad Eq. 2$$

2.2.3 Laboratory Testing

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

- Density Test

Density of brick was calculated after a curing period of 7 and 28 days. The dimensions of bricks were calculated and dividing by the average volume which is 0.0014m3. A total of 36 samples been evaluated at the ages of 7 and 28 days. This test must be carried out in accordance with BS 6073: Part 1:1981 [10]. Brick density was calculated using Eq. 3.

$$Brick\ density\ (kg/m^3)\ = (weight\ of\ sample\ (kg))/(volume\ of\ brick\ (m^3))\qquad Eq. 3$$

- Compressive Strength Test

The compressive strength test is used to determine the durability of bricks used in building construction. The test was carried out in accordance with BS 3921 (1985), which specifies the testing of bricks [11]. The compressive strength is calculated by dividing the greatest load by the initial cross-sectional area of the bricks. The compressive strength test was performed in the Concrete Laboratory at University Tun Hussein Onn Malaysia (UTHM). The tests been performed after 7 and 28 days of cure. This test required 36 samples in total. Compressive testing was performed with three specimens for each mix. Eq. 4 was used to compute the compressive strength of the cubes.

$$\sigma = F/A\qquad Eq. 4$$

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

- 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]. Initial rate absorption (IRA) was calculated using Eq. 5.

$$IRA\ (kg^3min) = \frac{Mass_f - Mass_i}{A.t}\qquad Eq. 5$$

Where IRA = Initial rate of absorption, $Mass_i$ = mass of the sample in kilograms before soaking for time t, (kg), $Mass_f$ = mass of the sample in kilograms after soaking for time t, (kg), A = exposed area of the specimen (m^2), t = duration of immersion in minutes (min).

4. Results and Discussion

There are several experimental testings been conducted in this study as already mentioned earlier. This section presents the results of each experiment that were conducted based on methods. The data obtained throughout the experiments and testing were discussed, analyzed and interpreted.

3.1 Material Testing

- Sieve Analysis

From the data in Figure 4, it shows that the fine aggregates having 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 replacement in cement bricks. The results of fineness modulus for both fine aggregates and SFW obtained from this study similar to a preliminary study conducted by [4] who reported that the SFW has potential to be a replacement in production of bricks.

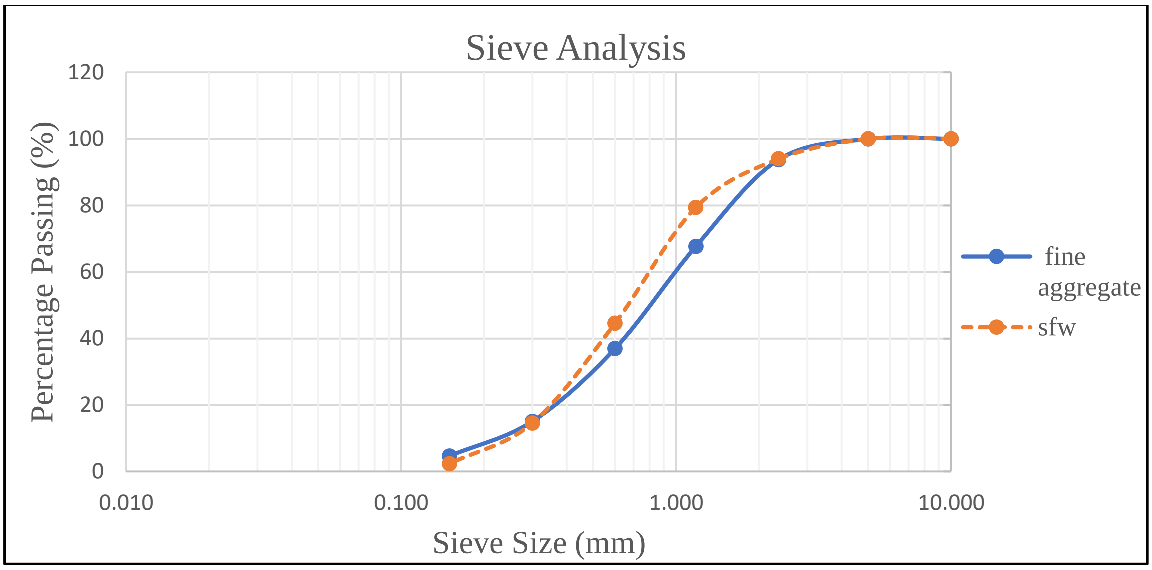

Figure 4: Grading curve of fine aggregates and SFW

- 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 3 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 projected to be lower. 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 (2022) 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 shown above similar to a physical properties of SFW conducted by Abd Wahab (2022) who reported that the specific gravity of sand is higher than SFW [13].

Table 3: Value of specific gravity

Materials	Specific gravity	Previous study value	Previous study researcher
Sand	2.683	2.66	Albano et al., (2009)
SFW	0.75	0.45	Abd Wahab, (2022)

- Bulk Density

To a certain extent, particles of the same size can be packed together, but as more smaller particles are added, the voids are filled with them, then the bulk density is increase. 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/m3 respectively.

