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Development of brick by utilizing rice husk ash as the partial replacement for clay

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Abstract The study was conducted at Sylhet Agricultural University Campus to find out how adding rice husk ash (RHA) affected the characteristics of Sylhet clay bricks. The goal of the study was to establish the ideal RHA percentage to utilize in brick production as well as the impact of RHA on the water absorption, compressive strength, shrinkage, density, and thermal properties of bricks. Therefore, an attempt has been made by using RHA from 5-20% by weight as clay replacement for bricks. The study figured out that water absorption of bricks increases with the increasing percentage of RHA. Brick containing 5% RHA showed the lowest water absorption, which was 17.8%, and the highest was 21.33% for 20% RHA-containing brick. It was also found that the highest compressive strength among all types of bricks was 8.401 N/mm^2 for 5% RHA-containing brick. Similarly, the brick containing 5% RHA had the maximum density (1676.395 Kg/m^3) and thermal conductivity (0.584 Wm^{-1}K^{-1}) of all the bricks combined with rice husk ash. The study also revealed no significant changes in shrinkage for all RHA Bricks and the percentages were the same, which was 14.28%. From the investigation, it is seen 5% rice husk ash can be the optimum percentage when mixing with clay and can be used in replace of first-class as well as second and third-class Manual Handling bricks, which are used in the construction of internal walls, foundations, and in temporary structures, respectively.

Keywords: water absorption, compressive strength, shrinkage, density, thermal conductivity, leachate

1. Introduction

Rice is a major agricultural crop in Bangladesh. The country produces 34.5 million metric tons of rice (the 4th largest in the world) annually and uses almost all of its production to feed its population (Baral 2016). About 78% of the weight of the paddy is received as rice, broken grains, and bran during milling, and the remaining 22% of the weight of the paddy is obtained as husk (Singh et al 2015). About 75% of the weight of this husk is made up of volatile organic stuff, while the remaining 25% is burned away to create rice husk ash (RHA) (Singh et al 2015). This RHA comprises 90%-95% amorphous silica (SiO_2) (Safiuddin 2010).

A small building component known as a brick is created from clay or mixtures and burnt in a kiln to achieve strength, hardness, and heat resistance. Due to its unique physical, chemical, and mechanical characteristics, brick is one of the most widely used building materials. Because of the significant demand for brick that has been created, particularly in the last few decades due to the growing population, brick materials are consistently in short supply. Currently, 1,500 billion units of bricks are produced each year worldwide, 1,300 billion (or 87%) of which are produced in Asia (Rahman 2022). Bricks are often exclusively produced of clay and water in Bangladesh. Engineers have been facing challenges in meeting the demand for brick material i.e., clay. To mitigate the demand for brick material and reduce environmental issues, alternative building material for bricks is required. This can be achieved by properly utilizing various agricultural or industrial by-products.

As Bangladesh produces enormous amounts of rice husk ash each year, which has an amorphous silica component, this will significantly lower the cost of building and can be used to create low-cost energy-saving brick (Kamruzzaman et al 2015). Khabir et al (2013) estimated that Bangladesh produces 9.9 million tonnes of rice husk and 2.5 million tonnes of rice husk ash per year. Tonnayopas et al (2008) successfully used burnt Rice Husk in clay brick to create high-quality bricks. The organic properties of RHA contribute more to the furnace's heat input. According to test results, the production of building-fired brick can employ a mixture containing up to 50% RHA additives by weight, especially for lightweight brick (Tonnayopas et al 2008). The addition of RHA material enhanced the physical and mechanical qualities of the clay mixture. The manufacturing of bricks from RHA waste contributes economically and offers building materials that are energy efficient. According to Hossain et al (2011), adding RHA to a brick does not modify the shape or size of the brick; hence the volume of the brick stays the same.

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Therefore, the objective of this study was to determine how adding rice husk ash to clay bricks affects certain qualities while preserving other properties, such as compressive strength, water absorption, density, thermal conductivity, and shrinkage.

