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Evaluation of interlocking moulded bricks with the effective usage of agro - waste fibres in construction industry

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ABSTRACT

For a very long time, fibres have been employed in building materials. The use of natural and synthetic fibres in prior studies and investigations has yielded promising findings because their presence has proved considerable benefits for the composite material's overall mechanical and physical qualities. The major objectives of this work were the creation of manually crushed interlocking mud bricks and a study of their compressive strength. Mud bricks containing rice husk (1–6% by weight of soil) and wheat straw (1–6 % by weight of soil) were made to accomplish this. Straw husk, a soil additive that varied from 1 to 6 %by weight, was also made by mixing rice husk and wheat straw. Compressive strength analysis was utilized to look at the interlocking mud bricks strength and failure pattern. Bricks made of mud under control had shrinkage cracks, whereas bricks made of fibres did not exhibit any symptoms of shrinkage cracking (wheat straw, rice husk and straw husk). As the number of fibres in the mud brick samples increased, there was a corresponding drop in compressive strength. However, interlocking mud bricks with fibres in them met the minimal strength requirements of several mud brick standards. Therefore, interlocking mud bricks with fibres can be used in earthen building as a long-lasting, cost-effective, and eco-friendly material based on the findings of compressive strength tests.

Selection and peer-review under responsibility of the scientific committee of the National Conference on Recent Advances in Construction Materials and Structures.

1. Introduction

In a wide variety of industries, individuals use materials to create both structural and non-structural properties. Bricks must be made from materials, and houses, which are necessary for a society, can be constructed out of bricks. Earth resources have been employed in building for countless years and are still in use now. Due to different economies and readily available materials, construction materials naturally vary from country to country. Throughout the world, fibres have long been a component of building materials. Additionally, composite materials have a long history of use, with fibres serving as reinforcement to improve the materials' qualities. More recently, fibre reinforced polymers have been utilised for more than 20 years in the building sector, showing advantages including improved strength, being lightweight, and being corrosion resistant by Al-Ajmi [1]. Each building material has qualities it is weak in and qualities it is strong in. For instance, concrete is known for having a high compressive strength, which is considered a crucial characteristic. On the other hand, its tensile strength is poor. Like this, soil typically has low tensile and shear strengths. Fibers are a useful material additive for building supplies. The qualities that the parent material lacks can be improved by choosing certain fibres and incorporating them into the construction elements to create a more well-rounded product. In addition to having a variety of forms and sizes, fibres have various properties. Considering that some fibres, such as glass, basalt, and recycled polyethylene terephthalate fibres, can degrade in alkaline settings, the fibre type will need to be carefully chosen if it is used. Fibres can replace the conventional and energy-intensive wired mesh and steel reinforcement bars to serve as reinforcement, lowering the overall cost of the building [20]. There will be less labour expense as a result, as well as less maintenance

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expense, less time spent on the construction site, and reduced build costs. Additionally, energy will be conserved because less fibre is often utilised than is needed to produce the traditional reinforcement, which typically requires a lot rawer materials. Incorporating fibres into building materials has a variety of advantages overall [21,22]. It is also possible to incorporate waste fibres into building materials, which would make use of waste products, lessen the amount of trash sent to landfills, conserve energy, be environmentally friendly, and support long-term approaches to the industry. The material composition of Wheat Straw (WS), Straw Husk (SH), and Rice Husk (RH) was given in Table 1 and shown as Fig. 2(a)–(c).

Even though numerous researchers have examined the characteristics of mud bricks made with various fibres, there is a paucity of information on interlocking mud bricks. Therefore, the development of manually compressed interlocking mud bricks and an analysis of their compressive strength were the main objectives of this study. To do this, interlocking mud bricks were manually compacted (which is seen as suited for in situ casting in underdeveloped and developing countries due to the availability of cheap labour). To facilitate practical use, the size of the interlocking bricks was chosen to be comparable to those of commercially available burnt clay bricks. The material properties of Wheat Straw, Straw Husk, and Rice Husk. were tabulated in Table 2.

In conformance with ASTM D 4318[3], raw ingredients in certain combinations were hand blended with plasticity water (13%). (ASTM, 2000) [4]. More water was added to the combinations including wheat straw, rice husk, and lime (1–3%) to achieve the necessary plasticity for the moulding of brick specimens by Bakker [5]. To prevent evaporation and establish uniformity, the mixes were then covered with a sheet and left for 24 h. Water was able to permeate the soil particles during this time, distributing water evenly throughout the soil [27,28]. In past investigations, a similar methodology was used. The mixes were again mixed after 24 h, and then manually compressed mixtures were used to fill the moulds.

