

## **CLAY-STRAW GREEN BRICK AS ECOFRIENDLY CARBON REDUCING BUILDING MATERIAL**

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### **ABSTRACT**

Clay-straw green brick is a revolutionary concept from the old mud houses in the Bangladeshi rural areas. It's a sustainable material for future architecture that reduces carbon emissions in our construction sector. Clay-straw brick is a low-cost and eco-friendly and sustainable material for building construction. This eco-friendly brick utilizes locally available components, including clay soil, straw fiber, Sylhet sand, cement, lime, and water. The mixture utilizes the plasticity of clay for strength, with cement and sand acting as stabilizers, lime minimizing shrinkage, and straw fiber reducing both weight and cracking. Incorporating straw helps reduce air pollution by reducing the need for straw burning in agricultural fields, which produces carbon and sulfur. After the experimental testing, findings determined the mix proportion of the brick as 2% lime, 8% cement, 61.2% sand, 30% clay soil, and 0.8% straw of all the mixtures. The bricks demonstrate satisfactory performance in durability, compressive strength, and eco-friendly impact. This brick is capable of replacing conventional fire-burned bricks and cement blocks. Clay-straw bricks can be used in load-bearing and frame structures, also in high-rise structures, due to their lightweight nature. Its' durability, lightweight, and less carbon-emission characteristics make it a sustainable alternative to conventional bricks in both rural and urban architecture.

**Keywords:** *Clay-Straw Brick, Carbon Emission, Sustainable Materials, Low-Cost construction, Lightweight brick*

## **1. INTRODUCTION**

Air pollution, caused by black smoke from brick kilns, is currently one of the most significant hazards in South Asia, including Bangladesh (Haque et al., 2018). Cement is one of the largest industrial sources of carbon emissions, accounting for 7-8% of global greenhouse gas emissions during the manufacturing process (Andrew, 2018; Khaiyum et al., 2023; Liao et al., 2022). A single burnt clay brick releases an average of 0.20-0.22 kg of (CO<sub>2</sub>), as shown in various studies, whereas 1 kg of ordinary Portland cement (OPC) releases an average of 0.8-0.9 kg of (CO<sub>2</sub>) (Bhairappanavar et al., 2021; Sousa et al., 2023). Carbon dioxide (CO<sub>2</sub>) and other greenhouse gases escape as straw that has been kept in the field or mixed into the Soil breaks down due to microbial fermentation (Yan et al., 2020). The burning of crop residue in open space after harvesting releases a lot of CO<sub>2</sub>, which is a significant contributor to climate change (Sun et al., 2016). Straw enhances the quality of clay bricks and is beneficial to the environment when mixed with them. The brick's comprehensive strength is enhanced when the proper proportion of straw is used. The bricks become more resilient, lightweight and thermally insulating (Chen et al., 2025; Vatani Oskouei et al., 2017). Also, it eliminates brick shrinkage and cracks (Dawood et al., 2021). As straw reduces brick's thermal conductivity, rooms stay warm in the winter and cool in the summer (Makomra et al., 2022; Tachaudomdach & Hempao, 2022). Also, it enhances the brick's durability and reduces water absorption (Xie et al., 2022). According to study findings, adding NaOH to straw reduces the bricks' capacity to absorb water, enhancing their resistance to moisture and durability (Morsy et al., 2022). Meanwhile, adding straw treated with NaOH may increase the bricks' comprehensive strength by as much as 34% (Ashour et al., 2021). Natural resources are being consumed more frequently as the building industry expands its operations. As a result, shortages and crises are emerging in the market, while the cost of building materials continues to rise. Meanwhile, there are negative environmental effects and a rapid depletion of natural resources (Arooz & Halwatura, 2018). Recycling waste materials in construction will benefit the well-being of all people by reducing carbon emissions and offering a viable alternative to costly housing (Udawattha & Halwatura, 2018). When clay has been stabilized with cement or lime, its physical characteristics are enhanced and it becomes appropriate for retaining walls and building. But the irreversible transformation of clay during the burnt brick manufacturing procedure results in enhanced carbon emissions (Venkatarama Reddy & Latha, 2014). Enhancing the physical qualities of building materials is mostly reliant on cement and lime (Millogo et al., 2008). Assessments have shown that adding a quantity of less than 10 percent by weight lime results in the development of trace amounts of calcium silicate hydrate and calcite, which enhance the bricks' sustainability and mechanical strength (Consoli et al., 2014). Straw was employed by the Egyptians to reinforce mud blocks approximately five thousand years ago (Rashid et al., 2019). Only the construction sector uses between 30 and 40 percent of all the energy (Kurmus & Mohajerani, 2021). The building's strength, durability, carbon emissions, and environmental impact are all influenced by the materials used in its construction (Udawattha & Halwatura, 2016). The key advantage of soil-based blocks is that they use less cement, which minimizes the carbon emissions produced during the cement manufacturing process (Soundarya, 2021). In Bangladesh and the South Asian region, there is still little research on how significant mud bricks actually are in reducing carbon emissions compared with burnt clay or concrete bricks, because they are considered sustainable. Additionally, not enough is known about their long-lasting, durable properties, such as their ability to absorb water, resist erosion, shrink, and split. The objectives that follow are our research's key goals: (i) To produce low-carbon and sustainable construction materials. (ii) To propose a replacement for conventional bricks and cement blocks, considering the economic factor. (iii) To improve brick quality by using unused and discarded straw.

