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Manufacturing of Low-Cost Bricks Using Waste Materials †

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Abstract: Bricks consume a massive quantity of clay. Using clay bricks causes erosion, lowers the water table, and harms the environment. This research examined various waste materials, including fly ash, quarry dust, marble dust, eggshell powder (ESP), and rice husk ash (RHA), in varying percentages to avoid using clay in manufacturing bricks. Compressive strength and water absorption tests were conducted, and the results were compared with the specifications for traditional clay bricks. It was observed that the compressive strength and water absorption values met the relevant standards needed for standard construction bricks. Furthermore, the cost of manufacturing bricks from waste materials was estimated, and the findings show that manufacturing bricks from waste materials cost less than conventional bricks. Finally, it was concluded that the brick industry could become more sustainable and economically feasible by using specific waste materials in manufacturing bricks.

Keywords: clay bricks; waste materials; cost estimation; production

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1. Introduction

Bricks are widely used in construction projects as they possess beneficial characteristics such as low cost, high durability, and ease of handling [1]. Clay is the primary raw material used in brick production. For brick manufacturing, almost 340 billion tons of clay are used annually [2]. The increasing clay use as a resource for manufacturing bricks has caused an alarmingly high degree of variance in this natural material [3]. This has therefore led several researchers to find alternative resources or ways to recycle the wastes produced by various industrial processes. As a result, many waste materials have been used in brick manufacturing, including marble dust [4], sludge from water treatment plants [5], fly ash [6], sugarcane bagasse ash [7], rice husk ash (RHA) [8], waste glass powder [9], sawdust [10], quarry dust [11], and eggshell powder (ESP) [12]. The properties of clay must be altered by the additives physically and chemically within a specific range, and they must not adversely affect the clay's strength and durability [13].

Fly ash is a typical clay component generated when coal is burned in coal-fired power plants. It is a varied substance with a glossy appearance made of mullite (alumina and silica) and iron oxides (hematite and magnetite) [14]. Its elemental composition is similar to that of brick soils. Bricks' strength can be increased and water absorption reduced by adding fly ash to clay [15,16]. RHA is a potential source of Amphorous reactive silica released by the combustion of rice hulls [17]. It has excellent thermal insulation and keeps the temperature stable. According to a study by Ramasamy [18], adding a small amount of RHA will increase the material's compressive strength. Food processing firms produce tons of eggshells as waste, which has led to environmental issues because of their inappropriate disposal in our environment [19]. The calcium carbonate in ESP dissolves in different acids and has a chemical composition similar to limestone [20]. ESPs are potential substitute raw materials for clay brick production [12].

A study by Dhanapandian and Gnanavel [21] indicated that up to 20% of waste marble powder improved water absorption. Adding waste marble to clay reduces the fire temperature without affecting the brick's properties [22] and thus lowers the production cost and saves energy. The bricks' physical strength at high temperatures was increased by including waste marble [23]. The fluxing effect of these wastes at higher temperatures boosted several brick properties, most notably flexural strength, compressive strength, and bulk density [4]. Past studies, e.g., from the authors of [24], have proven that waste marble powder may be used inexpensively in clay bricks. Quarry dust is produced by cutting and grinding the stone. Depending on the quarry fine dust's physical and chemical properties, it may be used to produce bricks as a filler, a replacement for clay, a colorant, a fluxing agent, or even body fuels [25]. Quarry dust addition improves the bricks' durability [26]. The potential use of naturally occurring wastes, readily accessible and inexpensive, is becoming increasingly more important in reducing building material costs without sacrificing quality. Given the above, this study investigated the behavior of bricks made by replacing clay with waste materials such as ESP, RHA, fly ash, quarry dust, and marble dust and estimated the cost of brick production.

2. Materials and Methods

2.1. Materials

The waste materials such as fly ash, quarry dust, marble dust, ESP, and RHA were collected from local dealers in Rajapalayam, Tamilnadu, India. Figure 1 shows the mixtures of all waste materials used in this study. The chemical composition of raw materials is shown in Table 1.

