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Development of Light Weight Bricks for Energy Efficient Buildings Using Rice Husk

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INFORMATION

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ABSTRACT

Rice husk is a waste material and finds use as a fuel. It seems to hold a lot of promise to meet many desired qualities of bricks though its use in the raw form. In this study, produced lightweight bricks using rice husk in raw form, mixing it with fly ash and cement. Prepared samples of a varying percentage of rice husk, cement, and fly ash and measured their compressive strength and porosity besides testing other usual mechanical properties. We fitted the resulting data in a model that may work as a benchmark of compressive strengths for bricks of different percentages of husk and cement. The weights of the bricks are reduced with an increasing percentage of rice husks and are lower than standard fly ash bricks by up to 45% with 12% husk content, whereas the porosity is on the higher side. In the separate batch of experiments added sand along with the above ingredients to observe slightly improved compressive strengths of the bricks. The cost of the rice husk reinforced brick is estimated to be less than standard fly ash or fired clay bricks. The higher porosity and silica-rich husk reduce the heat conductivity of the bricks. Their uses in building construction, particularly high rises, and green buildings, are expected to be beneficial. The process does not involve incineration at any stage and, therefore, has a low carbon footprint.

1. Introduction

Recent researches on brick technologies have been focusing mostly on reducing brick weight and on increasing thermal insulation (Bose, 2023; Bose, 2022; Parracha et al., 2023; Anjum et al., 2022; Turgut and Yesilata 2008, Chiang et al., 2009). Notable among such works are recycled paper mill waste (Bose et al., 2022; Bose and Dhar, 2022; Rauth et al., 2012), burnt rice husk (Chiang et al., 2009), diatomaceous earth, lime and gypsum (Kumar, 2002, Pimraksa and Chindaprasirt, 2009), recycle paper mill residue, and rice husk ash (Hwang and Huynh, 2015), porous bricks by incinerating clay bricks containing rice husk (Awanwadeekul et al., 2023; Görhan and Simsek, 2013).

Lightweight bricks help to reduce weight on the superstructure and foundation, leading to a reduction of cost for tall structures, whereas porous bricks are poor thermal conductors helping to construct energy-efficient green buildings (Tarek et al., 2023; Bose et al., 2021; Bose et al., 2019; Zhang, 2013, Boriesa et al., 2014). However, going by the lack of wide acceptance of any of the above technologies, it appears that existing technologies are insufficient to meet the need of the construction industry.

Rice husk is a waste material and finds use as a fuel. It seems to hold a lot of promise to meet many desired qualities of bricks though its use in the raw form is yet to be studied. Rice husk (RH) is the hard, protective shell of the grain and is the main byproduct of the rice milling process and is available in fairly large quantities in one area.

The world produced approximately 493.79 million tons of rice in the year 2019, and the Food and Agriculture Organization of the United Nations estimates the same to grow to 509.2 million metric tons in 2020 (http://www.fao.org/worldfoodsituation/csdb/en/).

Rice is the third largest cultivated cereal crop in the world.

With husk constituting more than 20% (Fig. 1) of paddy (Beagle, 1978), rice husk is one of the most abundant bio-waste on Earth (Araichimani et al., 2022; Bazargan, 2014).

Any commercial usage of the husk will yield economic as well as environmental dividends. It is observed that the rate of recycling of RH into value-added byproducts is about 10% (Foo, 2009). Rice husk ash can be used as a source of silica in concrete as an additive (Farid and Zaheer, 2023; de Sensale, 2006; Zerbino et al., 2011) and as a reinforcing agent for thermoplastics and rubbers. Rice husk is also used as cellulose fibers and for producing cellulose nanocrystals.

Fig. 1. Husk constitute roughly 20% of the paddy

A major part of rice husk or hull (RH) is burned to generate heat in the process of parboiling of rice or to generate power even though rice husk ash has many applications in materials science, particularly in Portland cement (it has a higher Blaine number compared to cement) and as soil ameliorant.

