Chapter 5
Sustainable Geopolymer Bricks Manufacturing Using Rice Husk Ash: An Alternative to Fired Clay Bricks

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5.1 Introduction

Bricks made of fired clay are widely utilized as construction materials around the globe, particularly for houses [1]. India is the main supplier of burnt clay bricks from South Asian nations. However, the most common methods for preparing bricks include cementing them or burning them in kilns at high temperatures between 800 °C and 1200 °C, which requires much energy [2]. Therefore, many chemical-activating wastes have been used as a constituent to lower the temperature required for brick production. Similarly, other by-products were added to cement to lower the amount of cement and improve its environmental sustainability [3]. Although fusing waste and substituting by-products for cement might assist production at lower temperatures, geopolymerization is a rather environmentally beneficial approach. The method utilizes less energy and emits less CO_2 since it requires a lower temperature [4].

Rich silica and alumina components are activated during the geopolymerization process in alkaline conditions [5]. Clay and ash are examples of precursor aluminosilicate materials. Fly ash, which is relatively rich in silica and alumina among the different precursors, is readily available in many regions [5, 6]. It has a wide range of applications in cementitious products, and numerous standards have been created to ensure its effective use. However, fly ash has some drawbacks; if the optimal range raises its amount in cement concrete, the consequent strength is diminished [7]. Fly ash can only be used at excessively high rates when activated in an alkaline

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atmosphere. Many studies have also been done on fly ash-based geopolymers, but it is still difficult to make bricks by applying pressure during molding [8, 9]. Another readily available raw material is clay, which can be utilized as a precursor and an additional cementitious material. However, due to its high alumina and silica content, it may gain the strength through geopolymerization, which has a much lower temperature requirement than firing [10].

In an alkaline condition, precursors are activated, producing sufficient compressive strength. However, Bernal et al. [11] emphasized that the compressive strength exhibited noticeable differences based on the precursors' reactivity even when employing the same precursors. The particles' chemical properties and surface area, which differ according to the various sources of aluminosilicate minerals, all affect the precursor's reactivity [12, 13]. The primary consideration for choosing a precursor is the reaction rate depending on the presence of amorphous form of Si and Al in the raw ingredients to produce an excellent result [14]. Thus, the viability of a precursor must be evaluated early by assessing its level of reactivity. Fly ash is reactive, although clay is typically made reactive by alkaline activation or thermal treatment [15]. Clay is primarily cured in the 27–60 °C range after calcination. However, using such high temperatures to calcinate clay renders the entire activity undesirable; therefore, other eco-friendly methods should be used to eliminate such differences [16]. As a result, the temperature conditions need to be modified to change clay from a simple filler to a precursor for geopolymer [17].

Na/Al, Si/Al, molarity of NaOH, temperature condition, etc., are a few important factors that affect the compressive strength during geopolymerization [18]. When utilized together as an alkaline activator, NaOH and Na_2SiO_3 produce better strength growth than when used separately. Although primary studies maintained the alkali-activator ratio of 2.5 and further increased it to 3 to generate weak geopolymer, researchers found that $Na_2SiO_3/NaOH$ equal to 1 produced a strong matrix for industrial fly ash and agricultural rice husk ash-based geopolymer blends [19, 20]. Low Ca fly ash-based geopolymer concrete produces greater compressive strength when the alkaline-to-precursor ratio ranges from 0.30 to 0.45 [21]. However, a semi-dry mixture that can be instantly de-molded is desired in brick. As a result, the alkaline to precursor ratio must be decreased, which affects the compressive strength and can be accommodated by molding pressure [22]. Molding pressure, particularly for geopolymerization, is another important factor that is sometimes overlooked, may favor the compressive strength. With a lower alkaline-to-precursor ratio, pressure makes precursors more wettable, which causes more considerable dissolution and increases the compressive strength [23].

This study presents the experimental investigation on how the percentage of rice husk ash, molarity of NaOH, and curing temperature affect the properties of geopolymer bricks. In addition, it uses leftover broken bricks and rice husk ash at the brick kiln as a precursor material to develop a new and sustainable brick for construction projects.

