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Recycling cotton fibres(CF) into building materials (Acoustic and mechanical study)

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ABSTRACT
In this research, we study the effect of adding cotton fibers on the acoustic and mechanical properties of clay bricks composed of clay, sand, and gypsum. We made 11 samples of these bricks and changed the percentage of cotton threads from 0% to 10%. We measure the change in the speed of sound transmission and calculate the value of mechanical stresses. The results showed that adding 3% of cotton fibers gives us the best percentage of hardness, 45.7%, and isolates 4.2% of sound. The portion of sound insulation also increases when we increase the portion of cotton fibers. These results enable us to use these bricks in the construction field to add the best performance to structures and to insulate sound inexpensively.

Keywords: Cotton fibers, Clay bricks, Mechanical properties,Acoustic properties, Sound insulation

1 Introduction

Humanity's view of building materials has changed. After the focus was on the durability of the dwelling, the focus became on the environmental field [1]. Engineers' focus has become directed towards making environmentally friendly building materials [2] that are not economical [3] and have low energy consumption [4]. Building with clay bricks is widespread in some countries in Africa, Asia, and Latin America [5-6-7]. Because it corresponds to some of the climatic characteristics of these regions [8]. To increase the durability of clay bricks, a group of materials is added. Some countries use palm fibers, [9] and glass fibers [10] and bamboo is used in areas of Africa [11] and animal waste is added in Australian areas [12] and straw is used in iraq [13]. Adding fibers to clay bricks aims to increase rigidity [14] and increase thermal insulation [15] and thus reduce energy consumption [16]. Cotton is a plant material consisting of natural fibers. It is produced by countries such as China, India, America, and Egypt [17] It is used in the field of textile and clothing industry [18] and the medical fieldas well [19].

Cotton fibers are converted into yarns to make fabrics [20]. Recently, the use of cotton fibers (CF) has spread in the fields of construction [21],and nowthe field of manufacturing polymers is more and more reinforced with natural fibers[22]. In this research, we will study the effect of adding cotton fibers to clay bricks. In terms of hardness and Sound insulation. We will use of scientific methods in the laboratory to calculate the change in the value of the stresses required to destroy the samples.

When we change the percentage of cotton fibers from 1%,2%, 3%,4%, 5%,6%,7%, 8%, 9%, and 10%, in return, we determine the best sample in terms of hardness to conduct experiments on to define the amount of sound insulation associatedwith these bricks. We conducted these experiments on bricks consisting of 45% clay, 23% sand, 15% gypsum, and 17% water.
The results show that cotton threads improve the mechanical properties of clay bricks in specific proportions. It has a positive effect in increasing the sound insulation of the samples and thus increasing the sound insulation of the buildings made of these bricks.

2 Methods and methods

2.1 Methods

2.1.1 Clay

Clay is abundant in southern Algeria. Clay is used to make ceramics [23] and bricks [24] and is largely used in the medical field [25] and cement industry [26]as well. We use red clay, with density = 2.51 g/cm^3. When analyzing 1000 grams of this clay, we obtain the results shown in (Table 1).It is characterized by a high percentage of SiO_2.We filterthe clay and use the particle size (< 5 mm).The physical properties of this clayare shown in (Table 2).
We obtained these results from the Public Works Laboratory in Adrar.

Table 1. Chemical composition of clay.

Elements	SiO_2	Al_2O_3	Fe_2O_3	K_2O	MgO	CaO + TiO_2+ MnO
Percentage	64%	16%	7.6%	3%	2.5%	7%

. **Table 2** . Physical properties of clay

Dry density(g/cm^3)	Natural density(g/cm^3)	Plastic limit(%)	Liquid limit(%)	Optimum moisture content(%)	Total cohesion (Pa)
2.48	2.51	13	68.4	14	24000

2.1.2 Sand

The Adrar regionin southern Algeria,covered with sand dunes,is identified as a desert area. In these experiments, we use dune sand. Its density is 1.75 g/cm^3. It consists of the following chemical compounds: silicon dioxide (SiO_2) and calcium oxide (CaO). The chemical and physical properties of the sand used are shown in (Table 3). We sift the sand and use the particle size (< 2 mm).
We add the sand to improve the clay mixture [27] and it is used as a building material [28], and a component of cement [29].Obtained results of the chemical composition from the Civil Engineering Laboratory, Adrar University, Algeria.

