Cogon fiber in earth brick as a sustainable building material

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Abstract

The study on earth brick mixed with cogon fiber and cow dung as a sustainable building material was carried out by an experimental method by field and laboratory set up. The study aims to technically analyze earth brick reinforced with cogon fiber and cow dung, determine favorable soil parameters, fiber length, fiber percentage, compare water absorption, CO_2 emissions, and cost per unit brick with that of commercial burnt clay bricks. The scope of study covers the physical and mechanical properties of soil and earth brick, design mix proportion for cogon fiber-reinforced earth brick as an alternative to burnt clay bricks in rural areas.

The study area covers the locality of Phuntsholing and Tading Gewog. From the experimental tests, suitable soil findings are well graded sandy soil with a specific gravity of 2.69, MDD of 1.34g/cc, and OMC of 18.75%. In the case of earth brick fiber length of 30mm and fiber percentage of 4% resulted in maximum flexural and compressive strength. The average water absorption of cogon fiber-reinforced earth brick was 25.38% determined, indicating that this earth brick is suitable only in dry environment or otherwise a better stabilizer is required to limit the water absorption and the unit cost of earth brick at Tading gewog was 25% cheaper in comparison to 3nd class burnt clay bricks. The future study required are durability, provision of interlocking mechanism, and strength variation with arrangement of fibers in the earth brick.

Keywords: *cogon fiber, cow dung, flexural strength, compressive strength, water absorption, mix design*

1. INTRODUCTION

Earth as a construction material is extensively used in most of the countries. Even these days, about one-third of people live in earthen structures and, in developing countries, this data is more than one half (Aubert et al., 2016). Recent interest in the use of natural material for earth brick production is due to high importing cost of burnt clay brick to meet the demand of construction industry (Subba, 2018). Traditional construction typology of Bhutan can be classified as rammed earth, stone rubble masonry, ekra (wattle and daub), adobe block, timber houses, and bamboo houses (Chettri et al., 2019).

Normally, earthen bricks have low ductility and tensile strength. As a result, the addition of natural fibers can be used to strengthen these bricks to enhanced properties like tensile durability, strength, resistance to shrinkage cracking, and enhance ductility (Mostafa & Uddin, 2016). Studies conducted between the compressive strength of fiber-reinforced earth brick and fiberless earth brick found out that compressive strength of fiber incorporated earth brick was much greater than that of conventional fiberless earth brick since fibers are very strong against stresses (Binici et al., 2005).

Commonly used natural fibers in earth bricks are coconut fibers, straw, and sisal fibers which have produced excellent results (Binici et al., 2005). The most dominant synthetic fiber that was used as reinforcement in earth brick was polyethylene fiber like concrete in other construction materials (Mostafa & Uddin, 2016). The use of synthetic fibers has made society face environmental loss due to emission of pollution at the manufacturing and recycling process of synthetic fibers (Amezugbe, 2013). Hence, the use of natural fibers had once again drawn attention. The search for new materials requires the use of renewable energy to minimize environmental impact and cost of production. Earth brick using sustainable natural plant fiber like cogon grass (Imperata cylindrica) for earthen masonry structures represents a major possibility of minimizing material, consumption of energy resource, and emission of pollution.

This research distinctly uses new natural fiber in earth brick with cow dung as additives recommending the design mix with optimum fiber length and fiber percentage. This research study reveals the result of tests on materials (soil and fiber) and sample tests on cogon fiber-reinforced earth brick. Comparative analysis of CO_2 emission and rate with burnt clay brick was carried out to confirm that cogon fiber-reinforced earth brick was a sustainable building material.

2. METHODOLOGY

2.1 Literature review

2.2 Material collection: Soil, fiber, and cow-dung

2.3 Material test:

2.3.1 Soil test

Lab test: Dry Density test, sieve analysis test, Atterberg limit test, specific gravity test, and swell test.