## **2. METHODOLOGY**

CSBs are made out of clay, Sylhet sand, straw, cement and lime as the primary components. Any of the selected materials could be used, depending on availability, to produce sustainable bricks. First, cut the straw into short parts of 8 to 12 mm. The straw was also treated with 1% NaOH and washed to improve its bonding properties and durability. The straw was washed with water after soaking, then dried, and compounded with other components. Following preparation of all materials, nine different

blends were prepared to investigate performance variation in clay–straw bricks. For all the mixtures, the water-to-cement ratio was kept at 60% by weight of cement. The materials were well mixed, and this procedure was performed manually for uniformity. The bricks were moulded using a wooden-framed mold with internal dimensions of 240 mm × 150 mm × 70 mm. The composite materials were placed in the mould and compressed to the required density (shape). A total of 36 brick samples were prepared in the experiment. The moulded bricks were allowed to sun-dry for 7–10 days in a natural ambient to lose their moisture content and to achieve adequate strength before testing. The entire preparation method of Clay–Straw Bricks (CSB) has been demonstrated in Figure. 1 of this paper for better visualization with respect to material selection, straw treatment, mixing, moulding and drying.



Figure 1: Preparation of the brick sample and prepared bricks placed for sun drying

### 2.1 NaOH Soaking Treatment

The straw was initially thoroughly air-dried in the sun before it was treated. After that, the dried straw was placed in a bowl and left to soak in a 5% sodium hydroxide (NaOH) solution at 25 °C for approximately 2 hours, using a 15:1 liquor ratio (Zhao et al., 2024). To ensure any residual NaOH on the straw's surface was fully removed, it was thoroughly washed with clean water several times after soaking. When the straw's final pH reached 7.00, the washing process was stopped. The straw was at last properly dried. The straw treatment procedure is shown in Figure 2. This treatment procedure improves the straw's quality and effectiveness (Caixeta Silva et al., 2024).



(a)

(b)

(c)

Figure 2: (a) Air-dried treated straw; (b) Alkali treatment of straw; (c) straw size (8-12) mm.

#### 2.1.1 Mix design and sample preparation

Nine Mix designs were adopted mainly in this study. The amount of straw used in these nine Mix designs was 0%, 0.8%, and 1.2%. Besides that, 2% lime and 4%, 6% and 8% cement were used. 20%, 30%, and 40% of the Mix design included clay. Table 1 shows the individual Mix designs used. The whole process was executed using a wooden mold. BDS 208:2009 states that the mold's original dimensions were 240mm x 150mm x 70mm (Juel et al., 2017).

### 2.1.1.1 Experimental programs

The Clay Straw Bricks (CSB) specimens were subjected to various tests, including the Water Absorption Test, the Comprehensive Strength Test. Furthermore, a cost estimate for the bricks has been prepared based on the nine mix designs. The water absorption test was carried out in accordance with ASTM C67 and the compressive strength of the bricks was determined according to the same standard. The results shown are mainly derived from the mean of three samples.

Table 1: Mix design of Clay straw Bricks

Mix Type	Straw%	Cement%	Lime%	Clay%	Sand%
C4-CL20-S0	0	4	2	20	74
C4-CL30-S0.8	0.8	4	2	30	63.2
C4-CL40-S1.2	1.2	4	2	40	52.8
C6-CL20-S0	0	6	2	20	72
C6-CL30-S0.8	0.8	6	2	30	61.2
C6-CL40-S1.2	1.2	6	2	40	50.8
C8-CL20-S0	0	8	2	20	70
C8-CL30-S0.8	0.8	8	2	30	59.2
C8-CL40-S1.2	1.2	8	2	40	48.8

## 3. RESULT & DISCUSSION

### 3.1 Visual Assessment

Each of these bricks measures 9.5 inches in length, 4.5 inches in width, and 2.75 inches in height, as shown in Figure -3. Also, every brick has an even surface and a uniform shape, precisely like a rectangular concrete brick.



