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Experimental Study on Rice Straw as a Sustainable Building Material

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Abstract: Straw, a readily available agricultural byproduct, poses significant disposal challenges, leading to environmental and health concerns.
The alarming consequences of stubble burning release approximately 19 million tonnes of harmful gases annually, contributing substantially to air pollution, soil degradation, and climate change. This staggering amount accounts for 25-30% pollution woes of cities like Delhi and severely impacts the entire Indo-Gangetic Plain. The combustion of stubble unleashes a toxic cocktail of pollutants, including particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NOx), and volatile organic compounds (VOCs).
Straw bale building blocks offer a sustainable solution for eco-friendly construction. This experimental study explores the feasibility of utilizing rice straw as a sustainable building material. The blocks were fabricated by mixing laterite soil, rice straw, cement and water in varying proportions. The mechanical properties are evaluated, including compressive strength, durability, indirect tensile strength, impact resistance tests.
Keywords: Rice Straw Building Blocks, Sustainable Building Material, Eco-friendly Construction, Mechanical Properties, Durability, Straw Disposal.

I. INTRODUCTION

Straw is a naturally occurring material which is the byproduct of agriculture. It is actually the waste generated after agriculture. In the countries where agricultural practice is most common, produce straw in bulk amount. Straw will take time to decay. As a result, the disposal of straw is a major threat to farmers. Straw is disposed either by burning or burying into the soil. It can lead to direct or indirect impacts on the environment. Burning of straw in bulk causes emission of carbon dioxide gas and other pollutants to the atmosphere. Cost of purchasing inorganic material is high when compared to organic materials. Straw being organic and available at cheap rate, it is a good alternative to inorganic construction materials. Also, straw has a good thermal insulation property. Due to the exhaustion of natural resources worldwide, the effects of global warming, and the search for low-cost materials, there is an urgent need to explore alternatives to traditional building materials. As long as human beings have been creating shelter, straw and grasses have been used in conjunction with a variety of building methods to provide safe, dependable, and comfortable housing in many climates and environments.

II. SPECIFIC OBJECTIVES

The specific objectives of this study can be listed as:

1) To evaluate the following mechanical properties of the straw reinforced mud/soil blocks.
   - ✓ Compressive strength
   - ✓ Indirect tensile strength
   - ✓ impact test
   - ✓ Durability (soundness, abrasion resistance, water absorption, erosion, size and shape test, structure test, colour test)
2) To compare the mechanical properties of normal soil-cement brick and rice straw-soil- cement brick.
3) To recommend an optimum percentage of straw bale in building blocks.

III. MATERIALS AND METHOD

Materials used for this study are rice straw, laterite soil, and cement. Laboratory tests such as compressive strength, indirect tensile strength, impact test, durability (soundness, abrasion resistance, water absorption, erosion test, size and shape test, structure test, colour test) were conducted to determine properties of bricks.

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A. Rice straw

Straw has been used as a building material for centuries for thatch roofing and also mixed with earth for cob walls, and wattle and daub walls. Straw bales were first used for building over a century ago by settlers in Nebraska in the United States, shortly after the invention of baling machines. Straw is the springy tubular stalk of grasses such as wheat and rice that are high in tensile strength. It is not hay, which is used for feeding livestock and includes the grain head. Straw is composed of cellulose, hemicellulose, lignins, and silica. It breaks down in soil, so waste straw can be used as mulch.

B. Laterite soil

Laterite soil is rich in aluminum and iron, formed in wet and hot tropical areas. Almost all laterites are rusty red due to the presence of iron oxides. It is prepared by the long-lasting and intensive weathering of the parent rock.

C. Cement

Cement is defined as a binding agent that is used to bind various construction materials. Given its adhesive and cohesive properties, it is an essential ingredient of concrete and mortar. Cement is mixed with water to form a paste that binds aggregates like sand or crushed rocks. Calcium, silicon, iron and aluminium compounds are closely ground to form a fine powdered product – cement.

D. Mix proportion

Mix proportion adopted for this study is given in below (TABLE 1). Five sets of rice straw bricks with various percentages were used in this study.