Table 3 . Chemical composition and physical properties of sand.

Chemical properties						
Elements	SiO_2	CaO	Al_2O_3	K_2O	MgO	**Others**
Percentage	**65%**	**15%**	**5%**	**2%**	**3%**	**10%**
Physical properties						
Methylene blue	Apparent specific gravity(g/cm^3)	Coefficient of curvanture (Cu)	Bulk specific gravity	Water absorption(%)	Sand equivalent (%)	Coefficient of uniformity
0.6	**1.43**	**1.7**	**2.53**	**2.15**	**86**	**1.1**

2.1.3 Gypsum

Gypsum is added to the clay mixture to increase itsdurability [30], and it is considered an environmentally friendly material [31].It is a good heat insulator[32]. In this research, we use gypsum from the Ghardaia region in southern Algeria. Its density is 1.4 g/cm^3.

We use particle size (< 1 mm). The chemical and physical properties of gypsum is shown in (Table 4). We obtained the results of the chemical composition from the Civil Engineering Laboratory at the University of Ghardaia, Algeria.

We conducted a granular analysis of 2000 kg of clay and sand.

Table 4 . Chemical and physical properties of gypsum

Chemical properties	
$CaSO+2H_2O$	35%
CaO	18%
SO_2	3%
SiO_3	16%
Al_2O3	11.7%
MgO	6%
Fe_2O_3	6.5%
Others	3.8%
Physical properties	
Fitness module	0.8
Unitary mass (g cm-3)	0.62
Real density (g cm3)	2.6
Starting setting time (min.)	19
Ending setting time (min.)	34
Compressive strength (MPa)	9

Normal stress - Tension (MPa	3

(Fig 1) shows the results of the granular analysis.
This test was performed by placing dry samples with a specific weight in a set of sieves of different diameters. The larger diameter is higher than the smaller diameter[33]. When we move the soil with a vibrating machine. The granules are arranged in descending order - from largest to smallest. The auger separates larger particles from smaller ones. We measured the remaining samples in each sieve and determined their percentage of the total quantity.
We draw a curve linking the percentage remaining in each sieve as a function of the diameter of the openings of this sieve. [34]

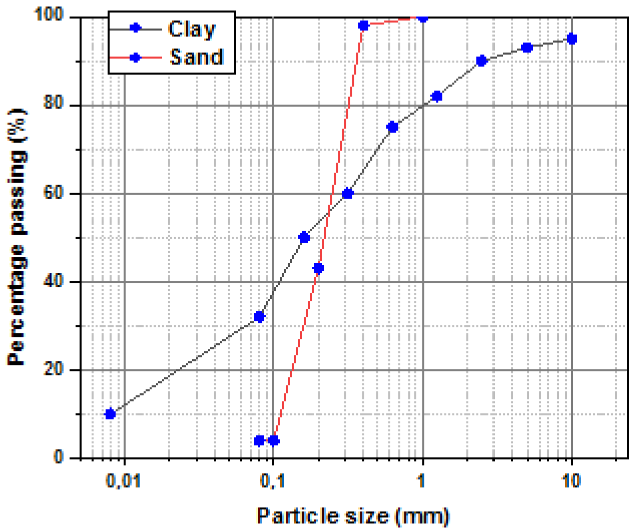

Fig 1 . Granular analysis results

2.1.4 Cotton fibres(CF)
Cotton is a group of plant fibers [35], used in the manufacture of threads [36] and oils are extracted from its seeds [37]. Its shrub grows in tropical and subtropical regions around the world. Its production requires a lot of sunlight and long periods free of cold. In laboratory experiments, we use cotton fibers imported from China.

Fig 2. Cotton fibres

Fig 2 represents the type of fibers used. The morphological structure of cotton fibers shows that it consists of 4 procedures[38]:

1 Cuticle :

It is a very thin layer attached to the outside of the main wall. It consists of cotton wax and a mixture of oils and fats [39].

