

Mechanical properties of compressed earth blocks reinforced with glass fibers and palm fibers: Experiments and simulation

Propriedades mecânicas de blocos de terra comprimida reforçados com fibras de vidro e fibras de palma: Experimentos e simulação

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Abstract

The civil and mechanical engineers are interested in studying how much load structures can support. Recently, the use of environmentally friendly materials has become widely spread in the field of construction because they do not contribute to the propagation of greenhouse gases, unlike cement construction. In this research, we try to address the problem of the fragility of clay bricks. We use the compressed earth technique and add palm fibers and glass fibers. We want to know the effect of adding these fibers on density, speed of sound transmission rate, and stresses. Preliminary results show the addition of 0.1%, 0.2%, 0.3%, 0.4%, and 0.5% of palm fibers and glass fibers, respectively. The density value increases between 1.1% and 11%. The speed of sound increases between 2.1% and 13.7%, and the stress value increases between 8.6% and 41%. These results enable us to set limits for the loads supported and borne by the walls built with these bricks.

Keywords: Compressed earth block. Clay bricks. Mechanical properties. Hardness. Simulation.

Resumo

Os engenheiros civis e mecânicos estão interessados em estudar quanta carga as estruturas podem suportar. Recentemente, o uso de materiais ecologicamente corretos tornou-se amplamente difundido no ramo da construção por não contribuir para a propagação de gases de efeito estufa, ao contrário da construção de cimento. Nesta pesquisa, tentamos abordar o problema da fragilidade dos tijolos de barro. Usamos a técnica de terra comprimida e adicionamos fibras de palmeira e fibras de

vidro. Queremos saber o efeito da adição dessas fibras na densidade, velocidade da taxa de transmissão do som e tensões. Os resultados preliminares mostram a adição de 0,1%, 0,2%, 0,3%, 0,4% e 0,5% de fibras de palma e fibras de vidro, respectivamente. O valor da densidade aumenta entre 1,1% e 11%. A velocidade do som aumenta entre 2,1% e 13,7%, e o valor da tensão aumenta entre 8,6% e 41%. Esses resultados permitem estabelecer limites para as cargas suportadas e suportadas pelas paredes construídas com esses tijolos.

Palavras-chave: Bloco de terra compactado. Tijolos de argila. Propriedades mecânicas. Dureza. Simulação.

1. Introduction

In most parts of the world, clay bricks are used in construction, and their use has increased today because studies have shown that they are environmentally friendly and save energy (Almutairi *et al.*, 2017). The study of the mechanical behavior of clay bricks makes it possible to predict the weight that the wall supports and the factors that increase its hardness or fragility. The use of different types of fibers with bricks has become widespread, as the fibers increase their cohesion (Zhang *et al.*, 2023). In mechanics, the impact force on bodies is studied, as it causes internal and external stresses (Komanduri *et al.*, 2001). It is under the effect of the force applied to it that pressure is distributed in the body and visible and invisible deformations occur. When studying the behavior of materials, it is necessary to know the physical and mechanical properties, as they facilitate the understanding of the properties of the material and its resistance to withstand the pressures applied to it, without mechanical deformation (Zhao *et al.*, 2005). To understand this behavior experimentally, we apply it to laboratory samples. We make bricks composed of 52% clay and 22% sand, plus 10% gypsum, and add palm and glass fibers of 0.1% 0.2% 0.3% 0.4%, and 0.5%. to the samples to see the effect of adding these fibers to the bricks. We study some physical properties such as density, sound velocity, and change the value of the force applied to the samples, and perform a numerical simulation. We use mechanical simulation software for a sample subjected to a three-point bending stress. Predicting the behavior of materials with the same mechanical properties. We obtain results that allow us to understand the behavior of clay bricks when subjected to mechanical stresses.

2. Materials and methods

2.1 Materials

Clay: The city of Aoulef is located in the eastern part of the province of Adrar, in southern Algeria (Figure 1).