TABLE 1
MIX PROPORTION

Sl No.	Selected proportion	Description
1	SC	Soil + Cement 10%
2	$SCS_{0.5}$	Soil + Cement 10% + 0.5% of straw
3	SCS_1	Soil + Cement 10% + 1% of straw
5	$SCS_{1.25}$	Soil + Cement 10% + 1.25% of straw
4	$SCS_{1.5}$	Soil + Cement 10% + 1.5% of straw

E. Indirect tensile strength test

The indirect tensile strength test is a method used to measure the tensile strength of materials like laterite soil bricks (Sujatha et al., 2023). This test is particularly useful because bricks often fail in tension rather than compression. An empirical formula is applied to get the indirect tensile strength. Brick sample placed as in compressing testing machine, but the face with 7.5 X 10.5 cm is taken on bed. A compressive load applied gradually. The load is typically applied until failure occurs.

$$\text{Tensile strength} = \frac{0.648\,P}{dl}$$

$$d = \frac{1.30\,(a \times b)^{0.625}}{(a+b)^{0.25}}$$

Where, P = force (N), d = equivalent diameter (mm) and l = length of the specimen (mm).

F. Erosion test

Spray erosion test is based on BIS code IS 1725, 1982 (reaffirmed in 2002) and it closely simulates the effect of rainfall intruding on the surface of a wall. Three parameters where simulated during the test. One is the rain drop diameter which is taken as 2 mm corresponding to the medium intensity rainfall. The second one is the maximum terminal velocity at impact which is taken as 6.5 m/s. The third parameter is the maximum intensity of rainfall which is taken as 15-30 mm/h. A 100 mm diameter spray shower with 36 holes of 2mm diameter was devised and was used for the test. Water was sprayed through that holes at a pressure of 1.5 kg/cm^2 using a centrifugal pump.

$$\text{Weight loss in \%} = \frac{w_1 - w_2}{w_1} \times 100$$

where, w_1= Initial weight
w_2= Weight after 2 hours

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IV. RESULT AND DISCUSSION

A. Properties of Soil

Properties of laterite soil used in this study are given in TABLE 2.

TABLE 2
PROPERTIES OF SOIL

Experiments	Results
Water Content (%)	11.35
Specific Gravity	2.68
Liquid Limit (%)	40.75
Plastic Limit (%	27.48
Shrinkage Limit (%)	10.6
Plastic index (%)	13.27

B. Properties of cement

Properties of cement used in this study are given in TABLE 3.

TABLE 3
PROPERTIES OF CEMENT

Experiments	Results
Specific Gravity of Cement	3.16
Fineness of cement %	9%
Standard Consistency	31%
Initial Setting Time	75 min

C. Experimental Investigation

After curing 28 days the mechanical properties of soil-cement rice straw bricks samples were determined in accordance with standardized procedures.

1) Compression Strength, Indirect Tensile Strength and Water Absorption

The compression strength test, indirect tensile strength test and water absorption test results are given TABLE 4.

TABLE 4
TEST RSULTS

Sl. No.	% of rice straw added	Compressive strength (N/mm^2)	Indirect tensile strength (N/mm^2)	Water absorption (%)
1	0	2.67	1.16	15.75
2	0.5	2.11	0.85	17.76
3	1	2.25	0.98	19.19
4	1.25	2.01	0.94	19.78
5	1.5	1.85	0.7	20.46

2) Impact test

The impact test result is given in TABLE 5.

TABLE 5
IMPACT TEST

Sl No.	% of rice straw added	Brick condition	Quality of brick
1	0	Un broken	Good
2	0.5	Un broken	Good
3	1	Broken	Bad
4	1.25	Broken	Bad
5	1.5	Broken	Bad

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3) Abrasion resistance

In abrasion resistance test all bricks have retained scratches indicating the brick are not sufficiently hard to resist abrasion.

4) Efflorescence Test

The efflorescence test result is given in TABLE 6.