According to past investigations, a typical hand-moulding approach [23,24] was used to condense the bricks for this purpose. The specimens were exposed to the sun for a month after the moulds were removed after 15 min. To manufacture the brick specimens for the investigation, a variety of trial moulds and casting techniques were used. First, bricks were prepared using wooden orthogonal-sided moulds. However, after casting, cracks and distortion were seen because of shrinkage brought on by the water that the wooden mould had absorbed. Additionally, it was challenging to remove the brick specimens because soil had adhered to the mould sides. The brick samples were then cast in vertical steel moulds with tapered sides.

Shrinkage cracks were observed in the control specimens, but neither rice husk nor wheat straw was found in the specimens that were incorporated into it by Blissett [9]. Shrinkage fractures in mud bricks devoid of fibres have been seen by numerous other studies as well by Binici [6–8] Quagliarini and Lenci [9]. As crack propagation tended to slow down in the control mud bricks two days after casting, the soil's maximum allowable shrinkage had been reached studied by Ashour [2]. The interlocking wheat straw-and-mud bricks produce compressive strength, with a coefficient of variation (CoV) of under 5%. After adding 2% and 4% of wheat straw, the compressive strength dropped to 338 and 211 MPa, respectively, and was seen to decline with increasing concentration of 38 MPa. With a CoV of less than 5%, the compressive strength values of the interlocking mud bricks containing rice husk are shown in Fig. 1.

With increasing rice husk content, these specimens likewise demonstrated a decrease in compressive strength. For instance, the control mud brick samples had a compressive strength of 3.8 MPa, but the samples with 5% rice husk had a compressive value of 2.9 MPa [10,11]. However, the interlocking mud bricks containing 1% rice husk had compressive strength that was comparable to control brick specimens [12]. It is well known from the literature that improperly compacting soil with fibres causes voids to form by Khedari [13] Tang [26]. The rise in voids with increasing fibre content may be the cause of the interlocking mud bricks' decreased compressive strength. Mud brick specimen cavities were not effectively eliminated in this study's hand compression of the mud bricks. Binici [7,8] found that adding fibres to mud bricks and mechanically compacting the specimens resulted in an increase in compressive strength [15,16]. When comparing wheat straw-filled mud brick samples to rice husk-filled brick samples, it was found that the strength loss was more significant in the wheat straw-filled brick samples [17–19]. Jamal [33] reviewed the consumption of hemp, kenaf and bamboo natural fibers in cement built concrete.

Table 1
Composition of Wheat Straw, Straw Husk, and Rice Husk.

Composition	Wheat Straw %	Straw Husk %	Rice Husk %
Moisture	8.25	9.22	10
Cellulose	32 – 41	30 – 35	31 – 35
Hemicellulose	21 – 27	20 – 30	21 – 28
Lignin	12 – 43	4 – 9	16 – 22
Volatiles	79	62.45	63
Ash	7 – 11	11 – 13	12 – 15