Figure 1- The location of AOULEF Adrar, Algeria.

The Clay is widely available in AOULEF Adrar, and it is easy to obtain. its density = 2.51 g/cm³. When analyzing 1000 g of clay in the quality and control laboratory in the city of Ouargla, south of Algeria, we obtained the following results:

Calcium carbonate CaCO₃ = 2,06%. Insoluble = 90,48 %. Chlorine (Cl⁻) = 20,227 mg. Calcium sulfate dihydrate CaSO₄·2H₂O = 2,65 %. Sulfur trioxide SO₃⁻² = 1,23 %. Sulfate SO₄⁻² = 147,33(mg/l). It consists of SiO₂ (64%). Al₂O₃ (16%). Fe₂O₃ (7.6%). K₂O (3%). MgO (2.5%). and CaO + TiO₂+ MnO (7%).

➤ Particle size (< 5mm).

We got the results from the Public Works Laboratory in Adrar.

Sand: In the experiment, we use dune sand, which is abundant in southern Algeria. Its density is 1.75 g/cm³. It contains chemical compounds: silicon dioxide (SiO₂) 66%. Calcium oxide (CaO) 15%. Magnesium oxide (MgO) 2.3%. Aluminum oxide (Al₂O₃) 4.5% Potassium oxide (K₂O) 1.8%. consists of SiO₂ (65%). CaO (15%). Al₂O₃ (5%). K₂O (2%). MgO (3%) Others (7%).

➤ Particle size (< 2mm)

Gypsum: We use gypsum from the Ghardaïa region in southern Algeria, its density is 1.4g/cm³. It consists of Fe₂O₃ (6.5%) Al₂O₃(11.7%) CaSO₄+2H₂O (35%). SiO₃(17%). SiO₂(20%). MgO (6%). Others (3.8%). particle size (< 1mm).

Palm fibers: We use palm fibers found in southern Algeria. Figure 2 shows the type of fiber used. The physical and chemical properties were obtained from the civil engineering laboratory of the University of Ouargla, in southern Algeria. Chopped palm fibers, length 2 = cm.



Figure 2 - Palm fibers.

Table 1 – Physical and chemical properties of palm fibers.

Chemical properties			Physical properties		
Cellulose	Micellulose	Lignin	Tensile strength	Young's modulus	Elongation
27%	37%	28%	170-275 MPa	05-12 GPa	05-10%

Glass fibers: We use glass fibers from the factory in M'sila, Algeria. These fibers are used in the manufacture of optical fibers for the Internet. Figure 3 shows these fibers. Table 2 shows the physical and chemical properties of glass fibers. Cut the glass fibers, length 2 = cm.



Figure 3 - Glass fibers.

Table 2 – Chemical and physical properties of glass fibers.

Chemical properties						Physical properties		
SiO ₂	Al ₂ O ₃	CaO	MgO	B ₂ O ₃	Na ₂ O	Density	Tensile strength	Modulus of elasticity
		%				g/cm ³	MPa	GPa
60-65	2-6	14	1-3	2-7	8-10	2.68	1700	72

2.2 Methods

Sample preparation: We manufacture samples weighing 2 kg and measuring 20×10×5 cm³. We compress the ingredients in a hydraulic machine with a pressure of 2.5 MPa. The research team is divided into three groups:

- The first group chooses the best ratio to combine the clay, sand, and gypsum, and we determine the best water ratio.
- The second group measures the variation of density and sound transmission rate when adding fibers.
- The third group studies the evolution of the forces and stresses applied for the crushing of the samples.