2. Materials and Methods

2.1. Materials for RHA Brick

The clay used for this experiment was collected from Khadim and Boteshwar (located in Sylhet Sadar Upazilla). It was retrieved from a 3foot deep trench close to the local river. An excavator was used to dig and excavate the pit. Clay-based building materials have plastic characteristics and are also exceedingly compressible, robust, durable, fire, and weather-resistant.

Rice Husk was collected from the local rice mill of Majortila and Shahparan area of Sylhet Sadar Upazilla. Kerosene (approximately 100 ml) was sprinkled over the rice husk material before being burned for 8 to 9 hours that was open to the air. The amorphous content is influenced by holding time and burning temperature. When burning was completed, grey to blackish ash was obtained (Figure 1).

Figure 1 Rice husk ash.

2.2. RHA Brick Sample Preparation

Water, clay soil, and rice husk ash were used as the investigation's primary basic ingredients. The clay particles were screened through 4.75 mm sieve (ASTM E11 mesh No. 4) to remove unwanted foreign objects, such as aggregates, stones, or other contaminants and to create uniformly fine clay. The clay was then transferred through a pug mill to be mixed together homogenously and it was naturally dried for a few days to remove the moisture content that was already present so that the moisture amount utilized to create the sample could not be varied.

Samples were prepared by mixing, molding, drying, and firing. According to weight %, clay, water, and uniformly sized RHA were combined in an optimum ratio. Of the total brick weight, 5%, 10%, 15%, and 20% of RHA were extracted and blended with 95%, 90%, 85%, and 80% clay, respectively (Table 1). Uniaxial pressing was used to prepare hand-molded bricks. After that, sample bricks were allowed to dry naturally for 4-5 days in the air (Figure 2). Bricks were fired in a brick kiln at temperatures between 900°C-1100°C for seven to ten days before being properly burned and collected.

Table 1 Mixing proportion of clay and RHA.

Rice Husk Ash Bricks			
Sample	Clay (gm)	Rice Husk Ash (gm)	Total Wt. (gm)
R-0%	3500	0	3500
R-5%	3325	175	3500
R-10%	3150	350	3500
R-15%	2975	525	3500
R-20%	2800	700	3500

Figure 2 Bricks with different % of rice husk ash.

2.3. Measurement of Properties

2.3.1. Water Absorption Test

Three sample bricks of each kind were taken to test the water absorption of the burnt bricks. In the beginning, bricks were exposed to sunshine for a day while the dry weight was recorded. The weight of the bricks after being submerged in water for a day was also measured. Then water absorption percentage was calculated using the following equation (IS 3495:1992, Part II):

$$\text{Water absorption \%} = \frac{W2-W1}{W1} \times 100 \qquad (1)$$

where,
W_1 = Wt. of dry brick.
W_2 = Wt. of wet brick after 24 hours.

2.3.2. Compressive strength Test

Compressive strength tests on bricks were performed to measure the load-carrying capacity of bricks under compression. This test was carried out with the help of a Universal Testing Machine in the laboratory of the Department of Civil & Environmental Engineering at Shahjalal University of Science & Technology, Sylhet. Compressive strength was calculated from this formula (IS 3495:1992, Part I):

$$S = \frac{P}{A} \qquad (2)$$

where,
S = Crushing strength, MPa.
P = Maximum applied load, N.
A = Cross-sectional area (Thickness × Width), mm^2.

2.3.3. Shrinkage Test

The firing process causes shrinkage in clay brick. To measure the firing shrinkage of clay brick, the following formula was applied:

$$S = \frac{(La-Ld)}{La} \times 100 \qquad (3)$$

where,
S = Percentage of firing shrinkage.
L_a = Actual length.
L_d = Dry length.

2.3.4. Leachate Test

- 4 bricks were taken for the leachate test i.e., R-5%, R-10%, R-15%, and R-20%.
- Sodium Sulfate (Na_2SO_4) was used as the reagent.
- Bricks were immersed in 6-liter water with 3000 gm of Sodium Sulfate (Na_2SO_4).
- Bricks were immersed for 24 hours.
- pH, temperature, and iron concentration tests were conducted.