2 Primary wall:

It consists of cellulose. It is made up of fine filaments and plays a role in cell growth and elongation.

3 Secondary wall:

It also consists of cellulose. It consists of layers of fibers in a spiral shape. Cotton fibers are protected by layers against chemical effects [40].

4 Lumen:

It is a cylindrical void representing 30% of the cross-sectional area. Contains pigment materials that determine the color of the fibers [41].

Fig 3 shows the cotton fibers'morphological structure[42].

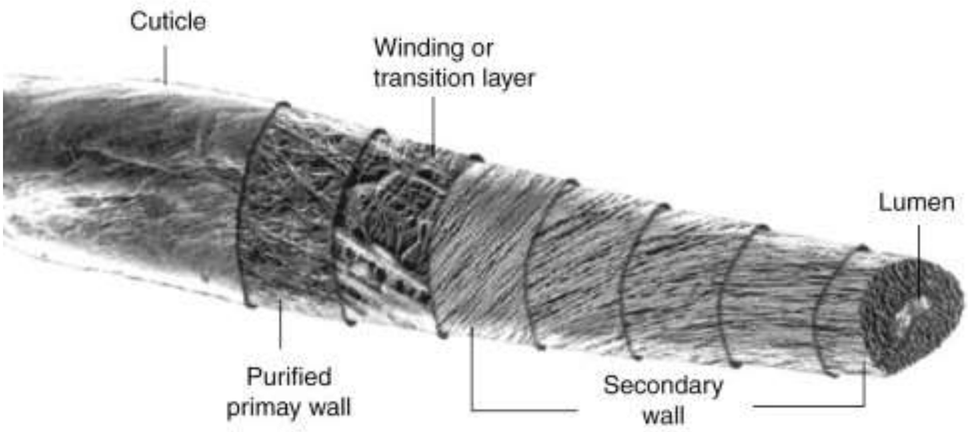

Fig 3 . Morphological Structure of Cotton Fibres.

Table 5 shows the cotton fibers' chemical composition[43].

We use cotton fibers 90 mm, long and 5 mm thick, with density of1.54% g/cm^3. Table 6 shows thesefibers'mechanical properties.

Table 5 .Chemical composition of cotton fibres.

Elements	Cellulose	Ash	Protein	Pectin substance	Oil, fat & wax	Other
percentage	94%	1.2%	1.3%	0.9%	0.6%	0.8%

Table 6 . Mechanical properties of cotton fibres

Tensile strength(MPa)	Young's modulus(GPa)	Elasticity recovery
400	4.8	At 2 % Extension – 74%
		At 5 % Extension – 45%

2.2Methods

2.2.1 Samplepreparation

- We measure aportion of 2000 g of the composite material, which consists of 45% clay(900g), 23% sand(460g), 15% gypsum(300g), and 17% water(340 cl).Fig 4 depicts the composition of the samples before adding the cotton fibers.
- Mix clay, sand, and gypsum for 2 minutes using an electric mixer.

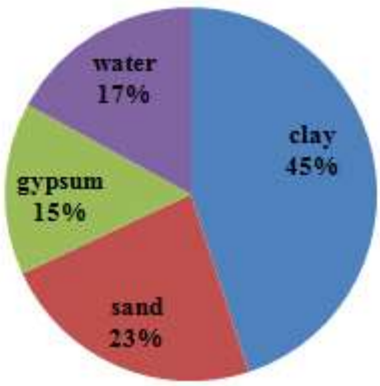

Fig 4. Components of the samples.

- Gradually add water and mix for 2 minutes.
- We place the obtained dough inside a metal mold with dimensions of 20×10×5 cm^3.
- We add cotton fibers in two areas inside the mold, lengthwise.
- We put the mixture, thenwe addthe fiber sand the mixture.
- Fig 5 shows how to place cotton fibers.