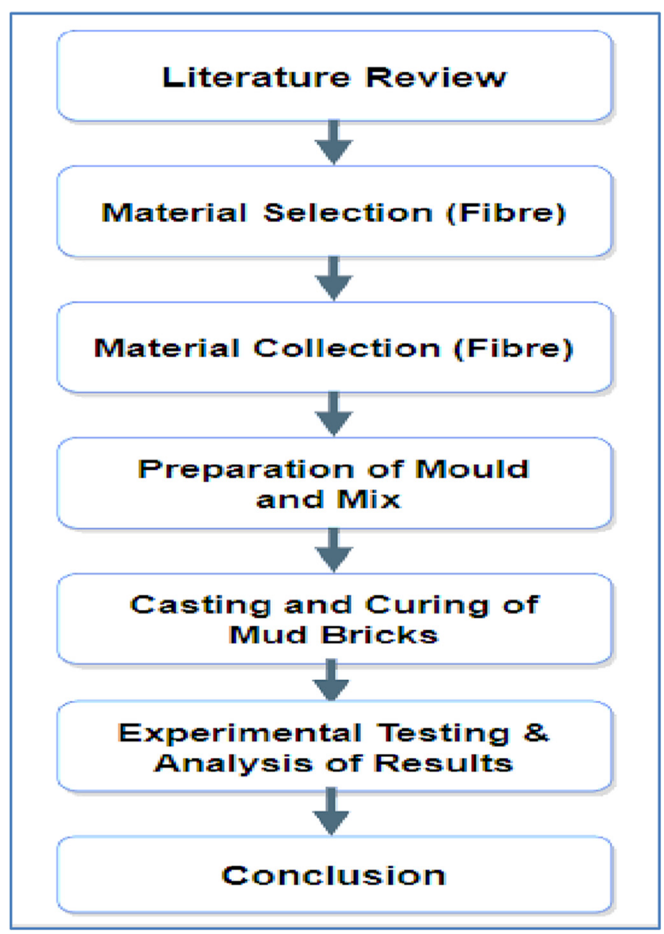

Fig. 1. Methodology [27,28].

Fig. 2. Raw materials: (a) Straw Husk; (b) Wheat straw; (c) Rice husk.

Table 2
Material Properties of Wheat Straw, Straw Husk, and Rice Husk.

Composition	Wheat Straw	Straw Husk	Rice Husk
Density	100 to 200 kg/m^3	100 to 200 kg/m^3.	100 to 200 kg/m^3
Moisture content	15 to 20%	18 to 25%	10 to 20%.
Tensile strength	5 to 30 MPa	1 to 10 MPa	1 to 10 MPa
Thermal conductivity	0.06 to 0.15 W/m·K.	0.05 to 0.15 W/m·K.	0.05 to 0.15 W/m·K.
Water absorption	250 to 500%	200 to 400%	200 to 400%

2. Objectives of the study

The development and assessment of manually compressed interlocking mud bricks, as well as their compressive and tensile strength, are the main objectives of this work. This was accomplished by manually compacting mud to form interlocking bricks. Additionally, for simplicity in practical use, the interlocking bricks' proportions were chosen to be like those of burnt clay bricks that are readily accessible in market. like in the mud bricks also contained other additions, such as wheat straw and rice husk, in varying amounts. Using wheat straw, rice husk, and a combination of the two, mud bricks are created specifically for this use in different proportions.

3. Materials and Methods

Wheat straw is a by-product of agriculture made of dried stalks of cereal plants that were collected after the grain and staff. About 50% of the yield is a result of it. Construction, bedding, and fodder are just a few of the many uses it can be put to. Around the world, concrete and clay are regularly bound together with straw. Cob, which is made of clay and straw, can be used for construction. wheat It takes little energy to transport and bale straw for use in construction, making it a frequent agricultural waste product. A considerable work has been done to enhance the use of rice husk (RH) in the production of burnt clay bricks, Because RH [14,31] has more silica, the primary component of brick clay, than other materials, it has been used as a component of brick clay. All clays contain silica, which, in combination with alumina, forms the silicate component that prevents cracking, warping, and excessive hardening. The RH has significantly smaller particles with a very small particle size of 25 μm, and this RH in turn comprises 85%–90% amorphous silica [25,26,29], which has a bigger specific surface area and enhances the material's characteristics but also durability. The mix proportioning of Interlocking Moulded Mud Bricks was developed and tabulated in Table 3.

Interlocking bricks are designed with specific patterns to allow them to fit together tightly and securely without the need for mortar or adhesive. The interlocking pattern enhances the stability, strength, and durability [25] of the structure built with these bricks. The tongue and groove pattern are a common interlocking moulding pattern used in the production of interlocking bricks. In this pattern, each brick is molded with a tongue (a protrusion) on one side and a corresponding groove (a recess) on the other side. The tongue of one brick fits into the groove of the adjacent brick, creating a secure and tight interlocking connection. This pattern allows for precise alignment and easy installation of the bricks without the need for mortar or adhesive. The interlock formed by the tongue and groove provides stability and strength to the structure built with these bricks [30].

3.1. Test for compressive strength

This test is carried out to determine the brick's compressive strength also known as brick crushing strength. Typically, 54 samples of bricks are brought to a lab for testing and examined one by one [27,28]. A brick specimen is placed on a crushing machine and

Table 3
Proportioning of mix for Interlocking Mud bricks.