2.3.2 Fiber test: Ultimate tensile load test

2.4 Equipment fabrication: Mold, wooden tamping rod

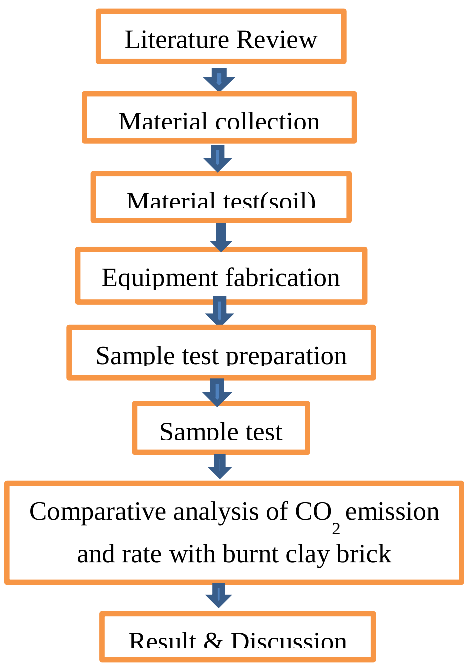
2.5 Sample Test Preparation: Blow determination

2.6 Sample test: flexural test, compression test, and water absorption test.

2.7 Comparative analysis with burnt clay brick:

CO_2 Emission and cost per unit brick

2.8 Data analysis and report write up.



3. LITERATURE REVIEW

The study on Strength of Reinforced Earth brick with Cow dung and Coir fiber concluded that the earth brick stabilized with 20% cow dung and 1% fiber shows highest compressive strength (Arunima et al., 2019).

Physical, mechanical and durability properties of soil building bricks reinforced with fibers (coconut husk, bagasse, and oil palm fiber) recommended high clayey soil to be used and fibers to be soaked for 48hours before casting (Danso et al., 2015).

Spanish Broom and wheat straw fibers were used for the improvement of mechanical properties of earth bricks. The results concluded that fiber length plays a significant role in the compressive strength of adobe bricks (Picuno, 2016).

4. MATERIAL COLLECTION

4.1 Soil:

The soil used in this earth brick was collected from the locality of Rinchending, Chhukha in the southern belt of Bhutan. Soil selection was done at the site by physical observation and laboratory tests were performed to identify the most suitable soil. Two potential sites were selected and technical tests were carried out. Soil sample A and B were collected from behind lab and near block C respectively.

4.2 Cow-dung:

The cow dung was readily available and collected from the nearby locality of Tading geog under Samtse dzongkhag. It was crushed and oven-dried. The dried cow dung was sieved through a 4.75mm sieve size (Arunima et al., 2019). Cow dung used contains fibrous materials, which further binds the matrix materials and acts as good additives (Olokode et al., 2012).

4.3 Congo grass (imperata cylindrica):

Cogon grass was readily available and collected from the locality of Tading gewog under Samtse dzongkhag. Different designated design lengths were adopted based upon a similar research article on analysis of compressed earth brick reinforced with banana fibers combating compression and flexural forces (Mostafa & Uddin, 2016). The fiber was submerged in water for 48 hours to saturate before adding to the mix to avoid the absorption of moisture contained in soil by fiber so that the OMC of the brick matrix is not altered (Danso et al, 2015).

5. MATERIAL TEST

5.1. Laboratory Test

5.1.1. Dry Density Test

Standard Proctor test was adopted in this research study to determine OMC and MDD as per IS 2720-7 (1980).

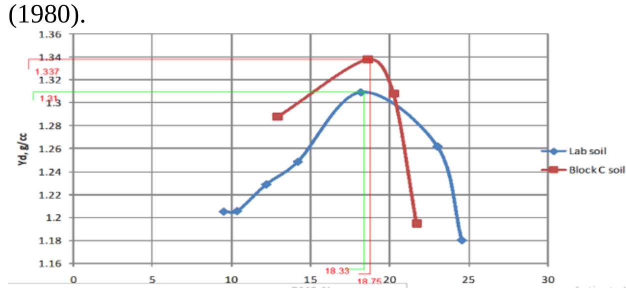


Figure 1: Comparative MDD and OMC of two soil samples

From figure 1 above the soil sample at block C appears to have comparatively high MDD. So block C soil was adopted in this project for earth brick production with MDD of 1.34g/cc and OMC of 18.75%.

5.1.2. Grain size distribution of soil

As per IS 1498 (1970), the grain size distribution curve identifies soil sample as well graded. Since percentage of sand was greater than the gravel, the soil is classified as sandy soil with a soil group of well-graded sand (SW) as per IS 1498 (1970) soil classification.