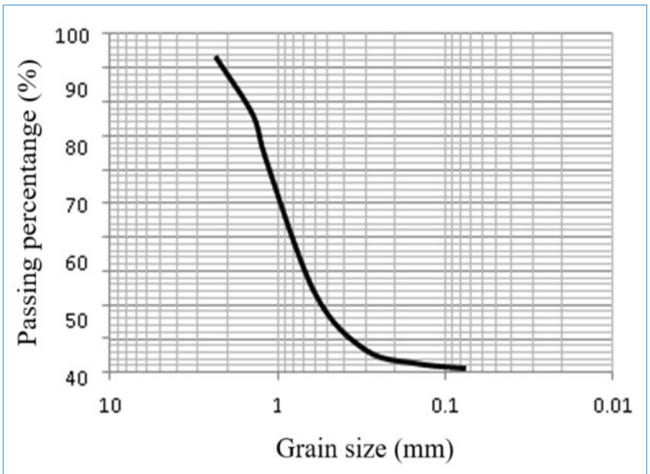

Fig. 2. Size distribution of grounded rice husk

The use of raw RH in construction materials is as old as two millenniums. Bricks made of raw rice husk and used to build the temples (built in the 2nd century AD) of the Batujaya, Karawang in West Java, Indonesia, are still in good condition. Thus, the suitability of RH as an ingredient of construction materials is well established. Several authors have examined the suitability of using either rice husk ash or burning the bricks after adding raw husk in the green bricks (Senthilkumar et al., 2023; Görhan and Simsek, 2013). There seems to be a lack of research on the use of raw husk per se as an ingredient for making lightweight bricks.

The husk is available all year round. The husk contains roughly 20% opaline silica (Chaudhary and Jollands, 2004). It also contains 25–35% cellulose, 8–21% hemicelluloses, 26–31% lignin, and waxes (Stefani et al., 2005). The presence of impurities and lignin in rice husk is deleterious to the formation of strong structural linkages with binding materials such as cement (Rajamani et al., 2023). It contains minimal digestible nutrients, and its natural process of degradation is very slow. Therefore, its disposal in the open is a concern (Madurwar et al., 2013).

In an extensive evaluation, Yarbrough et al. (2005) report acceptable properties of rice husk as regards emission of odor, smoke development, flame spread, moisture vapor sorption, and corrosiveness, among others in the context of using it in bricks. The traditional clay brick-making process consumes about 0.26 metric tons of coal for one thousand bricks leading to air, water, and land pollution (Madurwar et al., 2013). It is imperative to find alternative materials for making energy-efficient and lightweight bricks that can be manufactured through a less energy-intensive process. The thermal conductivity of rice husk has been estimated at 0.0359 W/(m.°C) by Houston (1972) and is also reported by Bhattacharya and Ali (2015), commenting that the value is comparable with the thermal conductivity of excellent insulating materials.

2. Research Gap

Though rice husk has several novel properties in the context of inputs to construction materials, most of the research use the destructive process in that the husk is burnt off, and the ash remains entrapped within the brick, causing the presence of empty spaces. There is scant research on the application of the raw form of rice husk in bricks or any other construction material. Therefore, there is a lack of understanding of the suitability of raw husk in brick making and the resulting changes in the mechanical properties of the bricks.

In this study, the aim is to examine the following.

- To study the percentage husk in bricks and the reduction of weight.
- To explore the relationship between the compressive strength of bricks with respect to percentage contents of rice husk in it.
- To study the relation between rice husk contents in bricks and the porosity.
- To study the influence of rice husk in bricks on its thermal conductivity.

The present study relates to a process that retains the husk and obviates incineration reducing the energy consumption in the manufacturing process. The presence of raw husks in the brick is likely to enhance its thermal insulation property.