5.2 Methodology

This investigation used rice husk ash and brick waste powder as precursors, with sodium hydroxide pallets and sodium silicate gel. Waste bricks and rice husk ash were collected from the brick kiln site near Bhimavaram, India. Waste bricks were collected and crushed in an initial crusher unit before being ground into a fine powder that could pass through a 300 μm sieve. Figures 5.1 and 5.2 illustrate the raw materials gathered at locations in the field and X-ray diffraction patterns (XRD), respectively. The sodium silicate gel to sodium hydroxide solution ratio was kept at 1.5, and alkali materials included sodium hydroxide solutions with 3 and 5 molarities. Moreover, the alkali activator to solids ratio was kept at 0.45. Table 5.1 lists the chemical constituents of brick powder and rice husk ash.

In this research work, precursors were mixed for 5 min, an alkali-activated solution was added, and casting was done. A total of six mixes were prepared with varying percentages of rice husk ash as 0%, 10%, 20%, 30%, 40%, and 50% in the waste brick powder geopolymer blends. The reference mixes were designated as M0, M1, M2, M3, M4, and M5, respectively for 0%, 10%, 20%, 30%, 40%, and 50% of rice husk ash in the blends. The specimens were manually compressed using a wooden compressor to create bricks with the dimensions of 190 × 90 × 90 mm. To prevent the water evaporation, the specimens were then covered. The molds were removed after the specimens had been at room temperature for 24 h, and one set of specimens underwent typical ambient curing for 56 days, while the other set was cured in the oven at 100 °C for 24 h. This study examined the curing conditions and molarity of NaOH on the specimens. Research has revealed that the geopolymer mixes' CO_2 emissions, energy efficiency, and cost-effectiveness decreased as NaOH molarity was reduced [24].

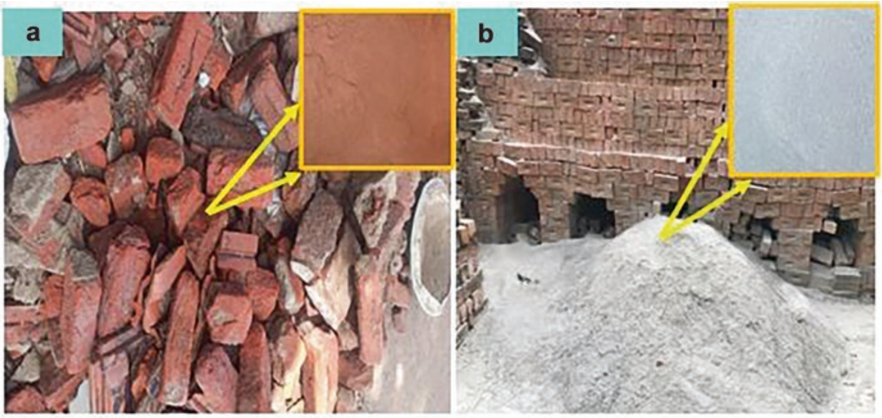

Fig. 5.1 Raw materials: (**a**) brick powder from waste bricks, (**b**) rice husk ash at brick kiln