2.3.5. Thermal Conductivity Test

Thermal conductivity was obtained using a model derived from a literature review using 256 test results for the thermal conductivity of various types of brick, concrete, and aggregates (Dondi et al 2004; Demirbas 2004; Blanco et al 2000; Glenn et al 1998), and measured as a part of this study by the following formula:

$$T = 0.0559e^{(0.0014D)} \qquad (4)$$

Where T stands for Thermal conductivity in $Wm^{-1}K^{-1}$ and D is the Dry density of the bricks in Kg/m^3.

3. Results and discussion

3.1 Water Absorption Analysis

Brick's strength depends on its water absorption capacity. Water absorption of bricks occurs due to the presence of pores or voids in the bricks. The more pores or voids in the brick, the more it will absorb water and reduces the load-carrying capacity. It was observed that for RHA bricks, water absorption increases with the increased percentage of RHA.

However, the rate of increase of water absorption was not the same, and it was relatively slow (Figure 3). According to Tonnayopas et al (2008), it can be seen that an increase in RHA replacement leads to an increase in water absorption. It was also observed that First Class bricks, in the case of Manual Handling bricks, absorbed a very lower percentage 15.93% (Figure 4) of water compared to RHA bricks (17.8%, 18.08%, 19.13%, 21.33%). But, Second and Third Class bricks absorbed (16.47% and 18.7%, respectively) nearly similar percentages to RHA bricks. The addition of 10% by weight of rice husk ash showed a minimum water absorption of 15.5% (Maheswari et al 2020).

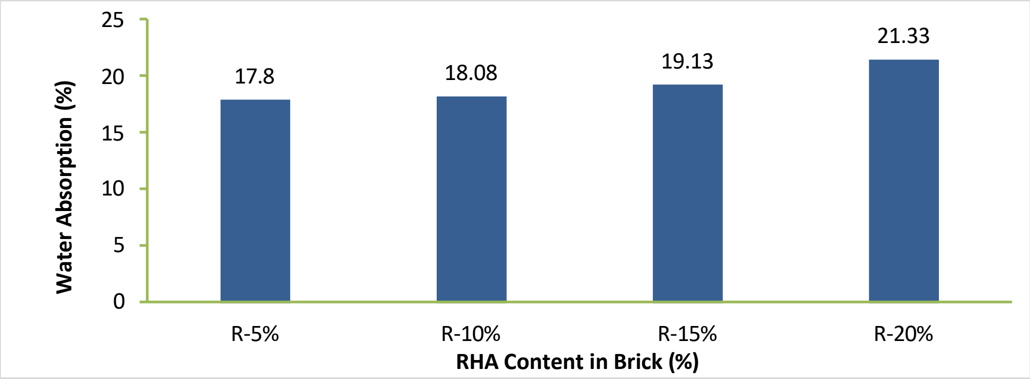

Figure 3 Water absorption % of RHA bricks.

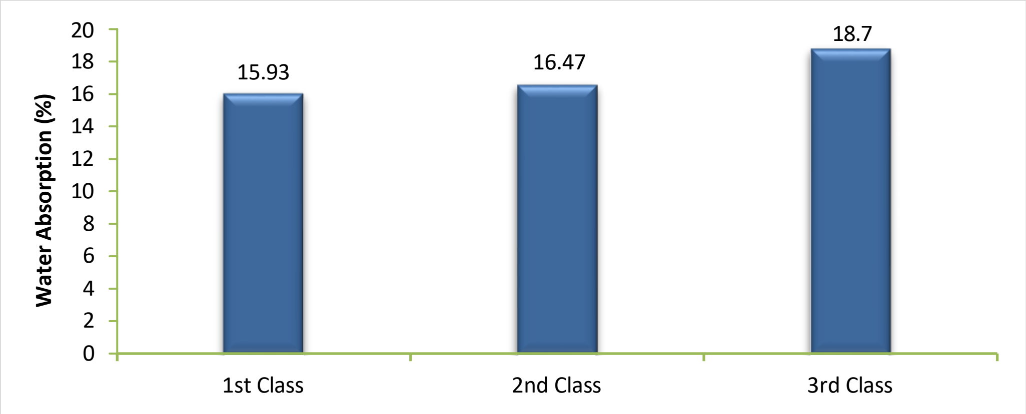

Figure 4 Water absorption % of manual handling bricks.