Mix	Mud	WS	Mud	SH	Mud	RH
	%					
M1	99	1	99	1	99	1
M2	98	2	98	2	98	2
M3	97	3	97	3	97	3
M4	96	4	96	4	96	4
M5	95	5	95	5	95	5
M6	94	–	94	6	94	6

subjected to pressure until it breaks. It is considered the maximum pressure at which bricks are crushed. The average test result is used to determine the brick's compressive/crushing strength out of the five specimens.

$$Compressivestrength = \frac{Ultimateloadatfailure}{AverageareaofBedface}$$

3.2. Water absorption test

For this test, bricks are weighed in their dry state before being submerged in fresh water for 24 h. Those are removed from the water and wipe out from cloth after 24 h of soaking [32]. The brick is then weighed while it is still wet. The water makes up the difference in weights.

$$WaterAbsorption = \frac{W1 - W2}{W1} x100$$

W1 = Weight of the saturated dried sample in grams.
W2 = Weight of oven dried sample in grams.

4. Experimental investigations

The interlocking mud bricks were constructed using soil, wheat straw, and rice husk as primary components. The soil's particle-size distribution shows that it mostly contained clay, silt, and microscopic sand particles. 59.6% of soil particles were fine sand size, as opposed to 25% of clay and silt-sized particles. There were also trace levels of medium sand (14%) and coarse (1%) sized soil particles. It was determined that the soil was low-plasticity clay because of its density of 1700 kg/m^3.

From agricultural farms of rice and wheat, wheat straw was gathered. It was discovered that the density of rice husk and wheat straw were both 114 kg/m^3 and 111 kg/m^3, respectively. 1–4% of wheat straw and 1–5% of rice husk, by weight of soil, were used in the manufacturing of mud bricks. Additionally, lime in its dry state was used to create mud bricks. 12%, 15%, and 19% by weight of soil and a mixture of straw husk (also known as rice husk) and wheat straw were used to create the mixture of brick examples. With varying amounts of lime, rice husk, and wheat straw, 54 specimens in total were cast. To test each combination, three samples were cast.

Fig 3. Making of Interlocking Moulded bricks.

Fig 4. Steel mould.

Mould preparation for block sizes with 12*6*8 in. of size for cross checking the strength of interlocking mud bricks of steel mould has been used for making of bricks as shown in Figs. 3 and 4 (See Fig. 7).

5. Result and discussion

Wheat straw fibre exhibits low thermal conductivity, which enhances the insulation properties of interlocking molded bricks. This can contribute to energy efficiency and reduce heating or cooling needs in buildings. The addition of wheat straw fibre can potentially enhance the mechanical properties of interlocking molded bricks [23,24], such as tensile strength and flexural strength. It can act as a reinforcing agent, increasing the overall structural integrity of the bricks and it have been graphically shown in Fig. 5(a). Straw husk fibre exhibits low thermal conductivity, which can enhance the insulation properties of interlocking molded bricks. This can contribute to energy efficiency and help maintain comfortable indoor temperatures. Proper processing techniques and compatibility with binding agents are essential to ensure good bonding and compatibility between the straw husk fibre and other constituents of the bricks. Additionally, considerations must be given to the moisture resistance of the bricks to prevent degradation or dimensional changes over time. Assessing the economic feasibility of interlocking molded bricks with rice husk fibre involves considering factors such as the availability and cost of processing the fibre, as well as market demand. The cost-effectiveness of large-scale production should be analyzed.

The size and density of the fibres may vary since rice husk fibres are thinner and lighter than wheat straw fibres, they mix more easily and form stronger bonds with the soil. As a result, the compressive strength of the interlocking mud bricks manufactured with rice husk was found to be higher than that of the bricks made with wheat straw. Clay bricks are made from straw husk, wheat straw and rice husk weren't heavily synthesized, making them an ideal building material because they do not require much natural energy to fire as conventional brick types do. Additionally, because their components are created from natural materials and not treated with chemicals or harmful substances, clay bricks are also safe for domestic use. The impact of various straw husk content percentages on the compressive strength of interlocking mud brick