3.2 Laboratory Testing

- Density Test

According to Figure 5, the densities of all the samples drop as the percentage SFW content in the sample increases. Brick SFW9W0.6 had the lowest density of 1607.14 kg/m^3 at 7 days curing, which was 30.12% less than the control brick but then increase as much 26.98% compared to control brick after 28 days with weight 1642.86 kg/m^3. The density of the control brick highest at 2300.00 kg/m^3 at 7 days and dropped to 2250.00 kg/m^3 after 28 days when compared with other samples containing percentage SFW. Furthermore, the number of air voids in SFW bricks reduced density when compared to controls. Because the increase in SFW replacement can reduce the density of bricks, the SFW content in SFW1W0.6 resulted is higher in density rather than other bricks samples containing SFW. This is due to SFW has low specific gravity. Other results showed that the density of bricks decreased with increasing curing age. It demonstrates that samples of SFW3W0.6 and SFW5W0.6, the densities obtained at 28 days were lower than 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.

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 shown above similar to a preliminary study conducted by I Hadi Izaan et al (2022) who reported that the replacement percentage of SFW reduced the density of the specimens bricks significantly.

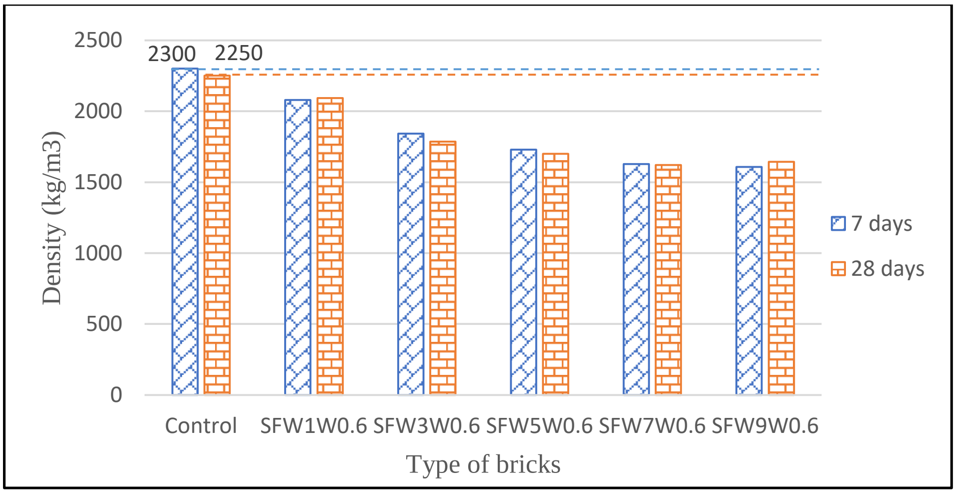

Figure 5: Density of cement bricks for 7 and 28 days

- Compressive Strength Test

Compressive strength of the samples is shown in Figure 6. 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 lasting 7 days and 28 days. All brick sample containing SFW has lower strength value compared to the control brick as at 7 days and 28 days, which are 15.50 MPa and 18.34 MPa respectively. The strength was decrease as for replacing 1% of SFW which the maximum strength obtained is at 13.80 MPa after curing 7 days and 15.13MPa after curing for 28 days. The strength of bricks starts to decrease for SFW1W0.6 followed with other samples containing SFW due to the increasing percentage of SFW fillers in the brick composition. The samples SFW9W0.6 has 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 SFW1W0.6 still obtained the highest compressive strength compared to the other samples containing SFW which are samples SFW3W0.6, SFW5W0.6, SFW7W0.6 and SFW9W0.6.

In addition, it was observed that the compressive strength increased with the increasing percentage of SFW for all samples as the curing time increased from 7 to 28 days. It can be shown that the increasing period time of curing, the strength of brick samples also increased. 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 conducted by I Hadi Izaan et al, (2022) who reported that the replacement levels of 5% of SFW and above reduced the compressive strength of the specimens significantly. Ornam et al., 2017 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].