The granular composition of the soil is determined by two tests: granulometric analysis and sedimentometry according to standards NF P 94-056 and NF P 94-057. 93

- ✓ We already know that the soil is composed of 70% clay + 30% sand (Zouaoui *et al.*, 2017).
- ✓ We change the proportion of gypsum from 0% to 20%, we add a fixed amount of water.
- ✓ We repeat the experiments to choose the best sample in terms of density.
- ✓ We change the water percentage from 10% to 20% because (less than < 10% of the samples are drier and more than > 20% of the samples are wetter).
- ✓ We use the relation (1):

$$W = \frac{WS - WD}{WD} \quad (1)$$

where WS is weigh the samples in the wet state, and WD is weigh the samples after 28 days of drying.

Figure 4 shows the best percentage of water that gives us the greatest density.

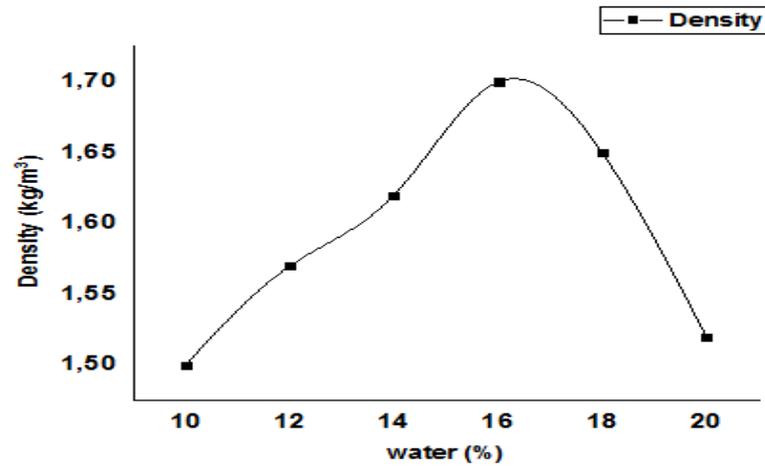


Figure 4 - Optimum water content at 16% of gypsum.

- The final composition of the samples is as follows 10% (200g) gypsum, 16% (320cl) water, 52% (1040g) clay, and 22% (440g) sand.
- Add the palm fibers and glass to the compound - clay + sand + gypsum - mix the mixture in an electric mixer, (Figure 5(a)), for 3 minutes, then add water and mix for 2 minutes.

We prepare samples according to Table 4.

- ✓ The total mass of the mixture is 2 kg. We place the mass in a metal mold whose dimensions are $20 \times 10 \times 10 \text{ cm}^3$.
- ✓ Then we apply pressure using a hydraulic press, (Figure 5(b)). After drying the samples for 28 days, we perform pressure.
- ✓ tests. We make 6 samples of each percentage of palm fibers and glass fibers. Figure 6 represents the samples.

Measure the change in density: The density is measured by applying the relation of the density law (2):

$$\rho = \frac{M}{V} \quad (2)$$

We weigh the samples and then measure their dimensions. The results of the density measurement are shown in Figure 7.

Table 4 – Sample preparation.

Code	Clay %	Sand %	Gypsum %	Water %	Palm fibers %	Glass fibers %
PGF0	52	22	10	16	0	0
PF1	52	22	10	16	0.1	0
PF2	52	22	10	16	0.2	0
PF3	52	22	10	16	0.3	0
PF4	52	22	10	16	0.4	0
PF5	52	22	10	16	0.5	0
GF1	52	22	10	16	0	0.1
GF2	52	22	10	16	0	0.2
GF3	52	22	10	16	0	0.3
GF4	52	22	10	16	0	0.4
GF5	52	22	10	16	0	0.5



Figure 5 - Used laboratory equipment (a) Electric mixer (b) Hydraulic press



Figure 6 - Laboratory samples.