3.2 Compressive Strength

It was figured out that compressive strength for 5% RHA brick was higher (8.401 N/mm^2) than other percentages of RHA bricks. It seemed increasing the RHA amount decreases compressive strength. But, at 20% RHA bricks, the compressive strength was slightly higher than 10% and 15% RHA bricks (Figure 5). Adding 10 % rice husk ash showed the highest strength at 5.97 N/mm^2 (Janbuala and Wasanapiarnpong 2015).

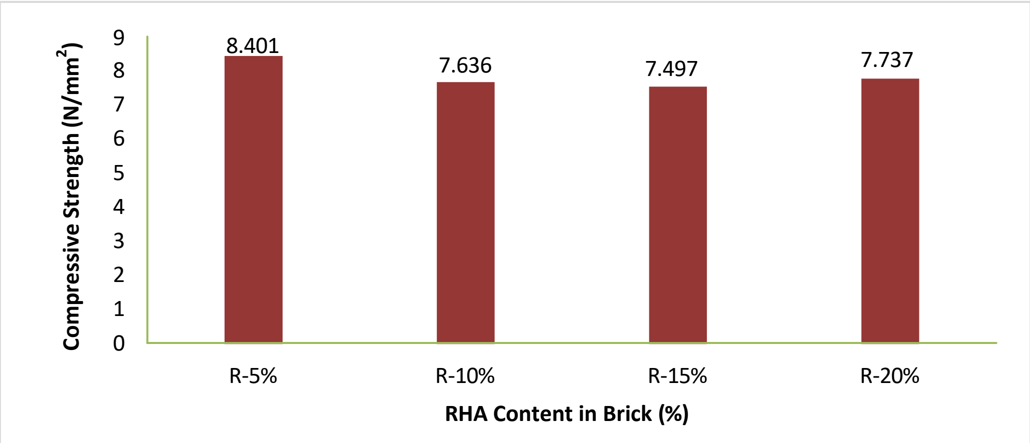

Figure 5 Compressive strength of RHA bricks.

It was observed that for Manual Handling First Class Brick, the compressive strength was 5.488 N/mm^2 (Figure 6). It was higher than the Second Class and Third Class bricks (5.191 N/mm^2 and 4.768 N/mm^2, respectively). It also showed that the compressive strength for Manual Handling Bricks was relatively lower than RHA bricks. Up to 20% of rice husk added to clay causes a progressive loss in strength, after that point, the compressive strengths rapidly decline. The addition of 10% by weight of rice husk gave a maximum compressive strength of 4.44 N/mm^2 (Maheswari et al 2020).

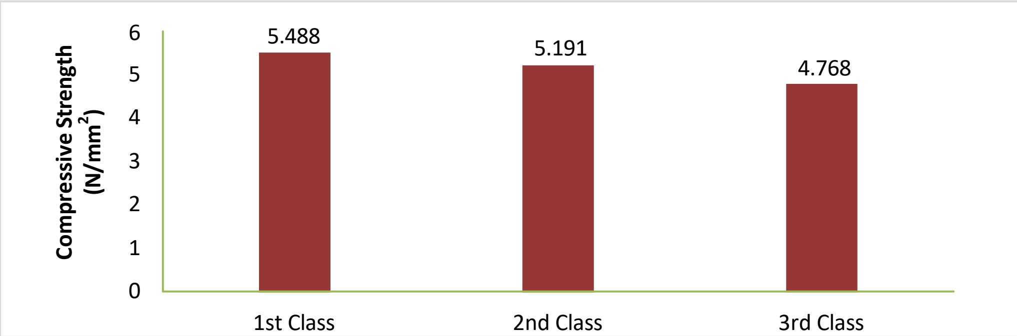

Figure 6 Compressive strength of manual handling bricks.

3.3 Shrinkage

Tensile stress increases due to shrinkage which can result in cracking, internal bending, and outward deflection. The quantity of shrinkage is affected by several variables, including the qualities of the constituent parts, their quantities, how they are mixed, how much moisture is present during molding, how dry the atmosphere is, and the size of the brick. The firing shrinkage effect will be greater if there is more water in the fresh brick.