5.1.3. Atterberg Limit Test

5.1.3.1. Liquid limit

Liquid limit corresponding to 25 no. of blows= 58.33%.

5.1.3.2. Plastic limit test

Average plastic limit= 47.5%

Therefore plasticity index (Ip)=Wl-Wp= 58.33-47.5= 10.83%. According to the plasticity chart as per IS 1498:

The soil is classified as inorganic silt.

- ✓ Degree of expansion low.
- ✓ High compressibility.
- ✓ Medium toughness.

So this means the soil can be made into the desired shapes by decreasing its volume and can absorb energy and deform without fracturing.

5.1.3.3. Shrinkage Potential of Soil

The results obtained from liquid limit test and plastic limit test, plasticity index was found as 10.83% and liquid limit was 58.33%. Figure 5 above depicts the plot of plasticity index and liquid limit, from where low shrinkage potential was observed. Low shrinkage potential indicates that with the change in moisture content, low volume change was observed (Graham, 2003).

5.1.4. SPECIFIC GRAVITY TEST

The specific gravity of 2.69 was observed for the given soil sample of block C.

5.1.5. Swell Test

Computed FSI was 11.3%, which indicates that soil has a low degree of expansion. The swelling of soil was observed to have no much impacts when it is used as building materials.

6. EQUIPMENT FABRICATION

6.1. Mold Fabrication

Mold size of (24*12*9) cm was adopted for flexure test. Mold size of (12*12*9) cm was adopted for compression test. Mold size of (24*12*9) cm was adopted for water absorption test.

6.2. Wooden Tamping Rod

The collected timber was shaped into a tamping rod and it was weighted using an electronic weighing machine (1.37 kg) and it was kept constant for all the cube sizes for the determination of the number of blows for manual compaction of soil dropped from a height of 305 mm with a constant compaction force.

7. SAMPLE TEST PREPARATION

7.1. Mix Proportion

For determining the flexural strength test, three soil bricks of (24*12*9) cm were prepared for each 0,1, 2, 3, 4 and 5cm fiber lengths with constant fiber percentage of 3% and 20% cow dung (Arunima et al., 2019).

Table 1: Mix proportion for flexural strength test (24*12*9) cm cube size.

Mixture	Proportion (%)	Weight (Kg)	Relation
Soil	100	5	
fiber	3	0.15	with total dry mixture
cow dung	20	1	with total dry mixture
Water	18.33	0.9165	with total dry mixture

Optimum fiber length obtained from the flexural strength test was adopted to determine the compressive strength of earth brick. Three samples of (12*12*9) cm were cast for each fiber percentage of 0%, 1%, 2%, 4%, 6% with a constant fiber length of 3cm, and 20% cow dung (Arunima et al., 2019).

Table 2: Mix proportion for compressive strength test (12*12*9) cm cube size

Mixture	Proportion (%)	Weight (Kg)	Relation
Soil	100	2.5	
fiber	0-6		with total dry mixture
cow dung	20	0.5	with total dry mixture
Water	18.33	0.4582	with total dry mixture

From the flexural test, the optimum fiber length obtained was 3cm and fiber percentage of 4% was computed from the compressive strength test. Therefore, for water absorption test, a fiber percentage of 4% with 3cm fiber length was used.

Table 3: Mix proportion for water absorption test (24*12*9) cm cube size

Mixture	Proportion (%)	Weight (Kg)	Relation
Soil	100	5	
fiber	4	0.2	with total dry mixture

cow dung	20	1	with total dry mixture
Water	18.33	0.9165	with total dry mixture

7.2. Blow determination test

A blow determination test was conducted to compute the number of blows that were required to achieve the maximum dry density of the soil. This test was improvised from the standard proctor test due to variation in the mold dimension. The number of blows required to achieve MDD was determined by the trial and error method. Mold dimensions of (24*12*15) cm and (12*12*15) cm were incorporated to accommodate the full height of the core cutter (13cm). An arbitrary number of blows was performed and the density of the soil achieved was confirmed by core cutter method. If the degree of compaction achieved was greater than 95%, the arbitrary number of blows performed was adopted for tamping of the earth brick as per THC 03. SADCSTAN.