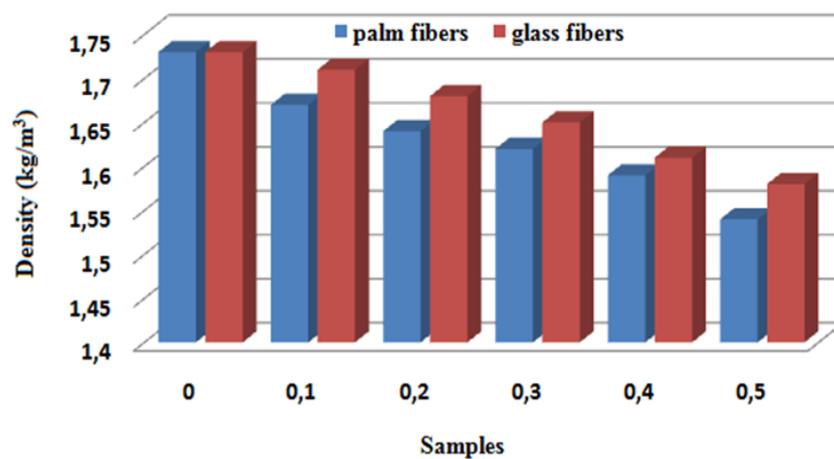


Figure 7- Density value changes in samples when adding fibers.

Measure the speed of sound transmission in the samples: To measure the speed of sound transmission, we use the device shown in Figure 8.

We measure the speed of sound at a distance of 20 cm. This device gives us the time needed to travel this distance. The results of the measurement of the speed of sound are presented in Figure 9.



Figure 8 - A device that measures the speed of sound.

Stress measurement: We measure the value of the stresses required to break the samples. We carry out compression and bending tests.

- We use the machine presented in Figure 10.
- We set the machine: Initial force 10 kN.
- The stress application rate is 0.4 MPa/s.
- Size: a rectangle of $200 \times 100 \text{ mm}^2$ (20000 mm^2).

The results of the stress measurement are shown in Figure 11.

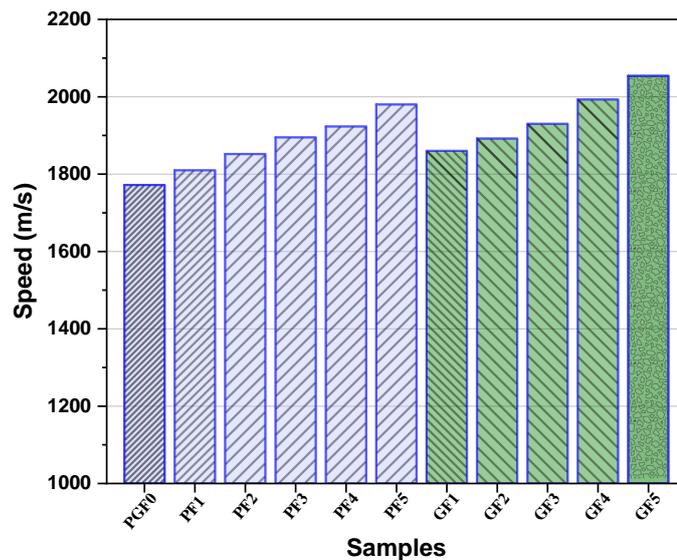


Figure 9 - The speed of sound transmission in the samples.



Figure 10 - Stress measuring device.

3 Results and discussion

3.1 Density

Density is an important property in the field of mechanics. When the density is high, it means that the particles in the material are more interconnected (Mei *et al.*, 2017). If we say that the density of iron is higher than that of copper, this means that the particles of iron are more compact and closer together than the particles of copper. From our experience, we notice a change in density when we add palm fibers and glass fibers (Rashid *et al.*, 2019).