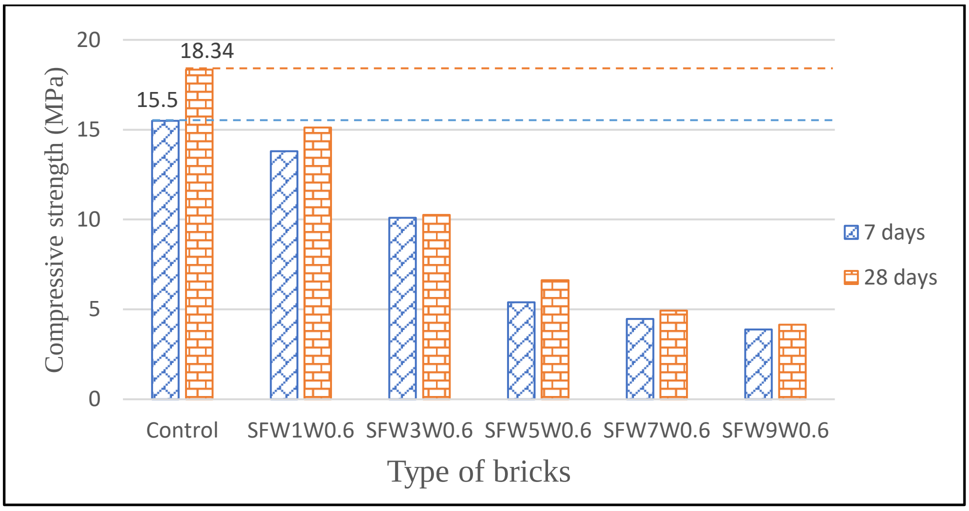

Figure 6: The compressive strength of cement bricks for 7 days and 28 days

- Initial Rate of Absorption Test

Initial rate absorption results for 7 and 28 days are presented in Figure 7. The data of IRA obtained in Figure 6 are meet the requirement. This is because the good rate of initial absorption is between 0.25 kg/m^2.min to 2.00 kg/m^2.min. This value can be referred to evaluate the performance of initial rate absorption on certain bricks [14]. 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 7, 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 SFW3W0.6 and SFW7W0.6 after 28 days curing and for the samples SFW9W0.6 for both curing at 7 and 28 days. On the 28 days, the initial rate of absorption recorded for samples SFW3W0.6 and SFW7W0.6 are higher than their 7 days. But for control bricks, samples SFW1W0.6, SFW5W0.6 and SFW9W0.6 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.

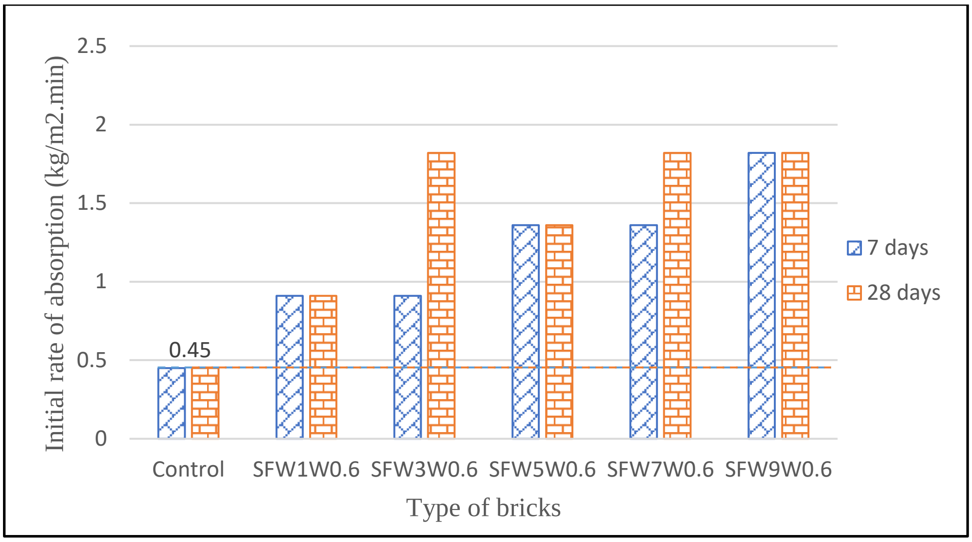

Figure 7: Initial rate of absorption of cement bricks for 7 days and 28 days

3.3 Optimum Percentage of SFW for Cement Bricks

The overall findings and data obtained from this study help to determine 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 SFW1W0.6 was the optimum percentage. The density test showed that SFW1W0.6 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 SFW1W0.6 also showed the lowest value which is 0.91 kg/m2.min compared to other samples and since it fulfilled the requirement which is less than 2.00 kg/m^2.min.

5. Conclusion

For the conclusion on this study, the first objective has been achieved. It can be proved with the results of density, compression strength, and initial rate absorption of cement bricks that containing with SFW as partially cement replacement. The overall results for density indicated that the average density of brick is lower compared to the control bricks. This can be stated that increasing SFW content in cement bricks will be a potential material to produce lightweight brick. Next, the result on the compressive strength of cement bricks decreases due to the increasing percentage SFW. 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.

The second objective also has been achieved where it can be concluded that the best sample is SFW1W0.6 when compared to other samples. Regarding the data, SFW1W0.6 obtained the highest value of strength overall regarding control bricks with 15.13 MPa which can be function as loadbearing internal wall that commonly used for constructed of small single-storey housing, commercial and industrial building. This sample also can be classified as a normal weight brick with density 2092.86 kg/m^3 and lowest initial rate absorption with 0.91 kg/m^3.min. 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. In terms of environmental impact, there might be significant values in reduction of sago waste in the river stream and reduction of carbon emission caused by cement, since based on demand analysis, the waste still can be used for admixture of production bricks. For recommendation, it is suggested to extend study with other tests such as permeability, carbonation and shrinkage test to investigate the durability of SFW and to improve the knowledge on the effect of SFW in production of brick. Therefore, the physical and mechanical properties of brick can be improved.

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