For mold size of (12*12*15) cm, 38 blows were adopted with constant compaction energy to achieve maximum dry density. For mold size of (24*12*15) cm, 48 blow was adopted with constant compaction energy to achieve the maximum dry density.

8. SAMPLE TEST

8.1. Fiber length determination

8.1.1. Flexure test

Flexural strength (MoR) measures a brick's ability to withstand a certain quantity of bending stress (Mostafa & Uddin, 2016). This test was performed on full-size brick (24*12*9) cm following ASTM C-67-07. The device used for the test comprised of a universal testing machine (UTM) and a force was connected to a data acquirement system by which force was recorded after every second. Three samples were tested for each particular fiber length. The rate of loading was taken as 1.27 mm/min.

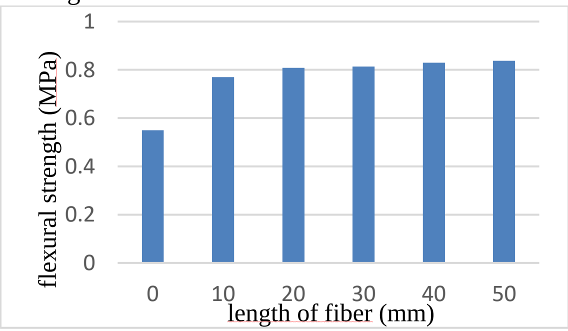


Figure 2: Graph of flexural strength Vs length of fiber

The test results indicate that the flexural strength of cogon grass reinforced earth brick increases with the increase in lengths of fiber. The maximum MOR attended was 0.838 MPa with fiber length 50mm. The results also indicate how the fiber-reinforced earth brick with the lengths of fiber 40 mm and 50 mm achieved the maximum tensile stresses with substantial increase by 50.7% and 52.36% respectively in comparison to that of unreinforced earth brick.

The unreinforced bricks revealed an abrupt failure, while block reinforced with fiber shows slow failure. Fibers were observed to bridge the cracks before failure. Fiber length of 50 mm was observed to produce highest tensile strength in bricks but due to the entanglement of fibers during the mixing and compaction process, 30 mm fiber length is chosen as the optimum fiber length.

8.2. FIBER PERCENTAGE DETERMINATION

8.2.1. Compression test

Compression test was performed on half-sized brick (12*12*9) cm having a maximum dry density of 1.34 g/cc in UTM at the College of Science and Technology laboratory under the supervision of a lab technician as per ASTM C-67-07. The rate of loading was taken as 1mm/min as per the study done by (Lan et al., 2018).

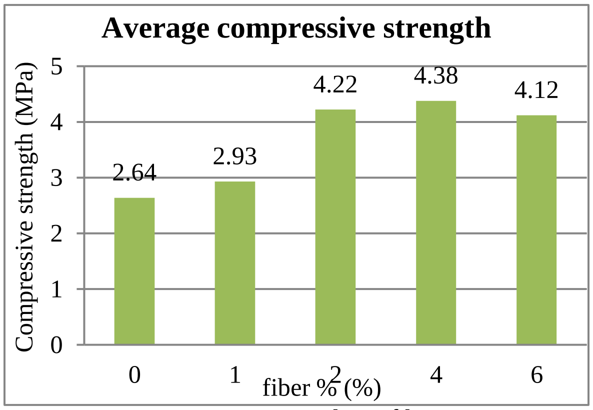


Figure 3: Compressive strength Vs fiber percentage

The highest average compressive strength of 4.38MPa was observed in 4% fiber mix. The increase of 60.3% compressive strength is observed in 4% fiber added with respect to the unreinforced earth brick sample. Thus fiber percentage of 4% was adopted as the optimum fiber percentage for earth brick production.

8.3. Water Absorption test

Three earth brick samples of dimension (24*12*9) cm were adopted with 3cm fiber length, 4% fiber percentage, and 20% cow dung. For water absorption test, specimens were oven-dried for 24 hours and it was left to cool. After cooling, the specimens were weighed. The samples were then submerged in water as per IS 3495 Part 2: (1992).

Specimens were taken out, dried with cloth, and weighted.