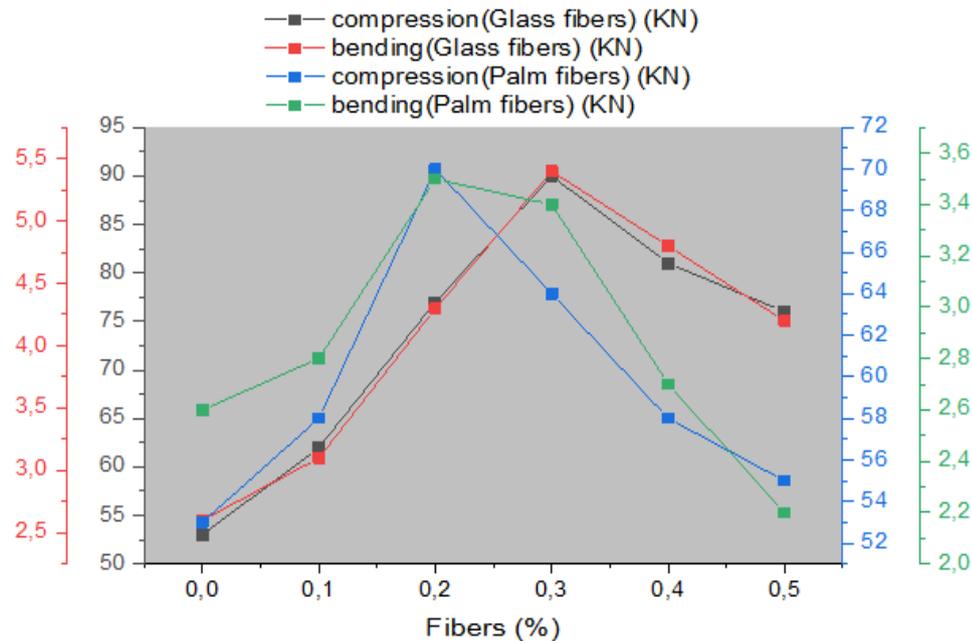


Figure 11 - Measure the value of stresses in the samples.

Samples that contain palm fibers: Compared to the sample without fiber, the density decreases when palm fibers are added.

Decrease of 3.4%, 5.2%, 6.3%, 8.1% and 11% for PF1, PF2, PF3, PF4 and PF5 samples, respectively.

Samples that contain glass fibers: Compared to the sample without fibers, the density decreases when glass fibers are added.

Decreased by 1.1%, 2.8%, 4.6%, 6.93%, and 8.67% in samples GF1, GF2, GF3, GF4, and GF5, respectively.

Density decreases sharply with palm fiber compared to glass fiber (11% > 8.67%) PF5 > GF5.

The addition of palm fibers and glass fibers in clay bricks increases the pores inside the samples. With increasing sample size (Arslan *et al.*, 2021), both variables decrease the density (Zak *et al.*, 2016). As a result, the bricks become lighter and larger (Limami *et al.*, 2020).

3.2 The speed of sound transmission

The speed varies according to the medium in which the waves move. The speed of sound is related to the value of density, volume, and type of body (liquid, solid, gas) as well as the temperature of the medium (Filippou *et al.*, 2018).

In our experiment, we study the sound transmission rate to correlate the density and hardness of clay bricks. We notice a change in the sound transmission rate when we add palm fibers and glass (Mohammed *et al.*, 2018).

Compared to the sample without fibers, the bran velocity increases when palm fibers are added by 2.1%, 4.3%, 6.4%, 7.8%, and 10% in samples PF1, PF2, PF3, PF4, and PF5, respectively.

When we add glass fibers, the sound velocity increases by 4.7%, 6.3%, 8.18%, 11.1%, and 13.7% in samples GF1, GF2, GF3, GF4 and GF5, respectively.

When we add palm fibers and glass fibers, the number of voids inside the brick increases. This increases the openings for sound transmission (Gandia *et al.*, 2019).

As the percentage of fiber increases, the number of voids increases. The sound transmission rate is higher for samples that contain glass fibers because these fibers are synthetic and increase sound transmission (Yang *et al.*, 2016).

3.3 Stress

We perform strength tests to determine how well the samples can withstand external pressures and forces. In mechanics, we are interested in the study of loads on structures. Structural mechanics studies the behavior of structures under mechanical loads (Eslami *et al.*, 2018). In our experiments, we studied two types of force (compression force and bending force).