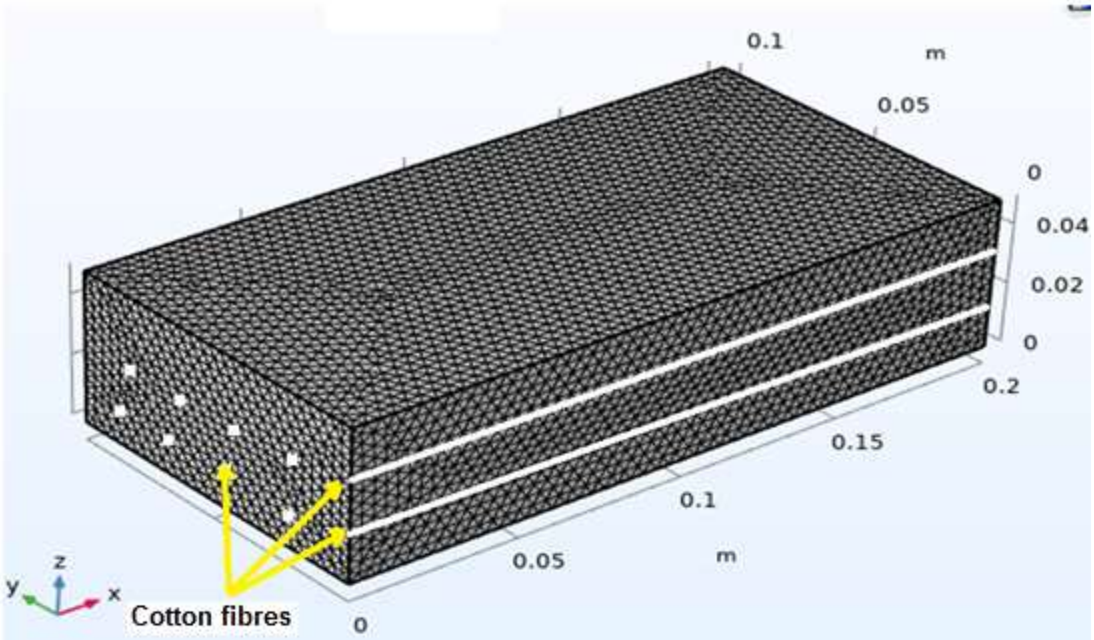

Fig 5. Distribution of cotton threads inside clay bricks.

- We make 6 samples of each portion of cotton yarn.
- We wait for the samples to dry for 28 days.
- We do a bunch of experiments.

The composition of the samples is shown in Table 7.

2.2.2 .Measuring the change in the speed of sound travel.

- After the samples dried for 28 days.
- We conduct non-destructive tests to determine the change in sound transmission speed when adding cotton fibers.
- Sound is identifiedas a mechanical wave resulting from vibration in a certain medium[44]. When the wave travels inside a solid body[45], its particles collide with each other[46], when the medium is solid, sound travels at a speed [47].

Table 7 . Sample preparation

Clay (%)	Sand (%)	Gypsum(%)	Water (%)	Cotton threads (%)	Code
45	23	15	17	0	G.C.S0
45	23	15	17	1	G.C.S1
45	23	15	17	2	G.C.S2
45	23	15	17	3	G.C.S3
45	23	15	17	4	G.C.S4
45	23	15	17	5	G.C.S5
45	23	15	17	6	G.C.S6
45	23	15	17	7	G.C.S7
45	23	15	17	8	G.C.S8

45	23	15	17	9	G.C.S9
45	23	15	17	10	G.C.S10

- In our experiment, we measured the speed of sound at a distance of 20 cm.
- Fig 6 represents the instrument used to measure the speed of sound transmission within samples.

Fig 6. Measure the speed of sound transmission

- This device measures the speed of sound transmission. The value displayed on the screen represents the amount of time required for sound to travel within a distance of 20 cm.
- We calculate speed using Law (1) :

$$\mathbf{S} = \frac{d}{t} \qquad (1)$$

S is speed(m/s). d is distance(m). t is time(s).

- The results of measuring the sound transmission speed are shown in Fig 7.