Table 1. Experiments design

Batches	Factors	Levels (dry weight %)	Responses
Composition 1	i. Rice husk	0–15	Mechanical properties such as i. Compressive strength ii. Water absorption iii. Density & porosity iv. Thermal conductivity
	ii. Fly ash	95–55	
	iii. Cement	5–30	
Composition 2	i. Rice husk	0–15	
	ii. Fly ash	70–55	
	iii. Cement	15 (fixed)	
	iv. Sand	15 (fixed)	

Fig. 3. Fossil Fuel Advancement Challenges (Alagoz, 2023a)

3. Methodology

3.1. Materials

Samples of two types of rice husk were collected: the whole husk usually results from manual de- husking process and broken husk – a byproduct from rice mills. The whole husk was oven-dried at 1500 Celsius to make them brittle and then grounded in a mixer-grinder. The grounded husk as also the mill-husk was sieved in a 0.6 mm size sieve (Fig. 3a) to remove fine dust particles. Early brick samples were prepared using both types of the husk, and the compressive strengths of the blocks measured that were found to be almost identical.

The experimental results presented in this paper pertain to husk obtained from rice mills, and the particle size after sieving ranged between 0.6mm and 2.0 mm (Fig. 2). Ordinary Portland cement was used in all samples. The design of the experiment is presented in Table 1. In the experiments varied the proportion of rice husk, cement, and fly ash in the mix to make bricks. We added water in the 50:50 cement to water ratio. Husk percentages were 3, 5, 7, 10, 12, and 15% on a dry weight basis. For each husk percentage, the cement contents were varied as 5, 10, 15, 20, 25, and30% on a dry weight basis, and the remaining part was fly ash. Three samples of each compositionwere prepared to replicate the same experiment multiple times to reduce experimentalerror or noise. The addition of sand with the above constituents resulted in marginally higher compressive strengths across samples of different proportions of ingredients. Therefore, a major part of the samples was prepared with rice husk, sand, fly ash, and cement by varying their proportions.

The ingredients were manually and thoroughly mixed to attain consistency, and samples were prepared by pouring the mix in standard molds of 70.6 mm size (Fig. 3b) and intermittently tapped using a tapping rod to ensure uniform consistency and to remove any air bubble. The mixeswere allowed to cure for three days within the molds for gaining rigidity and were then removed (Fig. 3c). The rigid blocks were then placed in a moist atmosphere for another three days, andwater was sprinkled every four to five hours. This was followed because the sample tended to decay when dipped inside the water at the early stage. The samples were then kept underwater forcuring for another 22 days, after which they were allowed to dry through the process of natural evaporation. Various tests were conducted, such as compressive strength, water absorption and porosity, thermal conductivity, and density.

A total of 72 samples were prepared, and all the samples were externally found to be reasonably uniform with no visible damage. Based on our hypothesis that the addition of sand would increase the compressive strength, we made two batches of samples. The first batch was prepared with a mix of rice husk, cement, and fly ash, whereas sand was added in the mix of the second batch of the samples along with those in the first batch (Table 3).

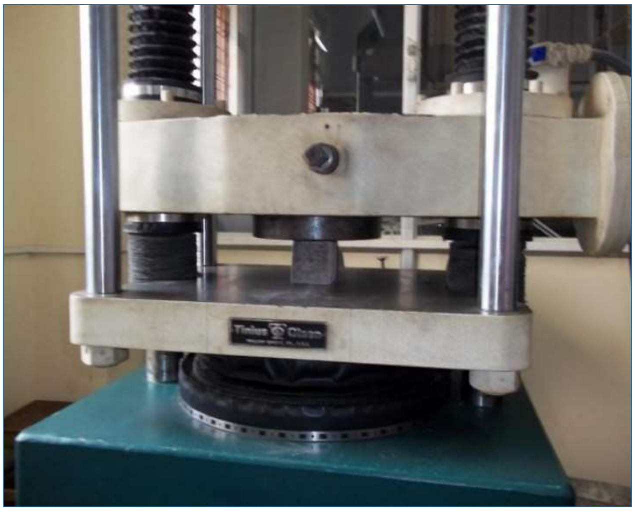

Fig. 4. Testing of compressive strength of the sample specimen on UTM

Table 2. Compressive strengths of the blocks

Cement (%)	Rice husk in brick samples (%)							
	0	3	5	7	10	12	15	
5	6.92	5.27	3.15	3.03	2.29	1.69	0.89	Compressive strength (MPa)
10	13.07	10.21	7.17	4.56	3.95	3.59	1.84	
15	17.08	14.67	10.51	7.37	6.39	4.71	3.77	
20	25.18	20.26	14.98	10.88	8.63	6.36	5.79	
25	30.24	24.67	20.95	15.94	12.25	11.15	9.53	
30	35.06	39.58	29.58	21.38	18.96	16.09	14.68	