Compressive force: When palm fibers and glass are added, the compression force increases (Oskouei *et al.*, 2017).

► Compared to the sample without fibers:

- When we add palm fibers, the compressive strength increases by 8.6%, 24%, 17%, 9%, and 3.34% in samples PF1, PF2, PF3, PF4 and PF5, respectively.
- When we add glass fibers, the compressive strength increases by 17%, 31%, 41%, 34.5%, and 30.3% in samples GF1, GF2, GF3, GF4, and GF5, respectively.
- With palm fibers, an increase in strength is observed when the percentage of palm fibers is increased to the concentration of 0.2% (70KN), after which the compressive strength decreases.
- With glass fibers, an increase in strength is observed when the percentage of glass fibers is increased to the concentration of 0.3% (90KN), after which the compressive strength decreases.
- We conclude that the addition of palm and glass fibers increases the hardness in specific percentages (Shaqour *et al.*, 2021), and its effect becomes the opposite in high percentages (Adegoke *et al.*, 2019).
- Samples containing glass fibers have higher cohesion and hardness than samples containing palm fibers because the tensile strength of glass fibers is higher than that of palm fibers (1700 MPa > 275 MPa) (Patel *et al.*, 2019).

Bending force: In the bending experiments, it is almost the same thing. When we add palm and glass fibers, the bending strength increases.

► Compared to the fiber-free sample:

- When we add palm fibers, the bending strength increases by 7.1%, 25.7%, 23.5%, and 3.7% in samples PF1, PF2, PF3 and PF4, respectively, and decreases by 15.4% in sample PF5.
- When we add glass fibers, the bending strength increases by 16%, 39.5%, 51.8%, 45.8%, and 38.1% in GF1, GF2, GF3, GF4, and GF5 samples, respectively.
- When we add palm fiber, we see an increase in strength up to a concentration of 0.2% (3.5KN), after which the flexural strength decreases.
- When we add glass fibers, we see an increase in strength up to a concentration of 0.3% (5.4KN), after which the flexural strength decreases.
- Compressive strength is 20 times greater than bending strength with palm fibers (70>3.5) KN and 16 times greater with glass fibers (90>5.4) KN.

- The compressive force is larger because the area to which the force is applied is large ($200 \times 100 \text{ mm}^2$), in contrast to the bending force ($12 \times 100 \text{ mm}^2$). (The dimensions of the pillars in (Figure 10) are $12 \times 100 \text{ mm}^2$).

We can calculate the constraints using relation (3):

$$\sigma = \frac{F}{S} \quad (3)$$

Learn more about the bending behavior of clay bricks. We perform a numerical simulation for clay bricks containing 0.3% glass fibers with the same properties. We choose this sample because it is the hardest.

We use COMSOL simulation software, which allows for multiple physical modeling. It draws geometric shapes and material properties (Brezmes *et al.*, 2015).

We enter the variables:

Sample size $200 \times 100 \times 50 \text{ mm}^3$ with a density of 1.65 kg/m^3 . Poisson's ratio is 0.5, initial force is 10 KN.

Type of material: Composite material.

Modulus of elasticity: 300 MPa. We take the results in the nodes. Figure 12 shows how to determine dimensions, and place pillars, and nodes. It can be seen that the 3-point bending stress concentrates the force in the middle of the specimen. The maximum value of the stress is located near the struts. Figure 13 shows the evolution of the stress value at the points where a force is applied.

The value of the stresses changes depending on where the force is applied. We find that the maximum failure stress of the sample is $6.3 \times 10^6 \text{ N/m}^2 = 6.3 \text{ MPa}$. In the applied experiment, we found that the value of stress that breaks a brick sample containing 0.3% glass fibers is $5.4 \text{ KN} = 4.5 \text{ MPa}$ ($5.4 \text{ KN} / 12 \times 100 \text{ mm}^2$).