Figure 2: Bricks samples on display

### 3.2 Compressive Strength

The load-bearing of clay bricks is based on their compressive strength. Nine different straw, cement, lime, clay and sand mixes were evaluated for this property. The straw cement mixture at 0.8%, had the highest strength and that with 1.2% straw had the lowest. A small amount of straw improved internal bonding, but a larger addition increased porosity and decreased strength. The performance was much improved by adding cement, with about 20–25% higher strength than the reference clay brick. The C6CL30S0.8 and C8CL30S0.8 series exhibited the highest strengths of 5.56 MPa and 5.67 MPa, respectively with C4CL40S1.2 and a minimum 3.38 MPa was observed on the brick samples of compositions containing up to 30% clay and a maximum of 0.8% straw gave best performance, whereas

higher proportions of clay or straw resulted in decreased strength caused by more shrinkage and less density.

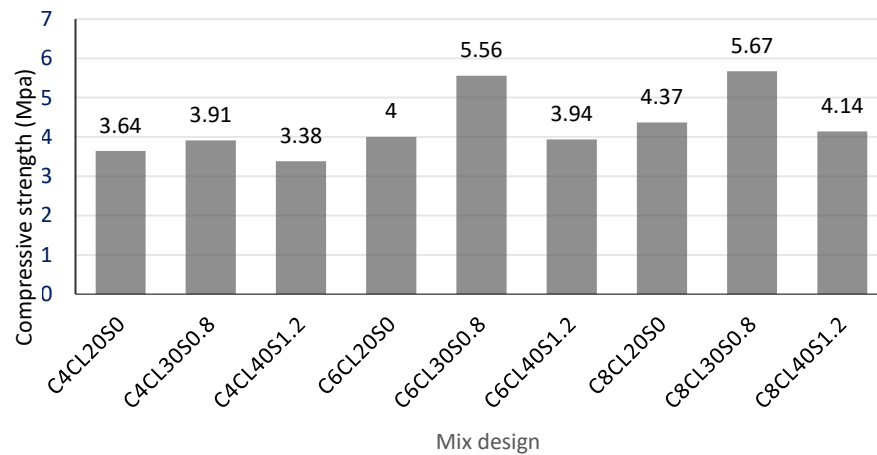


Figure 3: Relationship of Mix design and Compressive strength

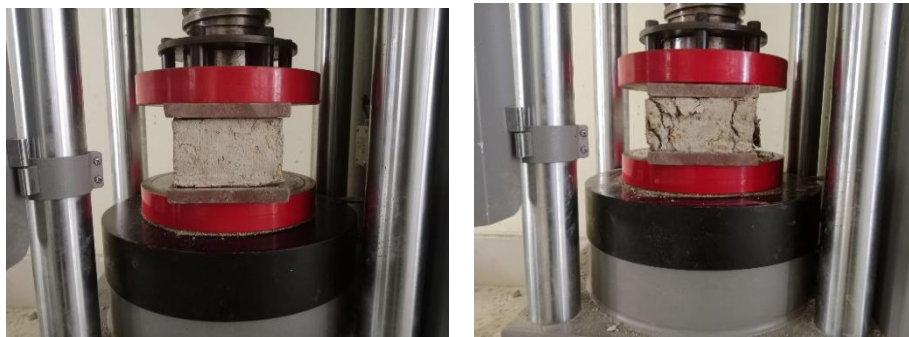


Figure 4: Compressive strength test and failure pattern of bricks

### 3.3 Water Absorption Test

Brick's porosity, density, strength, and durability can each be evaluated with the water absorption test. The findings of the tests indicated that Mix (C8CL40S1.2) showed the highest water absorption (22.3%), yet (C4CL20S0) was the mix that showed the lowest absorption rate (14.81%).