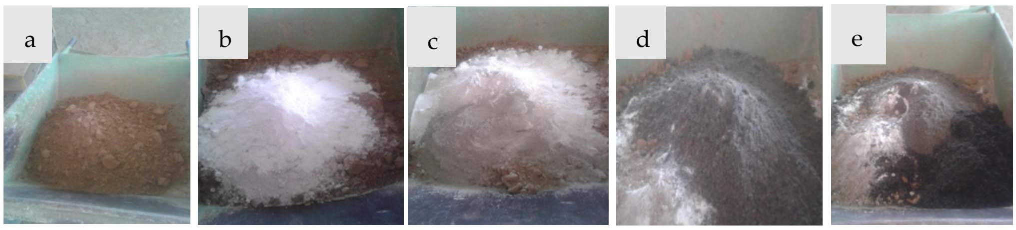

Figure 1. Waste materials: (**a**) class-C fly ash, (**b**) addition of ESP, (**c**) addition of marble dust, (**d**) quarry dust addition, and (**e**) RHA addition.

Table 1. Raw materials' chemical composition (% by weight).

Component	Fly Ash	Marble Dust	RHA	ESP	Quarry Dust	Cement
SiO_2	35–59	28.35	90.20	0.01	69.94	21.54
Al_2O_3	23–33	0.42	0.85	0.01	14.60	5.32
CaO	10–16	40.45	1.18	52.75	2.23	63.60
Loss on ignition	1–2	-	3.95	46.62	-	-
S	0.5–1.5	-	-	0.5-1.5	-	-
Fe	0.5–2	-	-	-	-	-
Fe_2O_3	-	9.7	1.38	0.01	2.16	3.6
MgO	-	16.25	1.21	0.51	0.38	1
SO_3	-	-	-	0.62	-	-

2.2. Mixing and Specimen Preparation Procedure

Different proportions of raw materials were used to make bricks, as shown in Table 2. The collected waste materials, cement, and water were mixed using a pan mixer until a consistent mixture was obtained. It was noted that to maintain the same amount of mixture consistency, for each trial, the amount of added water was 3 to 4 liters for a weight of 21 kg, and the amount of water used in each trial varied depending on the materials used. A conveyor belt was used to transport the mixed materials to the compression system for compacting, and bricks were cast using a hydraulic pressing machine with a 2200 psi pressure. The amount of compression that one brick was subjected to varied depending on the size of the materials. A total of 120 bricks (24 in each mixing ratio) were produced, each brick weighing approximately 3.5 kg. The produced bricks were taken and stacked for curing for 21 days to ensure a high-quality product [16]. A plastic sheet was laid in an area close to the brick-making unit and was covered immediately with a jute sack to prevent the bricks from drying too quickly. They were watered once every day for seven days, and to ensure a well-cured brick, they were left under plastic for eleven days [12]. Figure 2 depicts the specimen preparation process.

Table 2. Materials composition of various trails.

Materials	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Fly ash (%)	40	40	40	40	40
Marble dust (%)	10	10	10	10	10
Cement (%)	5	5	5	5	5
RHA (%)	2	2	2	3	3
Quarry dust (%)	40	38	33	27	22
ESP (%)	3	5	10	15	20

(**a**) (**b**) (**c**)

Figure 2. Specimen preparation process: (**a**) mixing of materials, (**b**) casting of bricks, and (**c**) curing of bricks.

3. Experimental Study

Testing bricks for strength, durability, efflorescence, and dimensional tolerance is mandatory [14]. In this study, a dimension test, water absorption test, compressive strength test, and efflorescence test were carried out to determine the quality of bricks. Details of these tests are discussed in the following sections.

3.1. Dimension Test

A total of 20 samples were chosen randomly from each mixed ratio, and the blisters were removed using a trowel before conducting the test. The dimensions of bricks were tested per India's industry standards (IS: 1077(1992), clause 6.2). First, all the selected bricks were arranged lengthwise in five rows on a flat surface, and the length of the overall bricks was measured using tape. The values were recorded for each row. Similarly, the bricks were arranged widthwise, and the values were recorded. Finally, all the bricks were arranged on the basis of height, and the overall height was determined. The observed values were recorded, and the standard deviations are shown in Table 3. It was found that the dimension tolerance values for bricks were within the IS limits [27].

Table 3. Dimensions of bricks.

Trail	Dimension (mm)			Tolerance (%)		
	L *	B #	D +	L	B	D
1	4517	2158	1378	−1.8	−1.9	−1.57
2	4533	2163	1386	−1.46	−1.68	−1.0
3	4528	2159	1394	−1.57	−1.86	−0.43
4	4522	2165	1375	−1.69	−1.59	−1.78
5	4548	2168	1382	−1.13	−1.45	−1.28

* Length; # breadth; + depth.