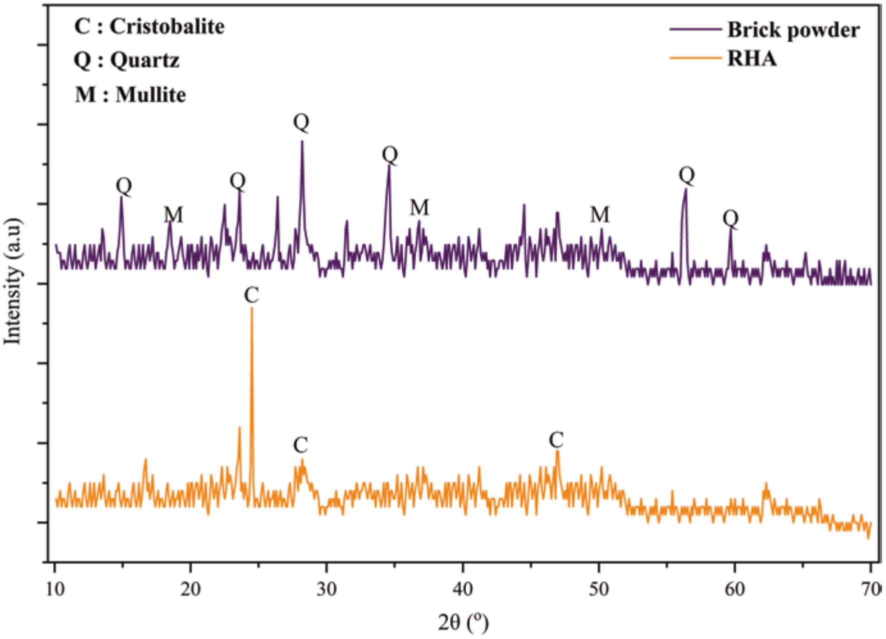

Fig. 5.2 XRD patterns of brick powder and rice husk ash (RHA)

Table 5.1 Chemical constituents of brick powder and rice husk ash

	Chemical constituents (%)					
Materials	SiO_2	Al_2O_3	MgO	K_2O	CaO	Fe_2O_3
Brick powder	69.4	13.6	1.7	4.1	1.3	7.4
Rice husk ash	95.4	0.4	0.5	0.1	0.7	0.6

5.3 Results and Discussion

5.3.1 Bulk Density and Strength Behavior of Geopolymer Bricks

Table 5.2 and Fig. 5.3 display the geopolymer bricks’ bulk density and compressive strength, respectively, as a function of variations in molarity of NaOH and curing temperature. In the table and figure, 3M and 5M stand for 3 molarity and 5 molarity of NaOH, respectively. Molarity of NaOH and curing temperature were the crucial and significant parameters in geopolymerization reaction and from sustainability aspects. Si and Al can dissolve from the aluminosilicate source more readily when there is greater alkalinity.

In all mixes, bricks had a density between 1565 and 1810 kg/m^3. Moreover, a small increase in the density was noted in higher NaOH molarity of geopolymer bricks, since sodium hydroxide with 5 molarity was higher than 3 molarity. Higher

Table 5.2 Bulk density of geopolymer bricks

	Bulk density (kg/m^3)			
	Ambient curing for 28 days		Oven curing at 100 °C for 24 h	
Mixes	3M	5M	3M	5M
MO	1745	1790	1780	1810
M1	1725	1745	1750	1760
M2	1675	1705	1690	1740
M3	1615	1670	1630	1690
M4	1590	1635	1605	1675
M5	1565	1580	1585	1640

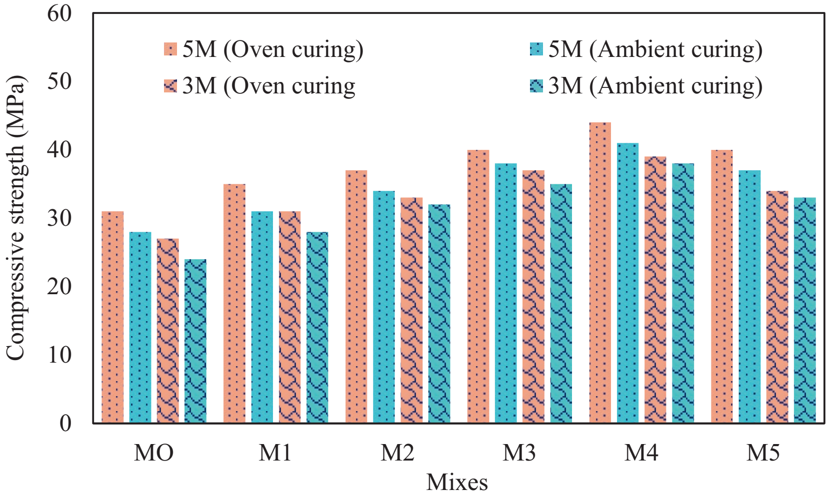

Fig. 5.3 Compressive strength of geopolymer bricks

compressive strength was obtained by high NaOH molarity and high NaOH molarity concentration. Compared to molarities of 3 and 5, an alkaline solution of 3 molarity demonstrated the maximum compressive strength in the present investigation. Since a lower NaOH molarity is less effective in the strength development, a similar result was observed in previous studies. All geopolymer bricks achieved higher compressive strength than the first-class brick standard as per IS 3495-1976, which is 105 kg/cm^2 (10.29 MPa) [25]. The highest compressive strength of 44 MPa (448.6 kg/cm^2) was reached in the current study using 5 molarity alkaline solution and oven curing temperature of 100 °C for 24 h.