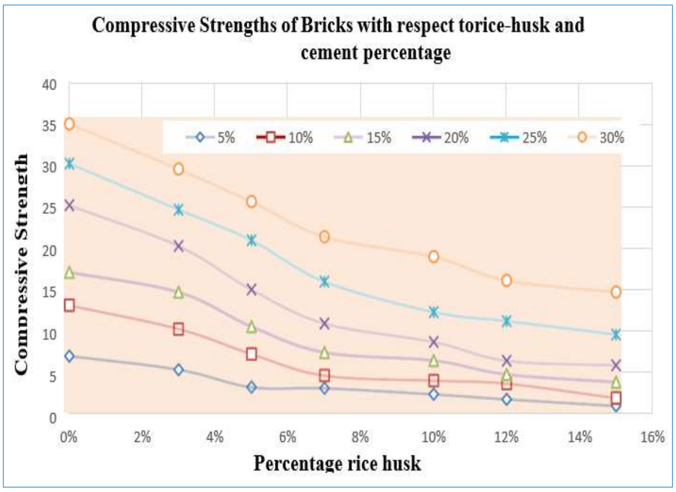

Fig. 5. Variations in compressive strength with respect to percentages of cement and rice husk in brick blocks

4. Results and Model Building

Compressive strengths (CS) of the blocks were measured in UTM (Fig. 4) are presented in Table 2. The averages of the three tests for each composition have been reported in this chapter. The blocks with no rice husk are used as controls. It is clear from the table that CS increases as cement concentration increases and CS reduces as husk percentage increases. Dry grounded rice husk has a density of about 250 kg/m^3 (Mishra et al., 1986).

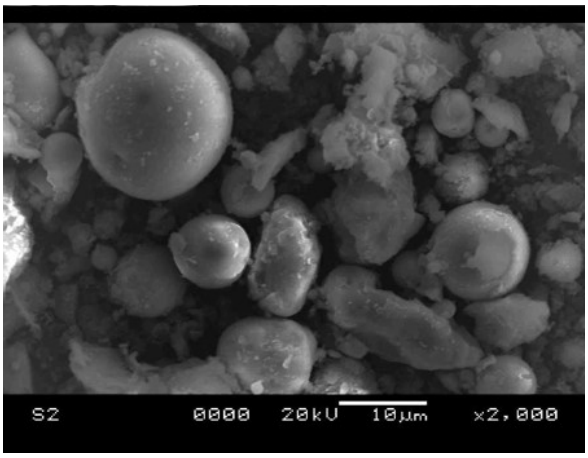

Fig. 6. SEM (morphology) of the sample specimen

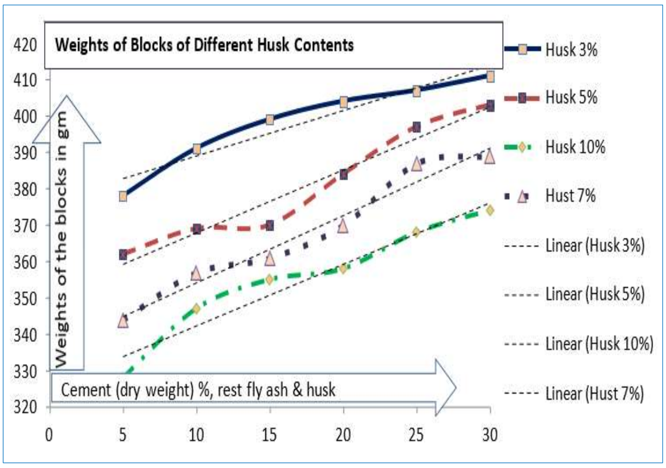

Fig. 7. Plot of the weights of the dry blocks of varying percentages of rice husk

The sample S were broken into fine particles for testing in SEM to check morphological consistency (Fig. 6). The image, magnified by 2000 times, shows uniformity. The data on the weights of the blocks and those of the control are plotted in Fig. 7 along with trend lines.