3.2. Water Absorption Test

Water absorption affects the durability of bricks. To conduct this experiment, three specimens from each mixed ratio were selected. Samples were first placed in an oven at 105 °C until they reached a consistent density. After being overdried, the bricks were immersed in water for 24 hours. Then, the specimens were removed from the water and cleaned with a damp cloth. The percentage of samples' water content was determined using:

$$\text{water absorption in } \% = \frac{W2 - W1}{W1} \times 100, \quad (1)$$

where W1 is the brick's dry weight, and W2 is the brick's wet weight.

Figure 3 shows the average water absorption results for brick in each mixed ratio. According to the protocol outlined in IS [27], the bricks must absorb no more than 20% of their weight in water after 24 h of immersion in cold water. Figure 3 shows that the water absorption values for bricks were less than 7% in each trial, meeting the IS requirements [27]. A lower rate of water absorption was observed in trail 1 with the increase in the percentage of quarry dust.

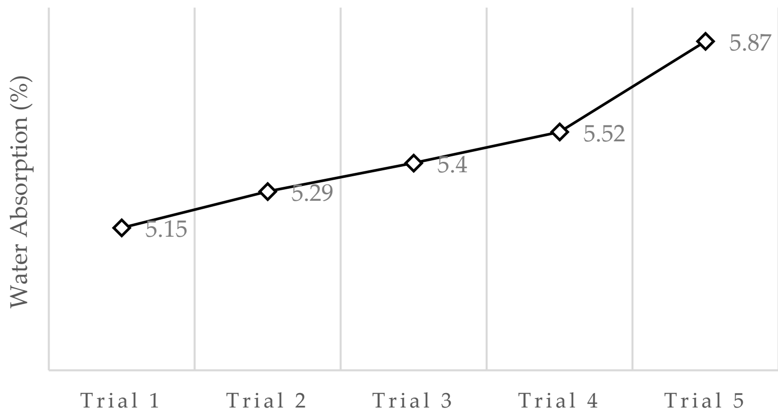

Figure 3. Water absorption results for brick samples.

3.3. Compressive Strength Test

The compression test machine measured the dry compressive strength of brick samples. Three random samples were taken from each mixed ratio, as in the water absorption test. The sample's face was subjected to a compression load with dimensions of 230 mm × 110 mm. The compressive strength was determined by dividing the overall load by the original cross-sectional area of the specimen. Figure 4 shows the compression strength test arrangement, and the average compressive strength results are displayed in Figure 5. From Figure 5, it was observed that the composition used in trial 3 achieved the highest compressive strength compared with other compositions used in other trials. However, the compressive brick strength results ranged from 7 to 14 N/mm^2, which could be classified as Grade A [28].

Figure 4. Compressive strength testing of samples.

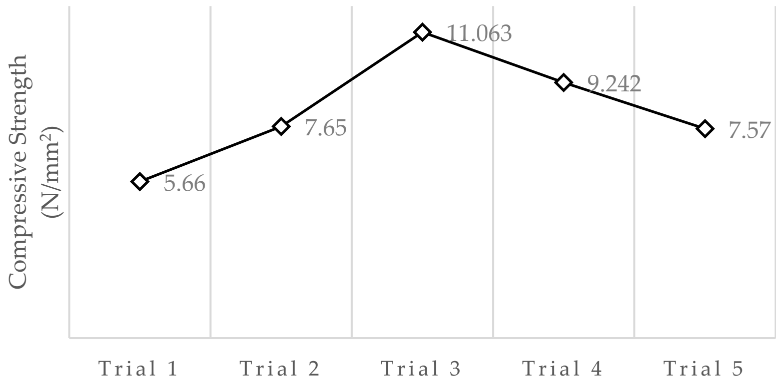

Figure 5. Compressive strength results for brick samples.

3.4. Efflorescence Test

According to Ukwatta et al. [29], salt deposits on brick surfaces lead to efflorescence, which detracts from the aesthetics of brick masonry structures. The samples were tested following the procedure given in IS 3495 (part 3) to determine the efflorescence. One random sample from each mixed ratio was selected. A shallow flat bottom tray was taken, and water was poured to a height of 2.5 cm. The samples were placed vertically in the tray and kept until they absorbed the water. When the bricks appeared to dry, the same quantity of water was poured into the tray and evaporated. Once the evaporation occurred, the samples' evaluation was tested on the basis of the classification provided in [28]. In this study, it was observed that there was no efflorescence in brick samples, indicating that none of the samples had been exposed to sulfate attack [28].