The compressive strength is divided into two categories by the Indian standard: the load-bearing range and the non-load-bearing range. A closer examination of clay brick waste-blended geopolymer bricks cast in this study and their compressive strengths in comparison to the standard indicated that all percentages of geopolymer bricks exhibited higher compressive strength than the standard load-bearing range (>5 MPa).

5.3.2 Water Absorption Capacity of Geopolymer Bricks

Table 5.3 depicts the geopolymer bricks' water absorption with varying NaOH solution concentration and curing condition. The Si/Al, Na/Al, and NaOH molarity are the important factors that affect the porosity of bricks, resulting in water absorption changes. The number of aluminosilicate bonds that forms increases with optimal molarity, Na_2SiO_3/NaOH ratio, and curing condition, making the mixture denser and more durable.

The higher percentages of rice husk ash improve the Al and Si leaching in the alkaline solution, and with higher concentration of NaOH the dense phases enhance, which results in fewer pores and impervious behavior of bricks. Additionally, the mixture's entire geopolymerization depends on the efficient curing temperature. Both molarity and curing temperature were considered to evaluate the physio-mechanical characteristics of bricks made of brick waste powder with an alkali activator. Bricks with higher dosages of additive content, molarity, and curing condition improved the water absorption capacity of bricks, as shown in Table 5.3. For instance, a higher percentage of rice husk ash blend provided lower water absorption at a given curing condition. The Si/Al ratio rises with an alkaline solution ratio, increasing the matrix complexity and density while decreasing the porosity. Maaze and Shrivastava [26] reported that the dense phases of geopolymer gel might impact the toughness of blended bricks, because it removes the essential component and weakens the dense phase, creating many voids in the mix. Some blends with a high alkaline activator had greater porosity, which increased the water absorption. Geopolymer bricks illustrated the desirable ranges and met the requirements of IS 12894-2002 and had water absorption rates of under 15% [26].

5.3.3 Micro-Structural Behavior of Geopolymer Bricks

Scanning electron microscopy (SEM) analysis was performed on the geopolymer brick mixes (M3 and M5), as displayed in Fig. 5.4. The surface texture and morphology of the brick specimens describe different aspects, such as the brick powder

Table 5.3 Water absorption of geopolymer bricks

	Water absorption (%)			
	Ambient curing for 28 days		Oven curing at 100 °C for 24 h	
Mixes	3M	5M	3M	5M
MO	14.5	13.9	13.8	13.1
M1	13.3	13.2	13.1	12.3
M2	12.7	12.2	12.4	11.4
M3	12.1	11.7	11.3	10.9
M4	13.7	12.5	11.7	12.1
M5	14.8	13.8	12.8	12.4