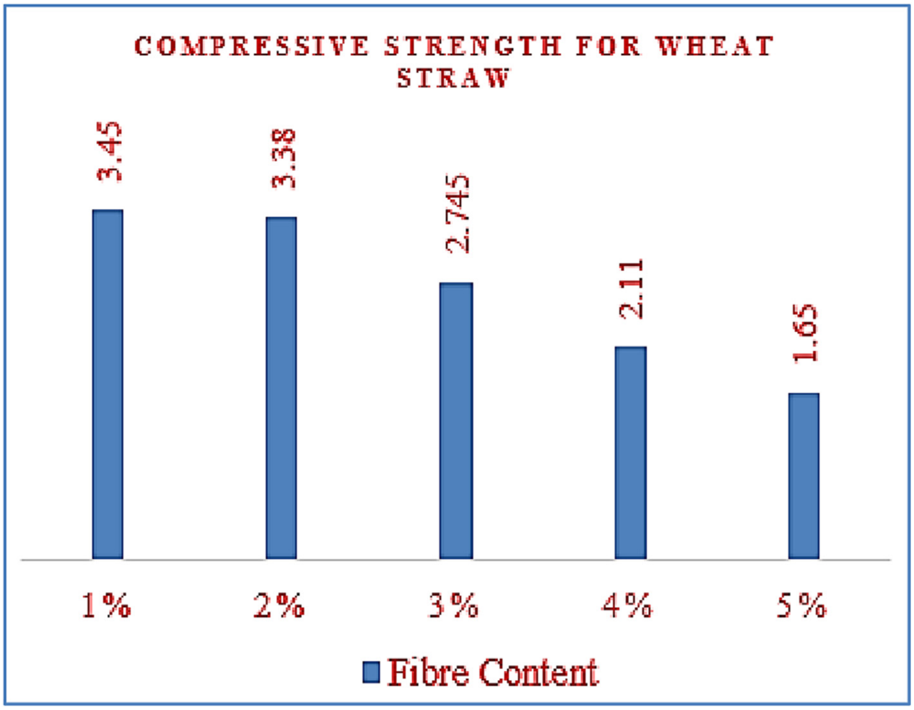

Fig. 5a. Compressive Strength in N/mm^2 - Wheat straw (WS).

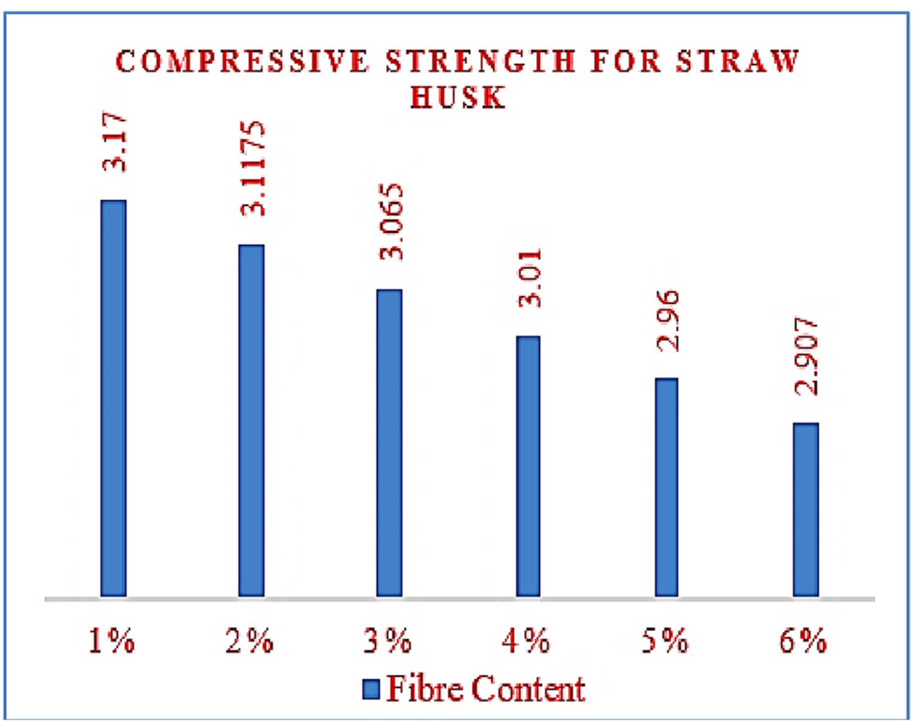

Fig. 5b. Compressive Strength in N/mm^2 - Straw husk (SH).

specimens with a CoV of less than 2% The mud bricks containing 1% straw husk were found to have a compressive strength of 3.17 MPa, whereas the brick specimens with 4% straw husk displayed a compressive strength of 2.96 MPa and it has been shown in Fig. 5(b). Because the mud brick samples were improperly compacted by using manual compression, the compressive strength was reduced. Bricks made of mud and lime that have a CoV of less than 5% have a high compressive strength. When lime was used as an addition, the compressive strength of the mud bricks reduced. Originally, the bricks' compressive strength was 1.27 MPa, but it ended up falling to 0.84 MPa.