The numerical simulations are 71.43% similar to the real experiments and 28.57% different. ($6.3 > 4.5$) MPa. Numerical simulation is used to predict the mechanical behavior of the samples (Akinwande *et al.*, 2017).

The results show us that sample GF3, which contains 0.3% glass fibers, and sample PF2, which contains 0.2% palm fibers, are the best in terms of toughness.

These fibers increase the hardness of the walls between 24% and 41% compared to the wall without these fibers.

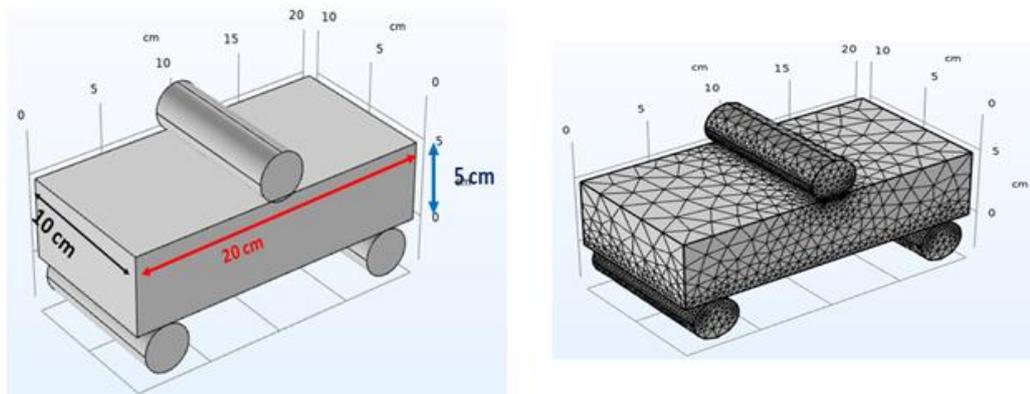


Figure 12 - Determine sample dimensions and initial conditions.

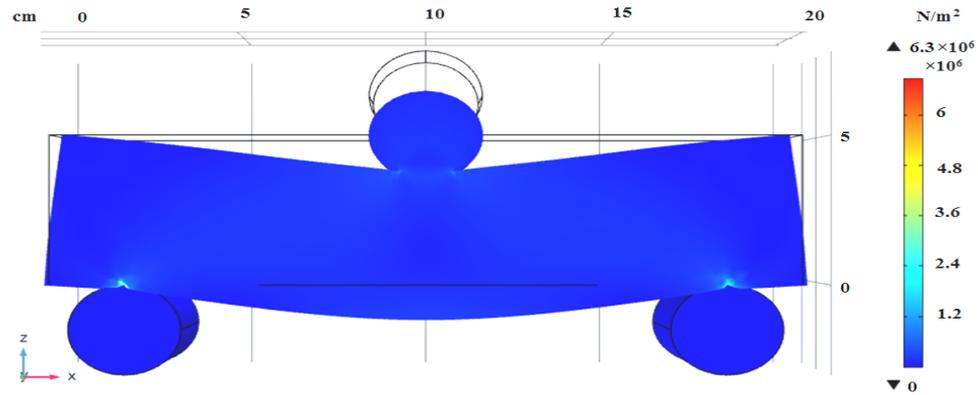


Figure 13 - Simulation results stress.

To find out the load that these bricks can support. We match experiments to reality. We use the relation (4) to connect weight and force:

$$1\text{N} = 0.102 \text{ kg} \quad (4)$$

- Samples containing 0.2% palm fiber increase the compressive strength by 24% (70-53) KN. This sample breaks at a force of 70 KN (it supports a weight of 7140 kg). Ordinary PGF0 bricks (without fibers) can support a weight of 5406 kg (53 KN).
- Samples containing 0.3% glass fibers increase the compressive strength by 41% (90-53) KN. This sample breaks under a force of 90 KN (it carries a weight of 9180 kg).