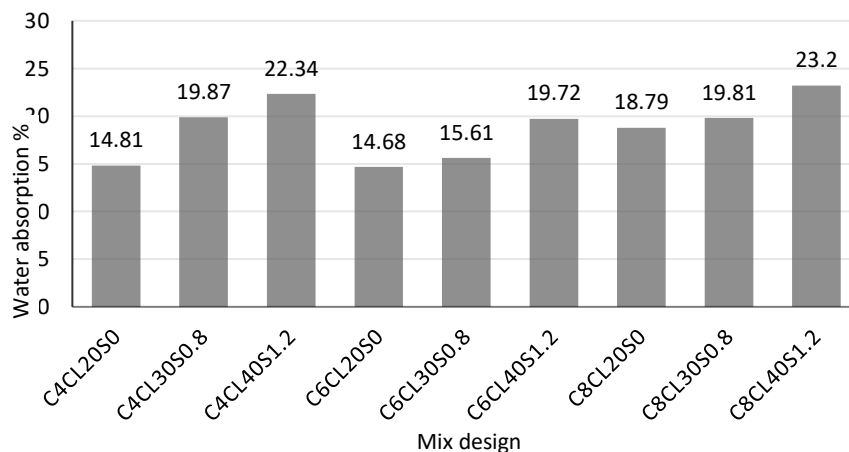


Figure 5: Relationship of Mix design and water absorption %

Brick's porosity, density, strength, and durability can each be evaluated with the water absorption test. The findings of the tests indicated that Mix (C8CL40S1.2) showed the highest water absorption (22.3%), yet (C4CL20S0) was the mix that showed the lowest absorption rate (14.81%). A steady increase in water absorption was observed between Mix (C4CL20S0) and Mix (C4CL40S1.2). On the contrary, Mix (C6CL20S) -(C6CL40S1.2) showed a relatively minor rate of water absorption as it has a larger cement percentage. The brick's capacity to absorb water has been enhanced in the mix designs (C8CL20S0-C8CL30S1.2) as water absorption gradually increases with increasing straw content.

### 3.4 Cost Analysis

Costs are vital at every stage of the commercial procedure as manufacturing expenses are an essential component of sustainability, profitability, and large-scale pricing of goods. Tables 2 and 3 present the costs of all components required to produce bricks, as well as the total manufacturing cost for each mix design.

Table 2: unit price of materials

Materials	Quantity	Price (BDT)
Sylhet Sand	1 ft <sup>3</sup>	50
Cement	50 kg	560
Lime	1 kg	25
Alkaline Activator (Solid form)	500 gm	120
Straw	10 kg	100
Clay	1 ton	600

Mix design C4CL20S0 gives the least costly bricks, based on the study, yet Mix design C8CL30S0.8 gives the most expensive bricks. The total manufacturing cost for bricks generally increases with the quality of the cement used. The comprehensive strength of the C6CL30S0.8 mix is approximately 0.11 MPa lower per brick than that of C8CL30S0.8. However, the production cost of C6CL30S0.8 is about 0.69 BDT per brick, lower than that of C8CL30S0.8.

Table 3: Material Cost for single brick for different mix ratios.

	Cement	Sad	Clay	Lime	Straw	Treatment Cost (BDT)	Total Cost (BDT)
C4-CL20-S0	1.52	2.93	0.41	1.7	0	1	7.554
C4-CL30-S0.8	1.52	2.49	0.61	1.7	0.27	1	7.592
C4-CL40-S1.2	1.52	2.09	0.82	1.7	0.41	1	7.533
C6-CL20-S0	2.28	2.85	0.41	1.7	0	1	8.235
C6-CL30-S0.8	2.28	2.42	0.61	1.7	0.27	1	8.282
C6-CL40-S1.2	2.28	2.01	0.82	1.7	0.41	1	8.214
C8-CL20-S0	3.05	2.77	0.41	1.7	0	1	8.925
C8-CL30-S0.8	3.05	2.34	0.61	1.7	0.27	1	8.972
C8-CL40-S1.2	3.05	1.93	0.82	1.7	0.41	1	8.905

#### **4. CONCLUSIONS**

The research demonstrates that in the construction sector, Clay Straw Bricks (CSB) may serve as an environmentally suitable, cost-effective, and sustainable substitute for conventional burnt clay bricks. The following significant findings have been revealed by this investigation:

- (1) The Comprehensive strength test results indicate that the combination (C8CL30S0.8) is the highest comprehensive strength (5.67 Mpa), whereas the mixed design (C4CL40S1.2) has the smallest (3.38 Mpa).
- (2) The water absorption test findings plainly demonstrate that the nine mix designs vary about the rate of absorption. The greater porosity and permeability driven by the larger amount of straw percentage are the reasons that the (C4CL40S1.2) mix design has the greatest amount of water absorption (22.34%), and the (C6CL20S0) mix design is the smallest.
- (3) The brick's costs fluctuated significantly according to the mix design, but the composition of the mix with the cheapest production cost (C4CL40S1.2) and the greatest cost (C8CL30S0.8) was identified.
- (4) Since these bricks do not need to be heated, they naturally dry in the sun, which significantly reduces carbon emissions. In comparison with conventional burnt clay bricks and concrete bricks, they consequently produce considerably less CO<sub>2</sub>. Despite this, CSB had potential as an environmentally friendly construction in the foreseeable future.

In conclusion, it can be stated that the (C6CL30S0.8) mix design is the most suitable and optimum mix amongst the samples tested since it provides an appropriate balance of Comprehensive strength, water absorption capacity, and Cost-effectiveness.

Anyway, additional study must be done to identify the optimum amount of cement to straw and to evaluate the way these bricks work in a real-world building context. The development of a carbon-conscious, green building sector will be helped by such research.

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#### **DECLARATION OF USE OF AI:**

The authors declare that Grammarly (an AI-based writing assistant) was used solely for grammar checking, language polishing, and improving the sentence clarity of the manuscript. No artificial intelligence tools were used for data generation, data analysis, modeling, figure preparation, result interpretation, concluding. The authors entirely developed all scientific content, analyses, result and conclusions.

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