The average water absorption of brick was 25.38% as referred to table 13 above. The maximum water absorption for bricks should be 20%. The water absorption of tested brick was more than the desired percent, this indicates that the earth brick sample is not suitable for a wet environment. It is suitable only for dry environment, or otherwise, a suitable stabilizer is required to reduce water absorption.

9. COMPARATIVE ANALYSIS OF CO_2 EMISSION AND RATE WITH BURNT CLAY BRICK

9.1. CO_2emission for burnt clay brick in comparison to the fiber-reinforced earth brick

Indian construction industries annually produce 70billion tones of bricks giving 5.243MTCE of CO_2 process energy emission (Shukla et al., 2009). We studied in our process energy emission for clay bricks does not involve any burning of fuels in the production process. Dry curing consisting of soil, CD, fiber, and water was performed. The soil was readily available at molding site without requiring vehicular transportation except for fiber. Molding of earth brick was manually produced. Even though some equipment was employed, CO_2 emission was very negligible compared to burnt clay brick production and was concluded as an eco-friendly building material with negligible CO_2 emission. Since no energy was used in this experiment.

9.2. Rate Analysis

Cost of unit 3rd class burnt clay brick = Nu. 7 /-

Cost of unit cogon fiber-reinforced earth brick at Phuentsholing town and Tading gewog were 24% & 25% cheaper in comparison to 3nd class burnt clay bricks.

10. RESULT AND DISCUSSION

10.1 Material Collection

10.1.1 Soil Test

10.1.1.1 Laboratory Test

i. Dry density test

Through this test, the MDD and OMC of the soil sample A were 1.31 g/cc and 18.33% respectively. For the soil sample B, the MDD and OMC were 1.34g/cc and 18.75% respectively. Since the MDD of soil sample B was greater than soil sample A soil sample B was used in this research study. A sieve analysis test on soil sample B was conducted for soil grading.

ii. Sieve analysis test

Soil sample used in this research study was classified as well graded sandy soil by analyzing the sieve analysis test. To understand the plasticity of soil Atterberg limit test was carries out.

iii. Atterberg Limit test

Atterberg limit test resulted in a liquid limit of 58.33%, a plastic limit of 47.5%, and a plasticity index of 10.83% classifying the soil as inorganic silt. Thus, the soil was found to have low degree of expansion, high compressibility, and medium toughness. A specific gravity test was conducted to confirm the inorganic property of soil sample used. Low shrinkage potential was observed indicating low volume change with the change in moisture content.

iv. Specific gravity test

Specific gravity of the soil used was computed to be 2.69. Since the specific gravity of 2.69 was greater than 2, this result confirms the inorganic property of the soil sample used.

10.1.2 Fiber Test

10.1.2.1 Ultimate tensile load

Through improvised tensile strength tests, the ultimate tensile load of 182.76N was resisted by three woven strands of cogon fiber. Since the cogon fiber was able to resist high tensile load, this indicates that the fiber has an ultimate tensile strength which can be incorporated in conventional earth brick to improve its mechanical properties.

10.2 Sample Test

10.2.1 Flexure Test

It was observed that the flexural strength increases with an increase in fiber length. Flexural strength increased significantly and remained constant with a negligible increase in flexure strength after 10 mm fiber length. The findings also confirmed that fiber lengths of 40 mm and 50 mm achieved the maximum tensile stresses with a substantial incremental of 50.7% and 52.36% respectively in comparison to that of unreinforced earth brick.

In all cases, unreinforced earth bricks demonstrated sudden failure, while the fiber-reinforced earth brick gradually failed because the fibers bridged the cracks before failure. It was observed that 50 mm fiber length gave the highest flexural strength of 0.838 MPa. Longer fiber length means more chances of entanglement which would ultimately reduce the workability of the earth brick. Considering this factor into account, 30 mm fiber length was considered as the optimum fiber length for earth brick in this research. A compression test was necessary to be conducted to know the optimum fiber percentage to be adopted in the fiber-reinforced earth brick.