Based upon the CS of interlocking mould bricks with WH, SH and RH, it is identified that maximum compressive strength was noted as 3.8 N/mm^2 in RH based brick at 1% when compared to

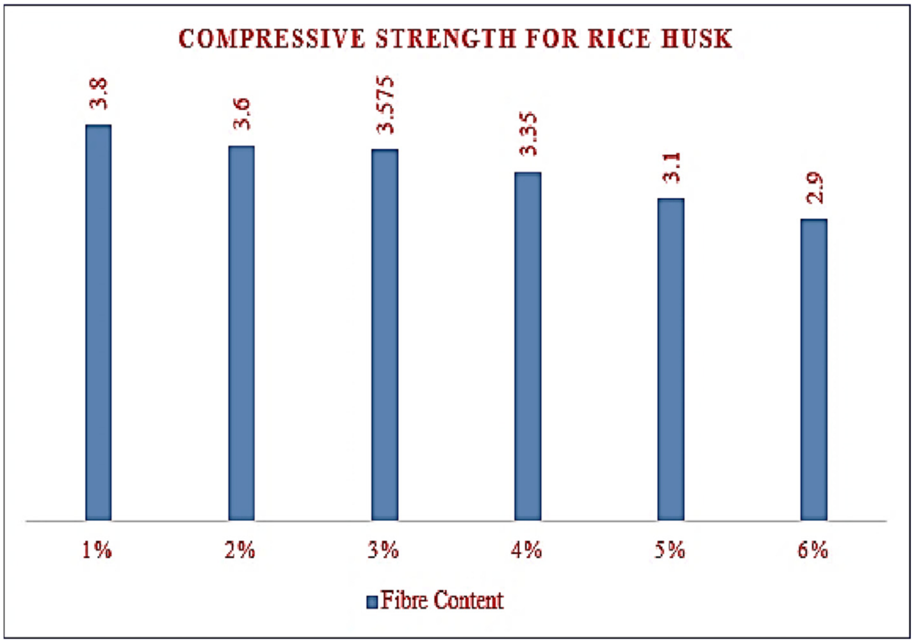

Fig. 5c. Compressive Strength in N/mm^2 - Rice husk (RH).

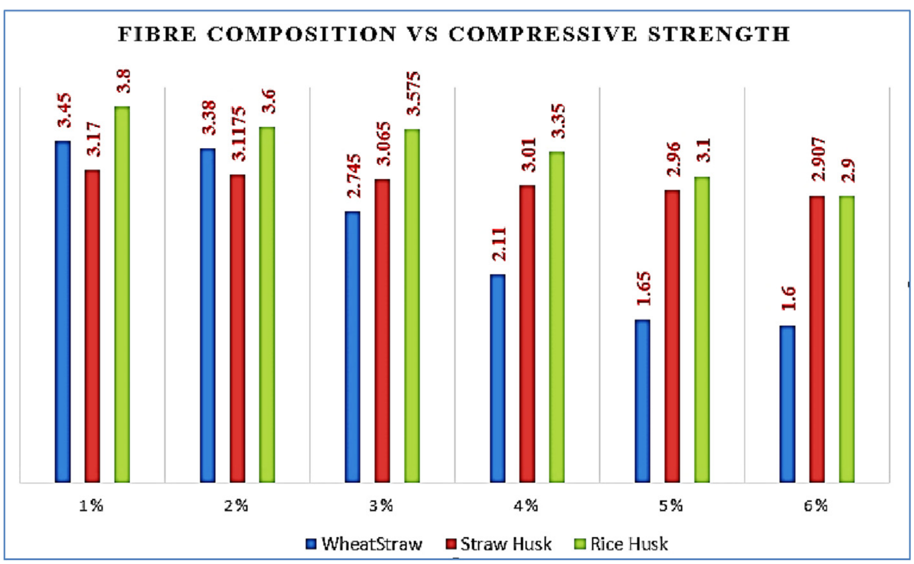

Fig. 6. Comparison of Compressive strength vs Fibre Composition.

the maximum CS for WS is 3.45 N/mm^2 and SH as 3.17 N/mm^2 and figured it Fig. 5(c) respectively. As per Fig. 8, it is observed that from 2% onwards it is gradually decreasing towards 6 % with its failure pattern of mud bricks for SH was shown.. Similarly, Water absorption is very poor in all the samples moulded. When coming to the shape test, steel mould provides a good finish to texture compared with the wooden mould as shown in Fig. 8.