Glass fibers offer the best rigidity compared to palm fibers because they are synthetic and are not affected by corrosion and wear. In construction, we use bricks to create walls. We can know the loads that the wall initially supports.

Figure 14 is a simulation of a brick wall containing 0.3% glass fibers with the same composition. Formed from 5 rows. Length 110cm height 50cm thickness 5cm. We apply to it a force of 20 tons.

It turns out that the greatest stresses that cause deformations in the wall are localized on the sides of the wall.

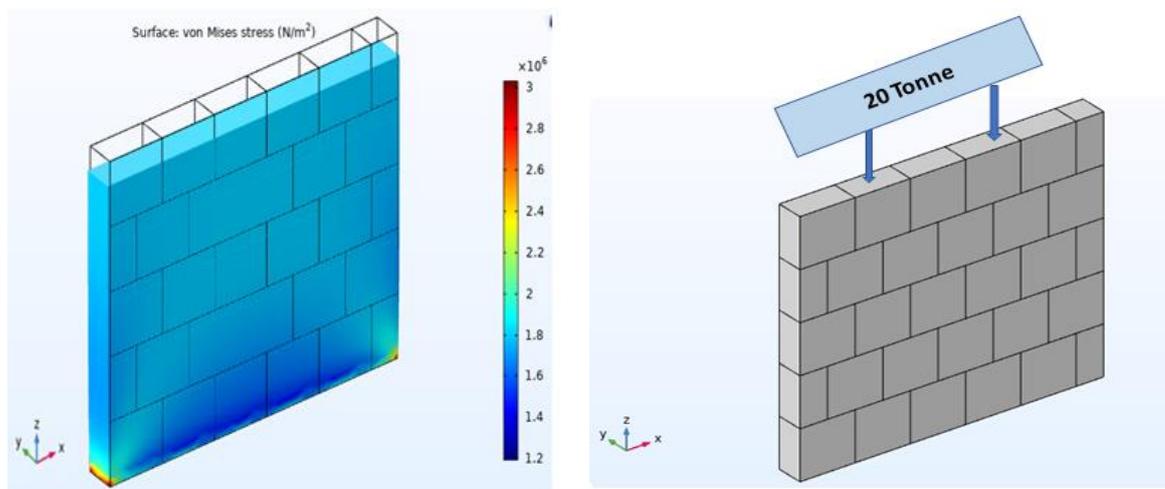


Figure 14 - Simulation of a brick Wall GF3.

4 Conclusion

Everybody has a limit to their ability to withstand mechanical stress. This corresponds to its physical and mechanical nature (Sommerfeld *et al.*, 2016). In addition to the cohesion of the internal parts, the value of density and the ability to resist climatic factors. The technology of compressed earth increases the hardness and durability of clay bricks (Barbero-Barrera *et al.*, 2020), because it gathers the largest mass of material in a given volume. This reduces the number of pores inside the brick and increases its hardness (Ruiz *et al.*, 2018). Understand the limits of the ability of bricks to support weights to avoid future cracks in the walls. and help us to increase the cohesion of the house.

In this research, we studied the effect of adding palm and glass fibers on the compressed earth block in terms of hardness and cohesion. We studied bricks composed of 52% clay, 22% sand, and 10% gypsum as reinforcing material. Its size is 20×10×5cm³. The best percentage of palm fiber is 0.2%, which increases the compressive strength by 24%, and bending strength by 25.7%. and the best percentage of glass fiber is 0.3%, which increases the compressive strength by 41% and bending strength 51.8%. When we add palm fibers and palm fibers, some physical and mechanical properties change, such as a decrease in density between 1.1% and 11%, an increase in sound velocity between 2.1% and 13.7%, and an increase in the value of stress between 8.6% and 41%. These values lead us to predict the mechanical behavior of walls built with such bricks in the future.

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