It was observed that Firing Shrinkage for all RHA Bricks (5%, 10%, 15%, 20) was the same (14.285%) (Figure 7).

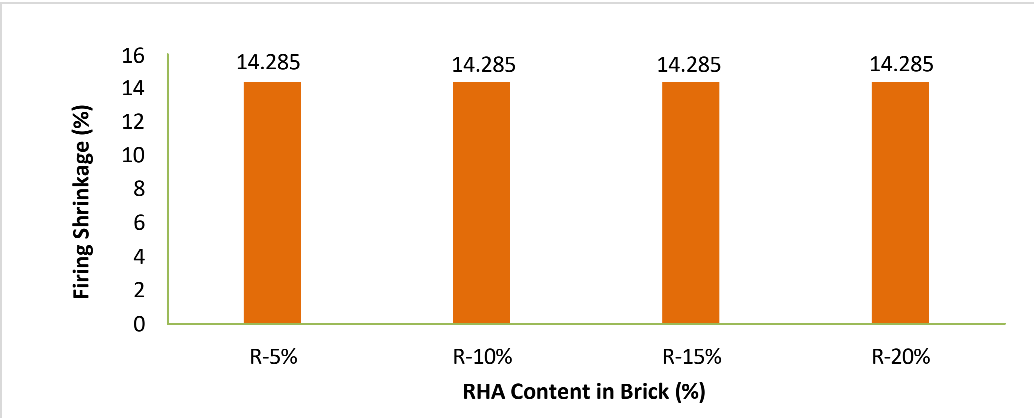

Figure 7 Firing shrinkage of RHA bricks.

It was figured out that, Firing shrinkage for 1st class manual handling bricks was 14.285% which was the same as RHA bricks. But, Firing Shrinkage for Second Class and Third Class bricks (both were 11.923%) lower than the First Class bricks (Figure 8). The linear firing shrinkage is decreased as the RHA addition content is increased (Tonnayopas et al 2008).

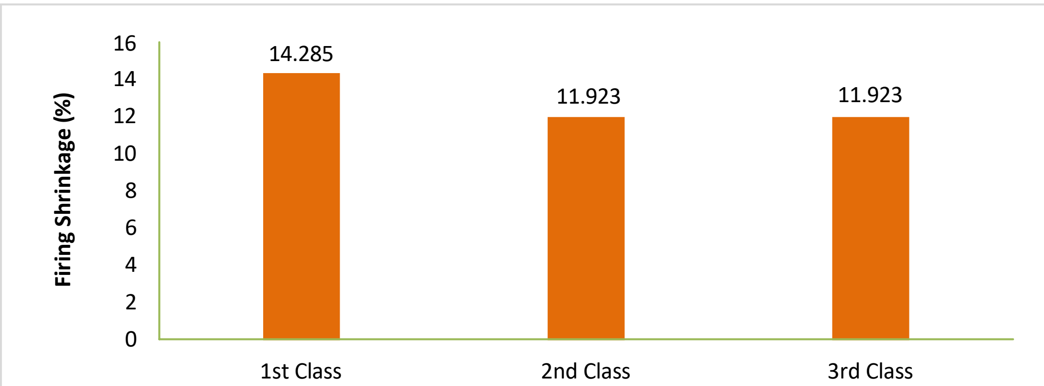

Figure 8 Firing shrinkage of manual handling bricks.

3.4 Density

Bricks became lighter as the Rice Husk Ash percentages increased (Figure 9). Bricks became lighter for 20% of the RHA percentage. The densities for burnt RHA brick samples R-5%, R-10%, R-15%, and R-20% had 1676.395, 1504.398, 1471.961, and 1403.98 Kg/m^3, respectively.