4. Cost Estimation

The cost of the waste materials per kg weight, including the shipping cost, was estimated in rupees (INR). The weight of the waste materials used in one brick is multiplied by the unit cost of the waste materials to calculate the total material cost. The cost of human resources and electricity used to manufacture the bricks were also considered. The total cost of brick production in the trials was estimated, as shown in Table 4. It was observed that during trial 1, the cost of production of one brick was INR 3.32, and the production cost gradually increased to INR 3.660 during trial 5. It is noteworthy that although the addition of quarry dust was reduced in each trial, the addition of ESP was simultaneously increased, affecting the cost of brick production. Table 4 shows that the optimum cost for brick manufacturing was the ratio used in trial 3, which indicates high compressive strength results (see Figure 5).

Table 4. Cost for production of bricks in each trial.

	Unit Cost (in INR)	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5	
		Weight (kg)	Cost (INR)	Weight (kg)	Cost (INR)	Weight (kg)	Cost (INR)	Weight (kg)	Cost (INR)	Weight (kg)	Cost (INR)
Materials											
Fly ash	0.7/kg	1.4	0.980	1.4	0.980	1.4	0.980	1.4	0.980	1.4	0.980
Quarry dust	0.42/kg	1.4	0.589	1.33	0.558	1.16	0.490	0.945	0.397	0.77	0.323
Marble powder	0.4/kg	0.35	0.140	0.35	0.140	0.35	0.140	0.35	0.140	0.35	0.140
Cement	6.50/kg	0.175	1.138	0.175	1.138	0.175	1.138	0.175	1.138	0.175	1.137
ESP	1/kg	0.105	0.105	0.175	0.175	0.35	0.350	0.525	0.525	0.7	0.700
RHA	0.10/kg	0.07	0.0007	0.07	0.0007	0.07	0.0007	0.105	0.010	0.105	0.010
Others											
Labor/brick	0.3		0.300	0.3	0.300	0.3	0.300	0.3	0.300	0.3	0.300
Electric supply/brick	0.07		0.070	0.07	0.070	0.07	0.070	0.07	0.070	0.07	0.070
Total cost			3.322		3.361		3.475		3.560		3.660

5. Comparative Analysis

The manufactured bricks were compared with conventional clay bricks' specifications and manufacturing costs. First, the optimum proportion of manufactured bricks was selected among the different compositions of trials. The results yielded from water absorption (5.4%), and compressive strength (11.063 N/mm^2) tests indicate that the composition of trial three was the optimum proportion for producing high-quality bricks; hence, these results were compared with the conventional bricks.

Three random samples of clay bricks were collected from local manufacturers. The manufacturers reported that manufacturing one clay brick ranges from INR 5–6. The same procedures were followed to conduct the compressive strength and water absorption tests for testing the samples. The test results of conventional bricks are shown in Table 5. The average weight of clay bricks was 3.258 kgs. From Table 5, it was observed that the produced bricks were found to be economically feasible, resulting in lower water absorption, higher compressive strength, and lower manufacturing cost compared with conventional clay bricks.

Table 5. Test results for conventional clay bricks.

Experimental Test	Sample 1	Sample 2	Sample 3	Average
Water absorption (%)	12.715	10.170	9.906	10.930
Compressive strength (N/mm^2)	5.260	9.010	8.860	7.710

6. Conclusions

Clay is the primary raw material used in brick manufacturing. However, the use of clay causes erosion and lowers the water table. In this study, an attempt was made to incorporate industrial waste materials into brick manufacturing to avoid using clay. The readily available raw waste materials such as RHA, quarry dust, fly ash, marble powder, and ESP were used in different proportions for brick production. Compressive strength, water absorption, efflorescence, and dimension tests were conducted to determine the quality of the bricks. The results obtained from the tests were compared with the conventional clay bricks. Additionally, the manufacturing cost of bricks from waste materials was compared with clay bricks. The findings indicated that the bricks produced from waste materials were economically feasible and yielded high compressive strength. Future research will focus on performing the sustainability assessment of manufactured bricks from waste materials on economic, social, technical, and environmental aspects.

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