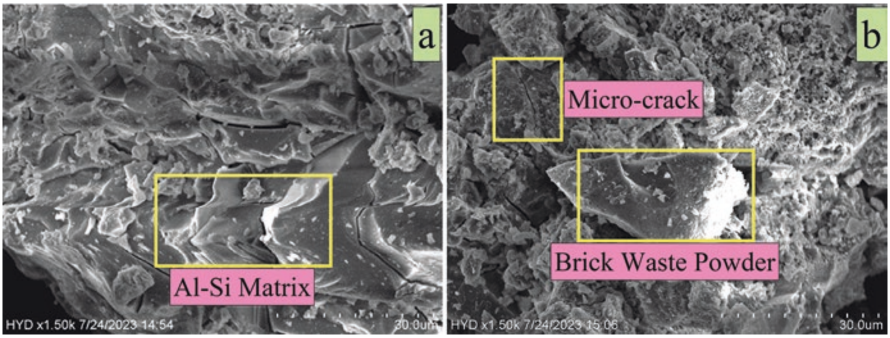

Fig. 5.4 SEM micrographs of mixes: (**a**) M3, (**b**) M5

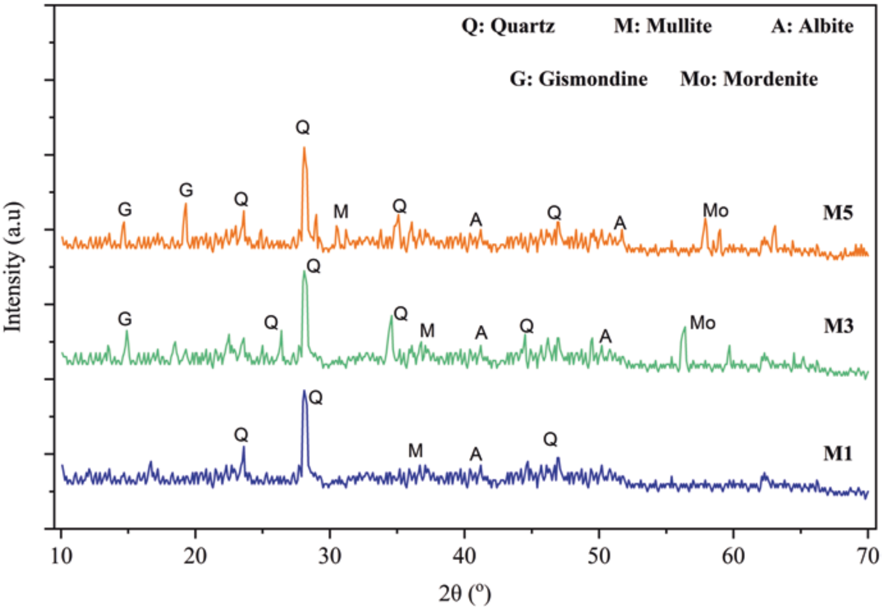

Fig. 5.5 XRD patterns of geopolymer bricks

and rice husk ash reactions in the geopolymer matrix. The SEM micrographs revealed the formation of many closely packed phases. Moreover, the amorphous silica presence of rice husk ash particles contributed to the Al-Si matrix. Developing a well-compacted geopolymer matrix could improve the porosity, water absorption, and compressive strength (Fig. 5.4).

Figure 5.5 depicts the XRD traces of geopolymer bricks with varying percentages of rice husk ash as replacement of brick powder, while the major peaks were observed in between the 2θ values of 22 and 34. The peaks represented the various crystal forms (quartz), and also indicated the other forms of crystalline particles present in the powder of waste brick. In addition, along with the albite ($NaAlSi_3O_8$), other traces such as orthoclase ($KAlSi_3O_8$) and gismondine ($CaAl_2Si_2O_8\cdot4H_2O$) were found in the geopolymer matrix. The tri-dimensional alumina silicate network (N—A—S—H) was found in geopolymer bricks in the form of mordenite ($Na_2Al_2Si_{10}O_{24}\cdot7H_2O$), which enhanced the dense phases and allowed the increase in the compressive strength and reduction in the water absorption.

5.3.4 Sustainability Aspects of Geopolymer Bricks

According to our findings, using clay bricks for walls has the most significant environmental impact because coal is utilized in the burning process. However, using bricks derived from agricultural waste has less environmental impact. The primary source of all emissions is coal combustion. Most of the time, the coal used for burning is of poor quality with a high sulfur content [27]. Because cement is their primary component, fly ash bricks have substantial effects. Each kg of cement emits roughly 0.83 kg CO_2 equivalent. Therefore, cement utilized in brick production contributes considerably to overall fly ash brick emissions [27]. Due to the lack of a firing process, geopolymer bricks from agricultural biomass blends have a less noticeable impact. NaOH and Na_2SiO_3 are important geopolymers with 1.88 and 1.915 kg CO_2 equivalent emissions per kg, respectively [28]. On the other hand, geopolymer bricks reflect the decreased consumption of Na_2SiO_3 and NaOH by adopting a lower molarity of 3 and maintaining the ratio of Na_2SiO_3 to NaOH at 1.5. The global warming potential of each brick is demonstrated in Fig. 5.6.