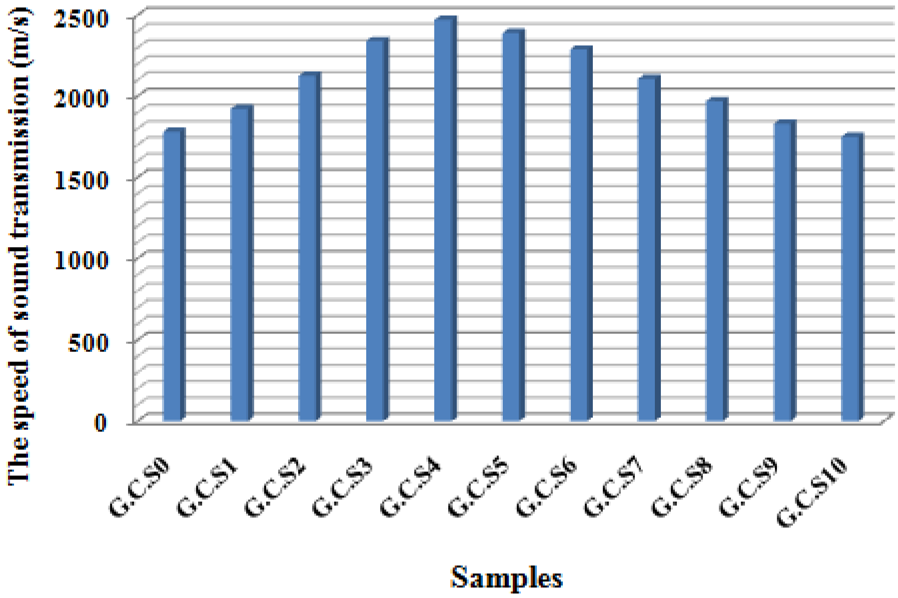

Fig 7 . Change in the speed of sound transmission in samples

2.2.3 Calculating the change in the value of the stresses.

To calculate the stresses, we use the pressure device shown in Fig 8.

Fig 8 . Stress measuring device.

We adjust this device as follows:

- The initial force is 10 kN
- Application speed is0.4MPa/s
- Applicable area: 200×100 mm = 20000 mm^2.
- We use the relationship (2) to calculate stresses:

$$\sigma = \frac{F}{A} \quad (2)$$

σ is stress.**F** is force.**A** is area.

The results of the change in stress value are shown in Fig 9.