TABLE 6
EFFLORESCENCE TEST

Sl No.	% of rice straw added	Observation	Efflorescence Indication
1	0	10% of the brick surface.	Slight
2	0.5	10% of the brick surface.	Slight
3	1	10% of the brick surface.	Slight
4	1.25	10% of the brick surface.	Slight
5	1.5	10% of the brick surface.	Slight

5) Size and shape test

All bricks are of similar size indicating addition of rice straw do not disturb the shape of the bricks.

6) Colour Test

The brick is copper hue in colour similar to laterite soil. Normally good quality bricks are deep red or copper hue colour. There for all bricks are of good quality.

7) Erosion test

The erosion test results are given in TABLE 7.

TABLE 7
EROSION TEST

Sl No.	% of rice straw added	Initial weight (kg)	Weight after 2 hours (kg)	Weight loss in %
1	0	2.620	2.514	4.04
2	0.5	2.54	2.38	6.29
3	1	2.48	2.28	8.06
4	1.25	2.202	1.985	9.85
5	1.5	2.615	2.28	12.8

8) Structure Test

The brick was broken in to two halves, then the two parts of the bricks are examined clearly (Fig 5.14). Here the rice straw that is added is spread uniformly throughout the brick. There are no lumps of the cement. There are very less pores present and there are no large bores which can affect the working of brick. As the bricks are satisfying the condition those bricks are acceptable as construction material.

9) Soundness test

The soundness test results are given in TABLE 8

TABLE 8
SOUNDNESS TEST

Sl No.	% added Rise straw	Sound	Brick Condition	Quality of Brick
1	0	Metallic sound	Un broken	Good
2	0.5	Metallic sound	Un broken	Good
3	1	Metallic sound	Un broken	Good
4	1.25	Less metallic sound	Un broken	Good
5	1.5	No metallic sound	Not broken	Bad

V. CONCLUSIONS

This study aims to investigate the potential of rice straw as a sustainable building material and focus on its mechanical properties. Based on the test results the brick using rice straw laterite soil with 43 grade of ordinary Portland cement is quite suitable for building construction. The optimum compressive strength is found to be 2.25 N/mm^2 for 1% of rice straw apart from the brick with no rice straw content. It can also be observed that the strength is within standard values for various percentage of rice straw content. In the impact test, it is observed that 0%, 0.5% of rice straw brick achieved good quality. More percentage of rice straw in brick decreases the quality. In indirect tensile strength test the highest strength was achieved for the ratio of 1% of rice straw apart from bare brick and the strength was 0.98 N/mm^2. As per BIS 1725: 1982, only the 0% rice straw brick met the erosion test limit of ≤5% weight loss, while bricks with rice straw additions failed to satisfy this condition. The bricks produced also satisfied water absorption criteria outlined in IS 1077:1992, with all combinations of 0%,1%,1.5% and 1.25% rice straw and the bricks belong to second class. In soundness test it was observed that 0%, 0.5%, 1%, 1.25% of rice straw brick are sound and more percentage of rice straw in brick slowly decreases the quality. In abrasion resistance test all bricks have retained scratches indicating the brick are not sufficiently hard to resist abrasion. All brick has seen about 10% of white or grey deposit on the brick surface, indicating presence of slight efflorescence in the brick. These bricks also passed the size and shape test, indicating quality for construction works. Upon breaking the brick into two halves, it was evident that the added rice straw was uniformly distributed throughout, and with no visible lumps of cement. Furthermore, the brick exhibited minimal porosity, with very few pores present and no large bores that could compromise its structural integrity. The brick is copper hue in colour similar to laterite soil, depicting normally good quality. In the study 1% of rice straw brick are better than the other percentage of rice straw brick. So, we can consider an optimum of 1%.

Here we can finally conclude that addition of rice straw in laterite bricks have some influence on the physical properties of the brick even though their performances are inferior to the bare bricks. Bricks made in this way can be used for second class applications. It can be seen that adding waste straw in brick manufacturing can be brought up as a solution to mitigate the issues of disposal of waste paddy straw and its utilization in construction field.

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