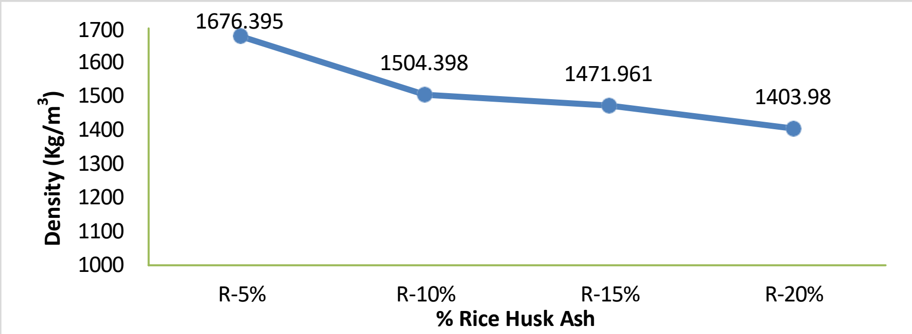

Figure 9 Density curve of RHA bricks.

Lastly, Figure 10 illustrates the density curve of Manual Handling bricks. For the Manual Handling bricks, 1st class had the most density among others, i.e., 1992.773 Kg/m^3. Brick got the highest density 1676.395 Kg/m^3, for 5% of Rice Husk Ash. Clay brick densities ranged from 1670 to 1850 Kg/m^3 in Karaman's (2006) study.

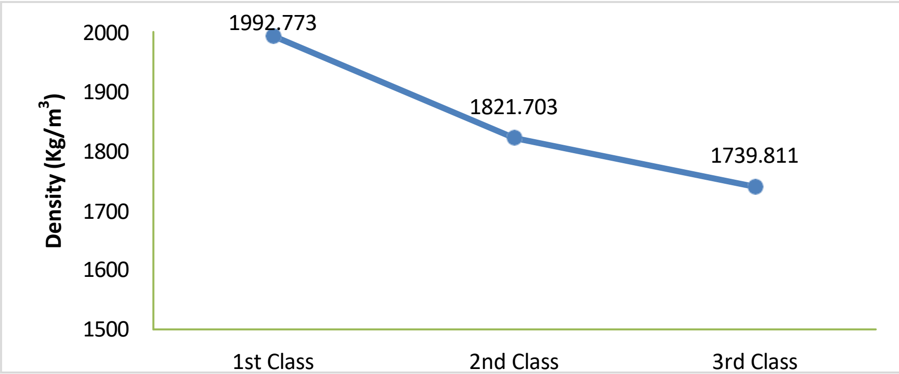

Figure 10 Density curve of manual handling bricks.

3.5 Thermal Conductivity

Bricks must reduce heat transfer from one side of the wall to the other. The good brick should have low thermal conductivity to keep the house cool in the summer and warm in the winter. According to earlier research, the thermal conductivity of handmade bricks varied from 0.59 to 0.61 Wm^{-1}K^{-1} (Cabeza-Prieto 2022).

The Figures 11 and 12 depict the Thermal Conductivity of Rice Husk Ash and Manual Handling bricks. Our burnt RHA brick sample R-5%, R-10%, R-15%, and R-20% had 0.584, 0.459, 0.439, and 0.399 Wm^{-1}K^{-1} and for Manual Handling, brick samples had 0.91, 0.716, 0.639 Wm^{-1}K^{-1}, respectively. Therefore, these render good-quality bricks. A lower density will result in a lower heat conductivity (Dondi et al 2004).

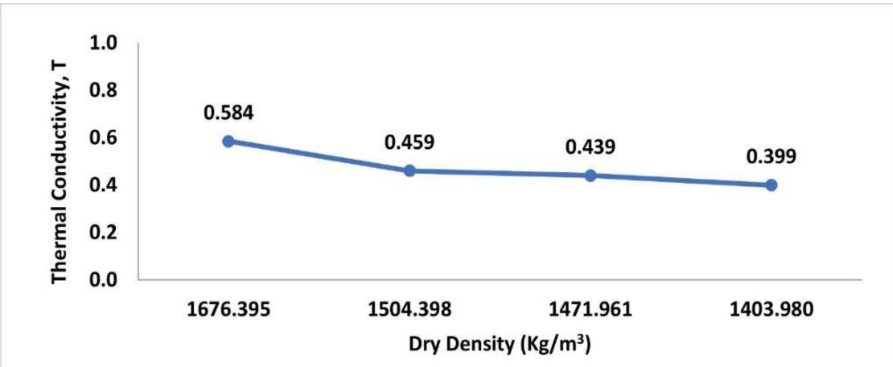

Figure 11 Thermal conductivity curve of RHA bricks.