It is clearly seen that the addition of the rice husk as an ingredient substantially reduces the weight of the block. A graphical representation of the compressive strength data of blocks of various compositions is presented in Fig. 5.

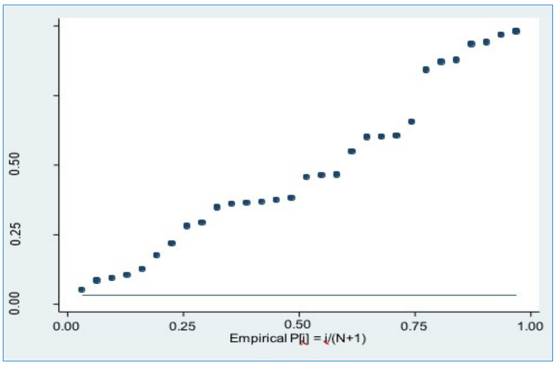

Fig. 8. Normal probability plot of residual: linear model

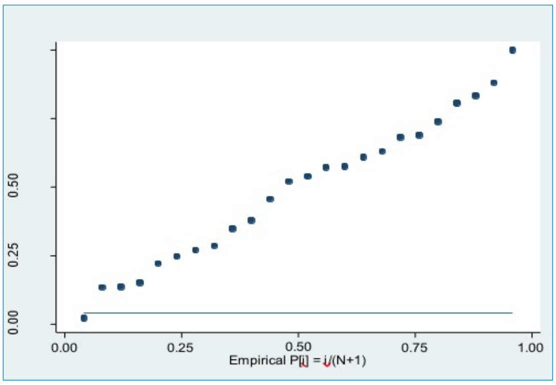

Fig. 9. Normal probability plot of residuals: log-linear model

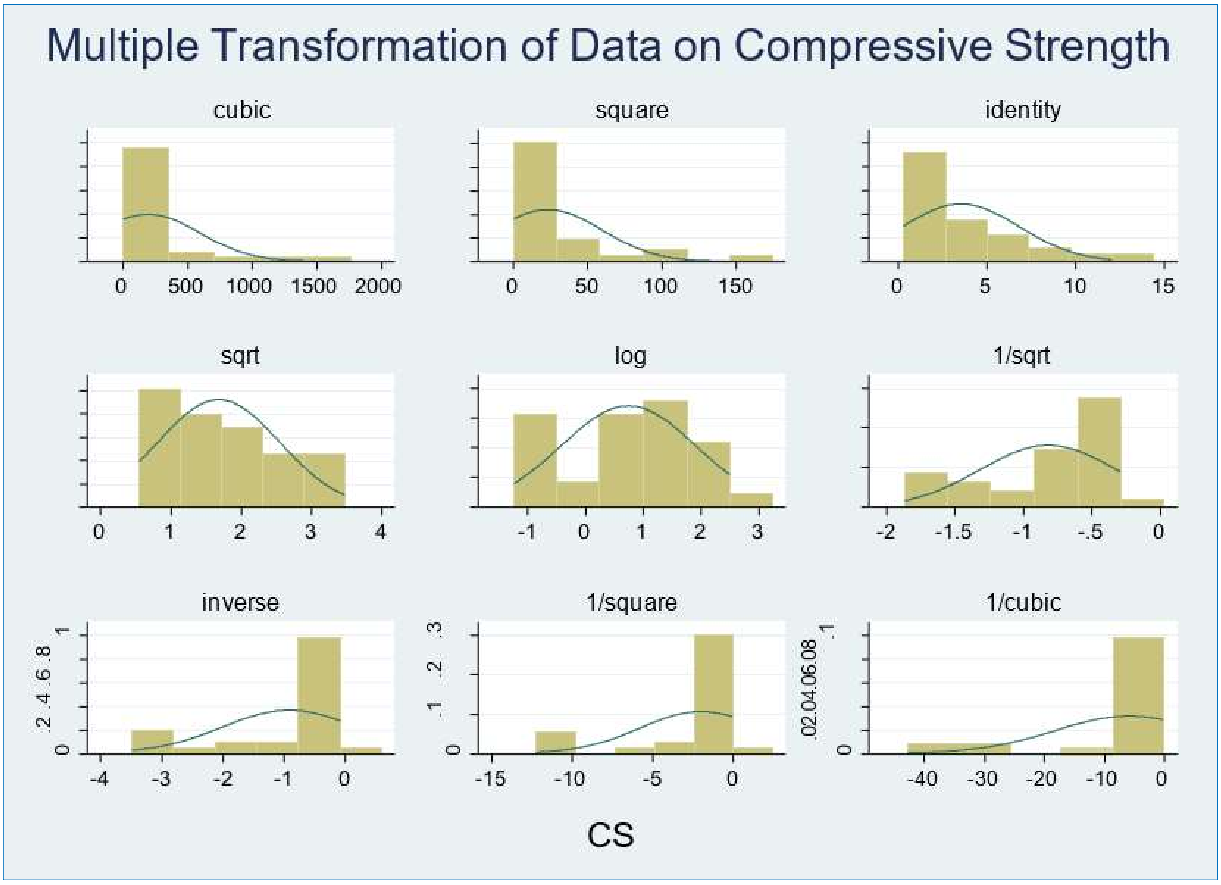

Fig. 10. Histogram of multiple transformations of the compressive strength (dependent variable) data

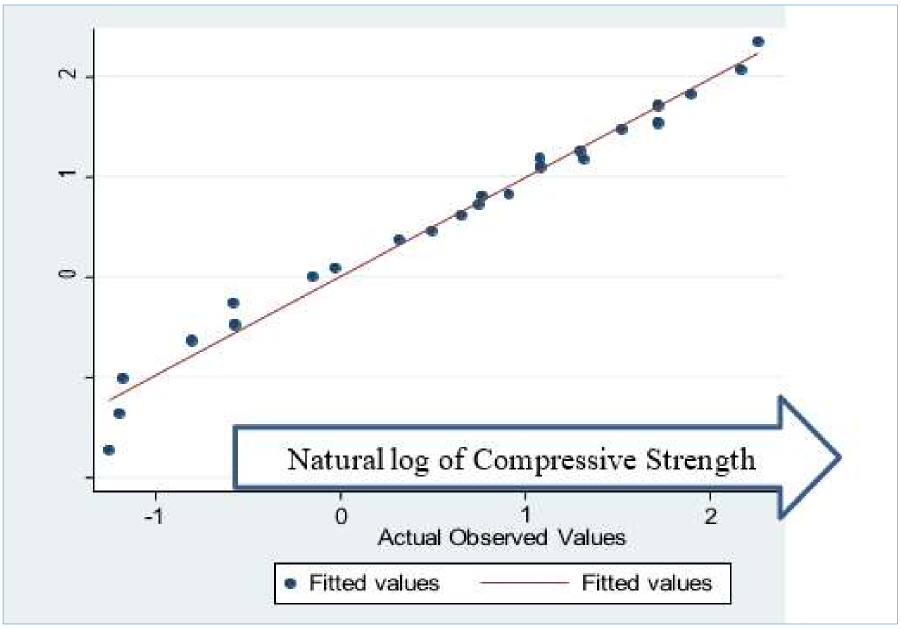

Fig. 11. Plot of the probability density of the residuals

Therefore, a mathematical model was developed that would help optimize cost and compressive strength. Within the range of cement content that the bricks are seemingly cost-competitive, a model can be built to predict some of the parameters representing the mechanical properties of bricks. Clearly, the drivers (explanatory variables) of the properties are the proportions of fly ash, cement, and IOT (without considering the role played by the contents of the water in the mix).

As such, in early estimates, the percentage of fly ash appears redundant as the regression results dropped this variable automatically. Fitting a linear relationship was attempted at the beginning, as per *Equation 1.*

$$cs = \beta_0 + \beta_1 * cp + \beta_2 * hp + \varepsilon \quad \ldots \tag{1}$$

where; *cs*, *cp,* and *hp* stand for compressive strength, cement percentage, and husk percentage respectively, β_0, β_1, β_2 are regression coefficient, and ε is the random error term that follows a normal distribution with mean 0 and variance of 1.0.