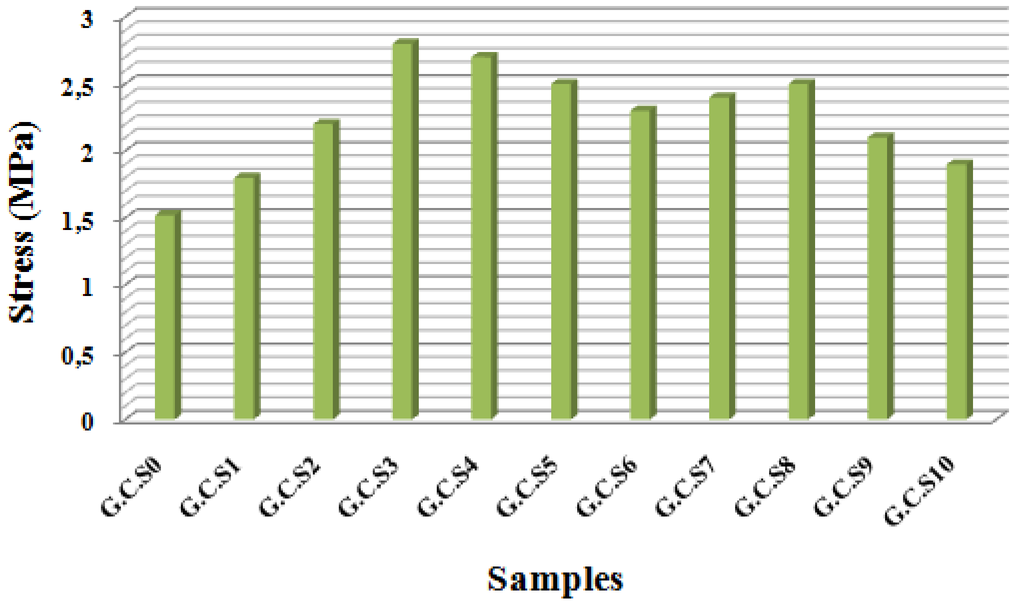

Fig 9. Change in stress when adding cotton threads

3 Results and discussion

3.1 Change in the speed of sound transmission

- The speed of sound travel changes according to the medium through which it travels[48].
- In the samples that do not contain cotton fibers, the sound travels at a speed of 1780 m/s, which increases by 7,38%,16,31%,23,93%, 27,93%, 25,52%, 22,2%, 15,52%, 9,64%, 2,73% in the samples G.C.S1,G.C.S2,G.C.S3, G.C.S4 G.C.S5, G.C.S6,G.C.S7, G.C.S8 and G.C.S9, respectively. And decrease by 1.7% in G.C.S10.
- When we add cotton fibers to clay bricks, it increases the cohesion of the bricks and thus increases their durability. This explains the increased speed of sound transmission[49].
- These results are consistent with the previous results [50].
- When we talk about adding cotton fibers to clay bricks, this includes sound insulation too [51].
- To determine the amount of sound insulation for bricks when adding cotton fibers, we use an acoustic measuring device Fig 10.
- We perform non-destructive tests to measure the difference in sound transmission between samples.

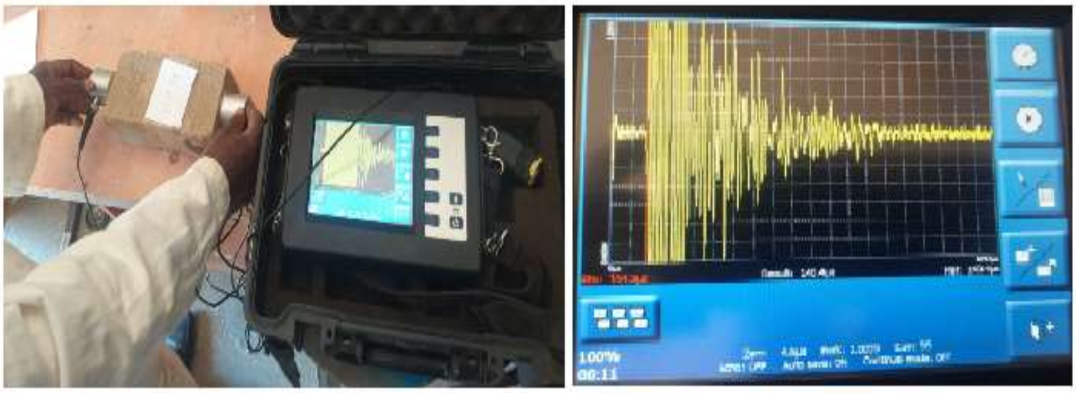

Fig 10. Calculating sound insulation in samples.

- Sound travels in solid bodies in waves[52].
- A sound wave is related to its frequency and wavelength.
- We can link the variables using Equation (3):

$$\mathbf{v = f \bullet \lambda} \qquad (3)$$

- v is Speed . **λ** is wavelength f is frequency.
- The speed of sound is related to the density of the brick. We can relate the speed of sound to the density of samples using Equation (4):

$$\mathbf{s} = \sqrt{\frac{\gamma \times p}{\rho}} \qquad (4)$$

s is the Speed of sound. **P** is Pressure. **ρ**is Density. **γ** is the Specific heat ratio.

The temperature at which the experiments were conducted was 30c^0.

- Fig 11 shows the sound insulation ratio of the samples compared to samples without cotton threads.