10.2.2. Compression Test

It was observed that the compressive strength increases to 4% fiber and dropped after 4%. The maximum compressive strength of 4.38 MPa was achieved when earth brick was incorporated with 4%

cogon fiber and the minimum compressive strength of 2.64 MPa was achieved when the earth brick had no fiber reinforcement. The increase of 60.3% compressive strength was observed in earth brick when it was incorporated with a fiber percentage of 4% in comparison to that of earth brick without fiber. These reveal that incorporation of cogon fiber enhanced the compressive strength of the earth brick. The lowest class designation for burnt clay bricks illustrates a compressive strength of 3.5 MPa which can be used for building purposes as per IS 1077 (1992): Common Burnt Clay Building Bricks-Specification. The earth brick in this research illustrates compressive strength of 4.38 MPa which implies that earth brick reinforced with cogon fiber can be used as a building material. Although the compression test validates the fiber-reinforced earth brick to be used in building material, water absorption property of brick was required to be analyzed.

10.2.3 Water Absorption Test

It was observed that the average water absorption of earth brick with cogon fiber is 25.38%. The maximum water absorption of earth brick is 20%. Due to the high water absorption rate, it is suitable in dry environment only, or otherwise, a better stabilizer is required to increase resistance to water.

Table 4. Overall test results

Test		Results
Soil	Dry Density Test	MDD= 1.34 g/cc OMC = 18.75%
	Sieve Analysis Test	Well graded sandy soil
	Atterberg Limit Test	Inorganic silt
	Specific Gravity Test	G_s = 2.69
Fiber	Ultimate Tensile Load	182.76 N
Sample Test	Flexural Test	Fiber length=30mm
	Compressive Test	Fiber percentage = 4%
	Water Absorption	25.38%

11. CONCLUSION

Cogon fiber-reinforced earth brick with cow dung presented in this research was technically analyzed. Favorable soil parameters, optimum fiber length, optimum fiber percentage, comparative analysis of water absorption, CO_2 emission, and cost per unit brick with that of burnt clay brick were investigated.

Future analysis seems essential generally for the improvement of adhesion of fibers with the clay matrix, addition of suitable stabilizers, and selection of other natural fibers, to further enhance mechanical properties of the fiber-reinforced earth brick.

REFERENCES

Amezugbe, F. A. (2013). *the Performance of Natural and Synthetic Fibers in Low Strength*.

Aubert, J. E., Magniont, C., Tribout, C., & Bertron, A. (2016). *Plant aggregates and fibers in earth construction materials : A review*. *111*, 719–734. https://doi.org/10.1016/j.conbuildmat.2016.02.119

Binici, H. (2020). *Investigation of fibre reinforced mud brick as a building material*. *January*. https://doi.org/10.1016/j.conbuildmat.2004.07.013

Chettri, N., Thinley, J., & Koirala, G. S. (2019). *The Comparative Study on Vernacular Dwellings in*. *01*(02), 42–47.

Danso, H., Martinson, D. B., Ali, M., & Williams, J. B. (2015). Physical, mechanical and durability properties of soil building blocks reinforced with natural fibres. *Construction and Building Materials*. https://doi.org/10.1016/j.conbuildmat.2015.10.069

Graham, T. (2003). Wattle and Daub : Craft , Conservation and Wiltshire Case Study A dissertation submitted by. In *Architecture* (Issue March). https://doi.org/10.13140/2.1.1875.2806

Lan, G., Wang, Y., & Chao, S. (2018). *Influences of Specimen Geometry and Loading Rate on Compressive Strength of Unstabilized Compacted Earth Block*. *2018*.

Mostafa, M., & Uddin, N. (2016). Case Studies in Construction Materials Experimental analysis of Compressed Earth Block (CEB) with banana fi bers resisting fl exural and compression forces. *Case Studies in Construction Materials*, *5*, 53–63. https://doi.org/10.1016/j.cscm.2016.07.001

Olokode, O. S., Aiyedun, ; P O, Raheem, ; D M, Owoeye, ; F T, & Anyanwu, B. U. (2012). Production and characterization of clay-cow dung insulating fire-bricks. *Global Advanced Research Journal of Engineering, Technology and Innovation*.

Shukla, A., Tiwari, G. N., & Sodha, M. S. (2009). Embodied energy analysis of adobe house. *Renewable Energy*, *34*(3), 755–761. https://doi.org/10.1016/j.renene.2008.04.002