The results of estimates based on experimental data indicate that the model fitness is poor even though both the explanatory variables are found to be significant. The residuals are not found to be normally distributed (Fig. 8) an essential condition for model fitness—and the adjusted R^2 value 81.61% is considered low given the type of data. The detailed results are not presented here for brevity. Consequently, multiple transformations of the CS data are performed that reveals log transformation to be appropriate (Fig. 10). Further analysis of data in various combinations leads to the conclusion that a log-linear model is the best suited for the data (Fig. 9). Thus, a model, in line with the popular Cobb Douglas production function, is proposed as in *Equations 2 and 3*.

$$cs = e^{\beta_0} cp^{\beta_1} hp^{\beta_2} e^{\varepsilon} \ldots \tag{2}$$

Alternatively,

$$\ln cs = \beta_0 + \beta_1 \ln cp + \beta_2 \ln hp + \varepsilon \ \ldots \tag{3}$$

The estimated model based on experimental data is presented in *Equation 4*.

$$\begin{aligned} &\ln cs = -1.8685 + 1.5742 \ln cp - 1.0358 \ln hp \ \ldots \\ &p\text{ - value } \ 0.000 \quad 0.000 \quad 0.000 \\ &t \text{ statistic } -9.32 \quad 28.65 \quad -13.83 \\ &\text{Adjusted } R^2 = 97.77\% \\ &F \text{ statistic} = \ 505.96 \ (p \text{ value of } 0.0000) \\ &VIF = 1.0 \end{aligned} \tag{4}$$

Expressing alternatively

$$cs = e^{-1.8685} cp^{1.5742} hp^{-1.0358} \ \ldots \tag{5}$$

The probability plot of the residuals (Fig. 11) in the log-linear model appears satisfactory. The scatter plot of estimated value versus the actual observed values of compressive strength is roughly a straight line (the first three observations are outside the larger pattern because of the log transformation of zero husk content) with a slope of 450 indicating that the model reasonably represents the relation between cement and husk percentage with compressive strength.

5. Evaluation of the Model on Leftover Data

The data that was kept aside and not used to fit the model is used to estimate the compressive strength, and the resulting values are very close to the observed values. The water absorption rate is much higher compared to standard fly ash brick.

This property warrants further research. On the flip side, the results indicate high porosity in the blocks (Table 3). However, high water absorption may pose a problem of water seepage through the wall. Therefore, proper care should be taken if such bricks are used on the outer walls. Ideally, the raw rice-husk bricks are better suited for the inner walls where water absorption is not a huge concern. Samples were also prepared with the cement content of 20%, 25%, and 30%. However, as they were not cost-effective, their results are not being reported.

Table 3 Influence of rice husk on mechanical properties of bricks

Average data of three samples from each category								
Sample No	**Rice husk (%) by weight**	**Cement (%) by weight**	**Sand (%) by weight**	**Fly ash (%) By weight**	**Compressive strength (MPa)**	**Water absorption rate (%)**	**Thermal conductivity ($W.m^{-1}K^{-1}$)**	**Bulk density (g/cc)**
C1	0	5	15	80	7.35	13.52	0.55	1.778
C2	0	10	15	75	15.26	12.98	0.54	1.788
C3	0	15	15	70	21.24	11.11	0.54	1.84
1	3	5	15	77	6.17	16.43	0.37	1.171
2	3	10	15	72	11.23	15.21	0.37	1.173
3	3	15	15	67	16.55	14.05	0.37	1.175
4	5	5	15	75	4.66	17.77	0.28	1.129
5	5	10	15	70	8.15	15.85	0.29	1.13
6	5	15	15	65	12.38	14.28	0.28	1.128
7	7	5	15	73	3.41	18.54	0.25	1.04
8	7	10	15	68	5.32	16.98	0.25	1.06
9	7	15	15	63	9.09	15.86	0.25	1.084
10	10	5	15	70	2.77	20.14	0.24	1.01
11	10	10	15	65	4.87	18.23	0.24	1.02
12	10	15	15	60	7.04	16.58	0.24	1.034
13	12	5	15	68	2.11	22.19	0.21	0.92
14	12	10	15	63	4.17	19.41	0.21	0.95
15	12	15	15	58	5.19	17.55	0.21	1.011