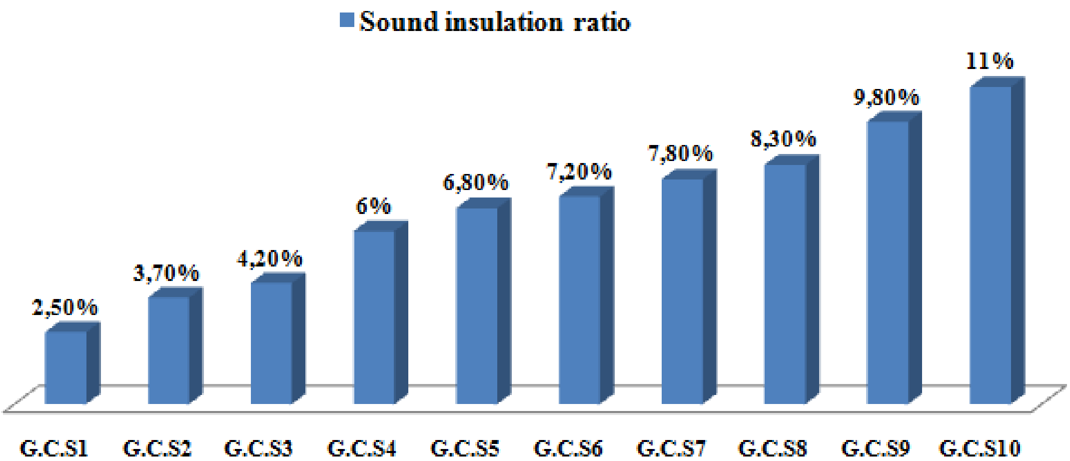

Fig 11. The percentage of sound insulation in the samples.

- The sound insulation results in the samples show that as the percentage of cotton fibers increases, the sound insulation rate increases with it [53].
- The density of the samples decreases when we add cotton threads [54] because the volume increases.
- The sound insulation ratio is irrelevantto the solidityof the samples.

Cotton is a sound-insulating material because it contains pores [55],such as plant fibers and glass fibers [56].

Adding cotton fibers to clay bricks produces a large number of small pores inside the samples [57], This allows sound waves to penetrate the material reachingthese pores[58].

Friction with the material converts sound energy into heat.[59]

Equation (5) ~~is~~ represents the power transmitted through the wave:

$$P = \frac{E\lambda}{T} = \frac{1}{2}\mu\omega^2 A^2 v \qquad (5)$$

E_λ the energy associated with one wavelength of the wave.

P is power transmitted.

μ *is the mass per unit length of the string.*

ω*isangular frequency of the wave.*

A is wave amplitude.

v is wave propagation velocity.

The sound insulation coefficient increases when the frequency increases [60].

Ease of sound insulation in materials that have a large number of voids.

In general, sound isolation provides a channel for sound input.

The holes must be small and connected to each other,or in the form of fibers - a mixture of fibers - for example, cotton fibers.

- Cotton fibers increase sound absorption by reducing the energy when sound waves passed.

3.2 Change in stress value

In the field of materials mechanics, the ability of materials to withstand stresses is studied [61].

Make sure it is not broken during the test.

Stress analysis is one of the important methods for designing structures [62].

We analyze the expected loads and compare them with material properties [63].

The endurance analysis enables us to increase the efficiency and performance of structures.

When cotton fibersare added to clay bricks, the stress required to destroy the samples increases[64].

Compared with samples without cotton fibers(G.C.S0), the stress value increases by 15.55%, 30.9%, 45.7%, 43.7%, 39.2%, 33.91%, 36.66%, 39.2%, 27.6%, and 20% in the samples.G.C.S1,G.C.S2,G.C.S3,G.C.S4,G.C.S5,G.C.S6,G.C.S7,G.C.S8
, G.C.S9 and G.C.S10 respectively.
Sample G.C.S3 (3%Cotton fibers) is the best in terms of solidity.
Adding cotton fibers to clay bricks gives them a hardness between 15% and 45%.
At certain percentages of cotton yarn,the bricks possess high solidity.
When a compressive force is applied to an area of brick, stresses spread in all directions [65].
Equation 6 shows the stresses on the axes (x.y.z)

$$\boldsymbol{\sigma} = [\sigma xx\ \tau xy\ \tau xz\ \tau yx\ \sigma yy\ \tau yz\ \tau zx\ \tau zy\ \sigma zz\ ] \qquad (6)$$

Compressive stress increases when the material is solid. Stresses spread in all directions, causing twists in the bricks (Fig 12).
Fig 12 represents a tensor of stress.