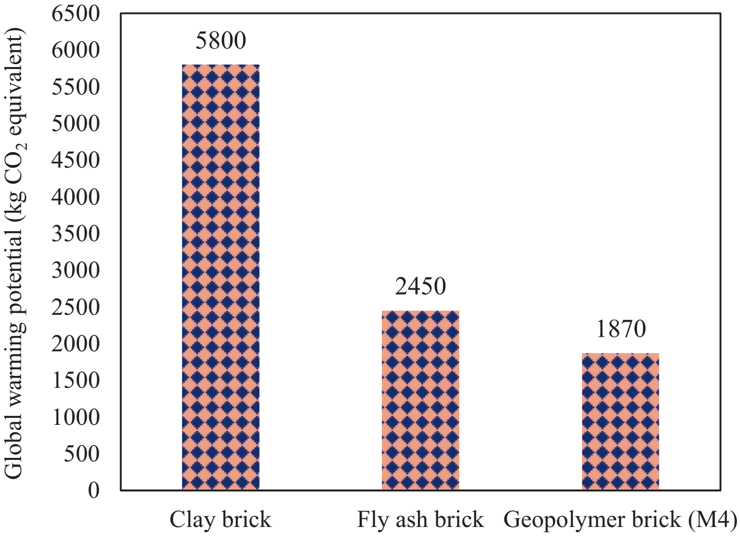

Fig. 5.6 Global warming potential of various bricks

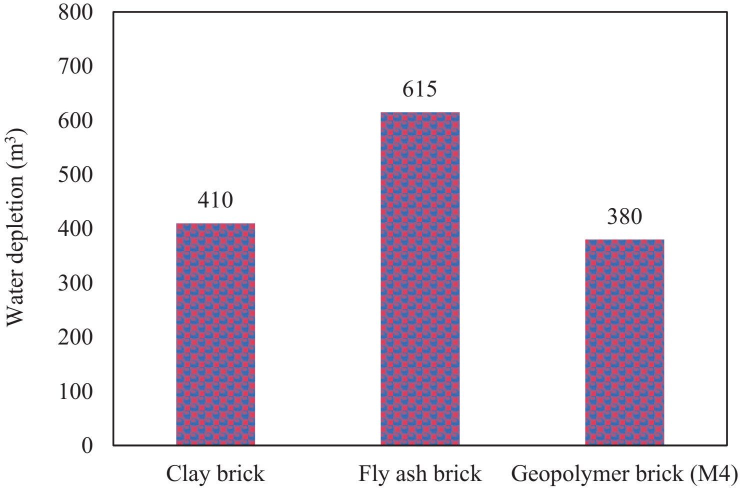

Fig. 5.7 Water depletion of various bricks

Figure 5.7 illustrates the operation's total water consumption, including brick and brickwork production. Since more water was needed to cure fly ash bricks, there was a considerable water shortage. Bricks made of clay and geopolymer had no cement content. Hence, water was not needed to cure them. The geopolymer brick's molding water content was lower than clay bricks.

5.4 Conclusions

This chapter focused on the possibilities for recycling waste bricks and agricultural waste rice husk ash to make construction materials made of geopolymers. The following conclusions can be drawn:

Addition of rice husk ash to geopolymer bricks decreased bulk densities due to lightweight (low specific gravity) rice husk ash. The highest bulk density was lower than 1700 kg/m^3, considerably lower than the range indicated in the standard (1700–2100 kg/m^3). It would therefore result in the production of lightweight and sustainable materials. When the amount of rice husk ash in geopolymer blends increased, the compressive strength enhanced dramatically. Furthermore, increased molarity and curing temperature showed stronger bonds at a given precursor concentration. The curing temperature and NaOH molarity concentration in the brick mixes had a substantial impact on the water absorption of the brick mixes. Increases in the dense matrix of the blends and consistent geopolymerization at higher curing temperatures minimized the water absorption of geopolymer brick specimens.

A large number of bricks are produced annually in the world, producing huge amounts of particulate matter, CO, and CO_2. Therefore, switching to geopolymer bricks instead of conventional bricks is sustainable for future development. A wide range of uses, including masonry, wall panels, pavers, industrial flooring, and canal lining are possible using geopolymer bricks with air curing.

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