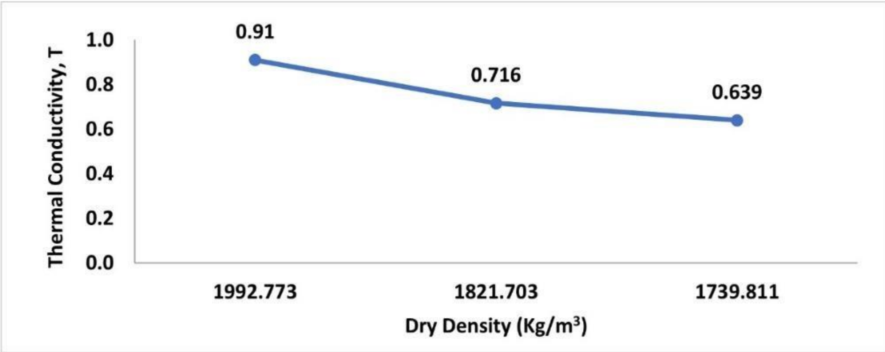

Figure 12 Thermal conductivity curve of manual handling bricks

3.6 Leachate Test

A half liter of sample water was taken from the leachate test, where RHA bricks were immersed in the sake of measuring pH, temperature, and iron concentration (Figure 13). The test results showed there was no remarkable leachate occurred (Table 2).

Table 2 Leachate test results.

Test (with Na_2SO_4)	Initial Value	Final Value
Temperature	26.1°C	26.6°C
pH	9.11	7.11
Iron Concentration (mg/L)	0.05	0.3

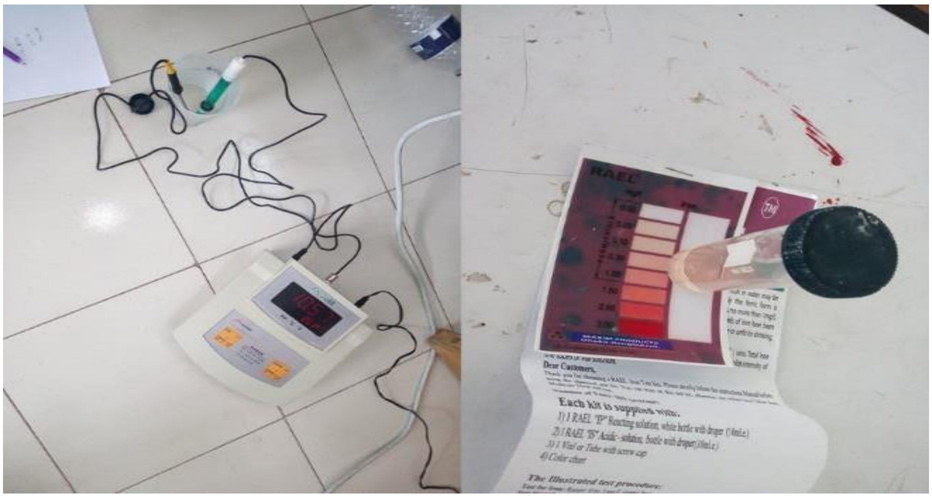

Figure 13 pH, temperature, and iron concentration test.

4. Conclusions

Compared to manual handling bricks, the bricks having rice husk ash as an admixture showed higher compressive strength. According to the study, the 5% RHA brick has the highest compressive strength of all brick kinds (8.401 N/mm^2).

Water absorption of Rice husk ash bricks is slightly higher than the manual handling bricks. It is observed that the lowest water absorption was 17.8% for 5% RHA brick and the lowest water absorption was 15.93% for 1st-class manual handling brick.

Bricks also become lighter, which can reduce the overall building's weight.

No noticeable leachate incident has occurred.

Thermal conductivity is also better than manually handled bricks. The highest thermal conductivity was found at 0.584 Wm^{-1}K^{-1} for 5% RHA brick.

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Conflict of Interest

The authors declare no conflicts of interest.

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