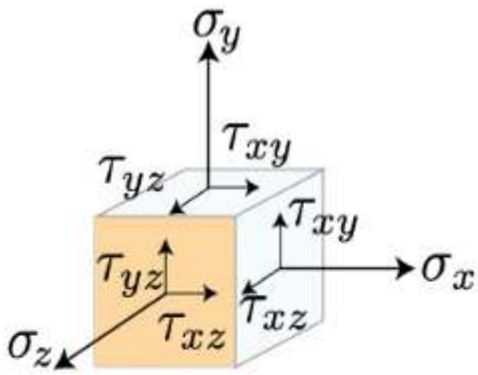

Fig 12 A tensor of stress

The tensor might be written in terms of coordinates, or in terms of matrices.
It distributes the components of the applied stresses along three parallel axes.
It signifies great importance in physics and applied engineering, because it determines the main stresses and distortions for us.
Clay brick is considered a combinationof material of numerous compounds (clay, Sand, gypsum, and Cotton fibers), and stresses are not transmitted equally in the same directions.
The resulting distortions when the samples are subjected to stress occur in three directions, but not equally.
Fig 13 represents a numerical simulation of a clay brick subjected to stresses (sample G.C.S3).
This figure shows the change in the shape of the sample in the axis of (x.y.z).
We use the ABAQUS software.

ABAQUS is one of the most powerful numerical analysis software inthe field of mechanics. It performs very complex studies with the principle of finite elements FEM

Where we can solve the issue of simple linear analyses and complex nonlinear simulation analyses[66],and simulate the transmission of stresses.

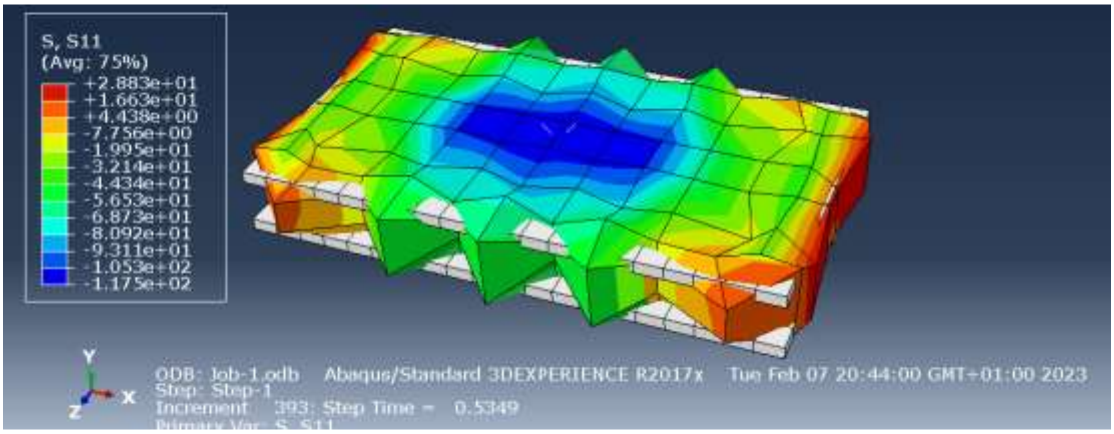

Fig 13 . Numerical simulation of clay bricks under stress.

Conclusion

We can recycle cotton fibers to increase the solidity of clay bricks and increase the sound insulation rate. In this research, we found that cotton fibers have a positive effect in increasing the cohesion of clay bricks. We were able to determine the best percentage of cotton threads, 3%, which gives us the best stiffness of 45.7% and sound insulation of 4.2%. We can combine solidity and sound insulation in clay bricks. This study aims to determine the effect of adding cotton fibers on the acoustic and mechanical properties of clay bricks.

Preliminary results indicate the possibility of using these fibers to increase sound insulation in bricks and, consequently, in buildings made of these bricks. In addition to increasing the solidityby 47.5%, the bricks are resistant consistent with climatic factors.

We conclude from measuring sound insulation that it is possible to link the percentage of cotton fibers to the percentage of sound insulation. After conducting a stress test, it was found that cotton fibers increased the cohesion of bricks by specific percentages. We can link the fiber percentage to the solidity percentage.

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