SH fibers help to distribute stress and reduce the formation and propagation of cracks in interlocking molded bricks. By reinforcing the brick matrix, fibers prevent cracks from expanding and enhance the overall crack resistance of the bricks. The inclusion of RH and SH fibers improves the durability of interlocking molded bricks. The fibers help to mitigate the effects of shrinkage, expansion, and environmental factors such as moisture absorption and temperature changes, thus reducing the likelihood of structural degradation over time. RH Fibers enhance the load-bearing capacity of interlocking molded bricks. By providing additional strength and reinforcing the brick structure, fibers allow the bricks to withstand higher loads and stresses without failure or deformation. The presence of RH and SH fibers increases the impact resistance of interlocking molded bricks helps to absorb and dissipate energy from impacts, making the bricks more resistant to damage caused by accidental or external forces. WS fiber acts as reinforcement within the brick matrix, leading to improved strength properties.

Fig. 7. Shape Test.

Fig. 8. Failure pattern for interlocking bricks under compression.

It enhances the tensile strength, flexural strength, and impact resistance of the bricks, making them more robust and resistant to external forces.

6. Conclusion

The following conclusions involving interlocking mud bricks with fibres were reached based on the results of experiments on compressive strength and other properties. The control mud bricks had cracks from shrinking. However, specimens with fibres did not show any evidence of shrinkage cracking (wheat straw, rice husk and straw husk). All permutations of interlocking mud bricks showed a similar pattern of failure.

- With increasing amounts of wheat straw, rice husk, and straw husk in the interlocking mud brick specimens, compressive strength was found to decrease as per Fig.5(a), Fig.5(b) and Fig.5(c).
- When wheat straw is used as an additive, it enhances the modulus of rupture as well as cracking at weight-to-straw ratios of 0.5 and 1% while also increasing both wet and dry CS. 1% of the total weight of the specimen bricks was the ideal level for wheat straw inclusion.
- The CS of the interlocking mud bricks with 1% rice husk was comparable to that of control brick specimens. Inadequately compressing soil with fibres results in voids developing which results reduced compressive strength could be due to the increase in voids due to increasing fibre content.
- According to the CS of interlocking mould bricks made of WH, SH, and RH, the maximum CS was found to be 3.8 N/mm^2 in RH-based bricks at a 1% higher level than the maximum CS for WS and SH in Fig.5(a), Fig.5(b).
- The mud bricks that included wheat straw (1–5%), rice husk (1–6%), and straw husk (1–5%) nevertheless met the minimum strength requirements of various standards for mud bricks and were employed in earthen building and Comparison of CS versus the Fibre composition was showed in Fig. 6
- By the addition of Rice Husk to clay, the strength gradually decreases and beyond the addition of Rice Husk the compressive strengths decreased rapidly as per Fig.5(c).
- Through this brick-making method, waste disposal issues and their impacts on the environment can be reduced. Utilizing rice husk in brick can cut costs, solve the issue of disposal, and provide a “greener” product with eco-friendly bricks. Interlocking mud bricks with fibres can be a cheap, environmental friendly, and long-lasting building material and it can be suggested to make low-cost housing.

- Incorporating natural fibers like straw husk, rice husk fibers, into interlocking molded bricks offers environmental benefits. These fibers are renewable resources and often derived from agricultural byproducts, reducing waste and reliance on non-renewable materials. Their use aligns with sustainable construction practices.

Natural fiber like WS, SH and RH is relatively lightweight. By incorporating it into the bricks, the overall weight of the bricks can be reduced without compromising their strength, which facilitates easier handling, transportation, and installation of the bricks. Overall, the addition of natural fiber in interlocking molded bricks leads to improvements in strength, crack resistance, durability, thermal insulation, acoustic insulation, and sustainability.

As part of scope of further work, long-term durability studies are necessary to assess the performance of interlocking molded bricks with natural fibers under various environmental conditions and aging factors. Research is needed to evaluate their resistance to factors such as moisture, temperature variations, chemical exposure, and biological degradation over extended periods. Conducting comprehensive life cycle assessments (LCAs) can provide insights into the environmental impact of interlocking molded bricks with natural fibers throughout their entire life cycle, including raw material extraction, manufacturing, use, and end-of-life stages. Further research is needed to assess the environmental benefits and potential trade-offs associated with their production and use.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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