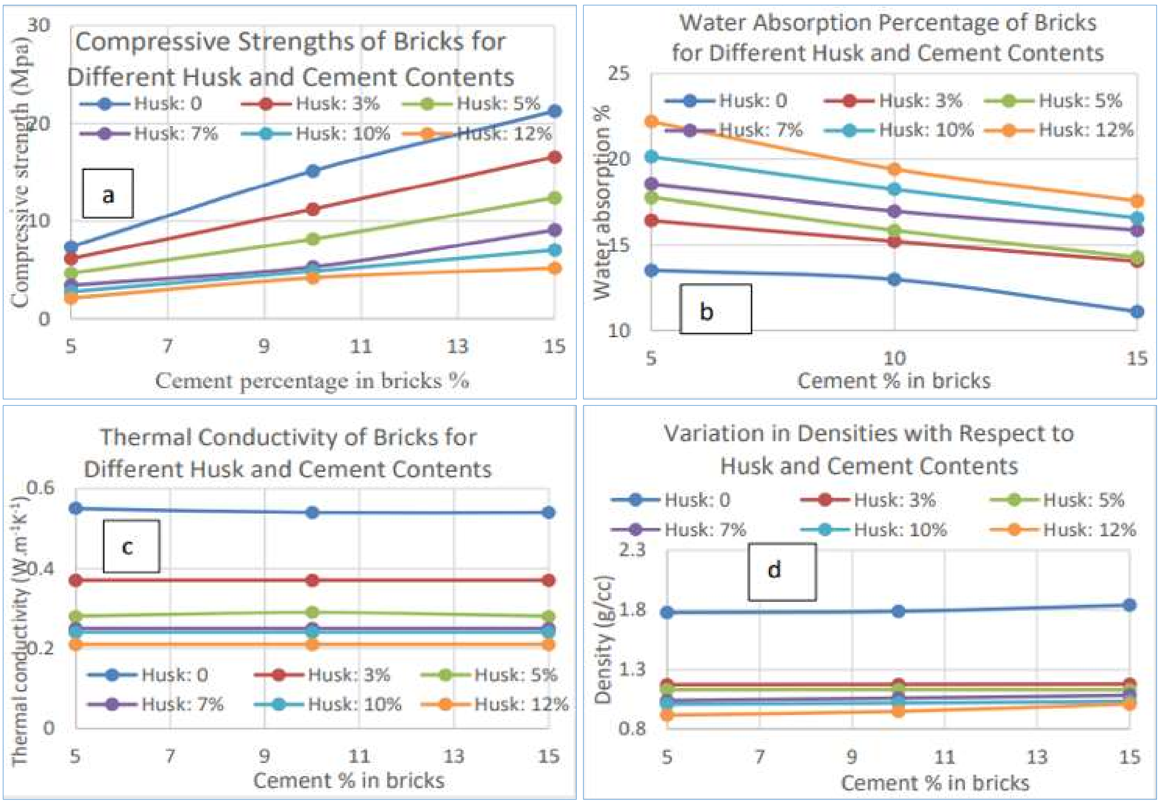

Fig. 12. Plots for variation in mechanical properties such as (a) compressive strength, (b) water absorption, (c) thermal conductivity and (d) density with varying husk percentage

6. Conclusion

The rice husk-fly ash-cement bricks are substantially lighter than conventional fired-clay or fly ash bricks. The lightweight and higher porosity make the bricks suitable for tall buildings, and the lower thermal conductivity helps in constructing green buildings. The addition of husk reduces the compressive strength to some extent. The water absorption is also higher compared to clay bricks. Thus, the bricks are likely to find applications in inner walls or partition walls. The process is carbon neutral. Further studies are possible to examine the addition of rice husk in the concrete mix. We introduced a mathematical model that may be emulated in new research to be used by professionals. However, there will be a need to estimate the parameters for different ingredients.

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