MECHANICAL PROPERTIES OF PLASTER REINFORCED WITH JUTE FABRICS

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ABSTRACT:

In recent decades, there is an interest in the construction industry for sustainable materials, respectful of the environment and capable of being easily recycled. In this work, the mechanical behaviour of materials composed of plaster and jute fabric is studied. The adherence of the jute fabric with the plaster and influence of jute fabrics in the bending, compression and elasticity of the composite is studied.

The jute fabric reinforcement improve the mechanical properties of the composite, providing structural stability to the specimens tested after the fragile rupture of the plaster matrix.

PALABRAS CLAVE: jute fabrics, plaster, mechanical properties.

1. Introduction.

Gypsum has been used since ancient times as a construction material for walls and ceilings. Its easy application, its ability to regulate humidity inside buildings, its good thermal insulation, the low energy necessary for its production, its widely distribution in the earth crust, makes the gypsum one of the most used and sustainable building materials [1].
Otherwise, the main weakness of gypsum is its brittleness and poor mechanical properties mainly under stress tension. Therefore, it is interesting to investigate different additives that could improve the mechanical properties of gypsum, the studies are focused on the use of reinforcement fibers or additives in a gypsum matrix.

The use of polymeric or metallic fibers has been investigated to improve the mechanical properties of gypsum. Eve et al. [2] blend different concentrations of polyamide fibers with commercial plaster, all the mechanical parameters of the composite decrease as the concentration of fibres is increased, except the fracture toughness. Gencel et al. [3] produce a gypsum composite containing diatomite and polypropylene fibers, it is observed that the addition of diatomite increases porosity and thermal conductivity coefficient and the polypropylene fibers increase mechanical properties. In [4],[5] Başaran et al. investigate the behavior of masonry walls with gypsum reinforced with various proportions of polypropylene and steel fibers, the reinforced gypsum increase significantly the stiffness of the walls.

It is possible to use additives from an industrial or construction waste recovering process and generate materials with added value from an environmental point of view. Nadal et al. [6] use polyamide that appear in the recovery process of end of life tyres as a reinforcement fiber, the results shows an improve in the compression and bending tests between samples prepared with different percentages of fiber. Piñero et al. [7] propose a composite material adding mineral wools from construction and demolition waste to the gypsum matrix, the addition of the fibers entails an increase of the surface hardness and flexural strength, however the compressive strength decreases. Khali et al. [8] study a gypsum plaster composites synthesized by blending plaster with different wastes like blast furnace slag, calcium carbonate and commercial poly vinyl alcohol polymer (PVA), the results shows an increase in the compressive strength for lower concentrations of the studied wastes.

In the last decades there is a growing interest in the use of natural fibers as replacement to synthetic fibers in reinforced composites of gypsum, due to their attractive features like the combination of good mechanical, thermal and acoustic properties. In many cases the fibers come from crop wastes, enhancing the environmental benefit of the composite [9],[10]. Otherwise, the hydrophilic behaviour of natural fibers is a disadvantage due to its interaction with the gypsum matrix, so the fibers are often subjected to treatments before mixing. Dalmay et al. [11] study the effects of adding natural fibres, hemp and flax, to a gypsum matrix. Hemp delayed the setting of plaster, so different chemical treatments were tested. The mechanical behaviour of gypsum was modified from brittle to a non-linear. Ioculano et al. [12], use biologically treated hemp fibers as reinforcement in plasterboards, the results revealed an enhanced toughness and a damage reduction for low impact tests. Ioculano et al. [13] research the interaction between chemical treated abaca fibers and gypsum matrix to produce fiber-reinforced plasterboards with good mechanical properties. The addition of low percentages of abaca fibers to gypsum leads to an enhanced toughness and flexural strength. Maaloufa et al. [14] determine the best percentage of cork and alpha fiber in a gypsum matrix to optimize thermal insulating and mechanical properties. Thermal conductivity is improved considerably, the alpha fiber increse flexure strength however cork makes the composite more brittle. F. Hernandez-Olivares et al. [15] use sisal fibers as a reinforcement in a gypsum matrix, the randomly distributed fibers produce an increase in the composite toughness.

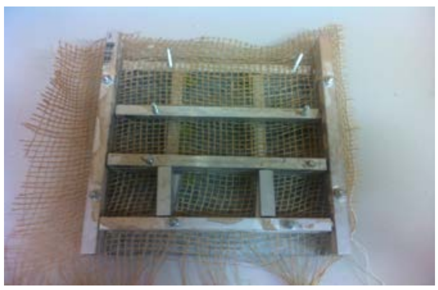
This work studies the mechanical properties of a sustainable composite of plaster reinforced with jute fabric. The adhesion of the jute fiber with the plaster is analysed and the influence of the location of the jute fabric at different cross section heights is tested. The results show an increase of flexure and compression tenacity and plasticity of the composite reinforced with jute fabric, compared to plaster or composites with jute fibers.

2. Materials

The matrix is gypsum, composed of calcium sulfate dihydrate, with the chemical formula $CaSO_4 \cdot 2H_2O$. When gypsum is heated at 100 ºC loses water content and it becomes to calcium sulfate hemihydrate $2CaSO_4 \cdot H_2O$, often called plaster.

The reinforcement material is jute fabrics. The fiber is derived from plants in the Corchorus genus, usually Corchorus capsularis and Corchorus olitorius, Jute fibers are 100% bio-degradable and are composed of parallel cellulose, semi-cellulose and lignin chains. The jute fabric is sold by the number of holes/dm^2. The jute fabric used is 22x22, this number are the existing square holes in a sample of 1 dm^2. The size of the holes of the chosen fabric allows the casting of the plaster in the mold. The area of the thread is 0.88 mm^2.

An aluminum mold has been designed for specimens of 140x40x40 mm. The mold allows to place jute fabrics or jute thread at different heights of the cross section: 1, 2 or 3 cm. Figure 1 shows the mold and the test specimens.



A) B)

Fig. 1. Mold and specimens

Specimens are made in accordance with the specifications of the Standard EN13279-2, Gypsum binders and gypsum plasters - Part 2: Test methods. Table 1 shows the mix parameters for the plaster.

Mix paramaters	
Gypsum/water	0,7
Mixing time (s)	60
Temperature (Cº)	25
Humidity (%)	65
Demolding time (h)	24

Table 1. Material parameters

Table 2 shows the specimens for the test.

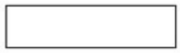
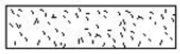
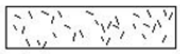
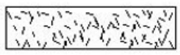
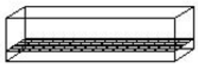
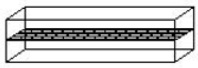
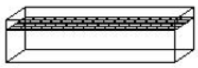
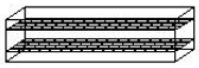
Specimen	Percentage of jute fiber	
P1	0% fiber	
P2	0,1% 3 cm fiber.	
P3	0,2% 3 cm fiber.	
P4	0,1% 5 cm fiber.	
P5	0,2% 5 cm fiber	
P6	Fabric at 1 cm from the bottom	 1 cm.
P7	Fabric at 2 cm from the bottom	 2 cm.
P8	Fabric at 3 cm from the bottom	 3 cm.
P9	Fabric at 1 and 3 cm from the bottom	 3 cm. 1 cm.

Table 2. Test specimens

3. Experimental

3.1. Scanning Electron Microscope.

Scanning Electron Microscope (SEM) images are taken, using a JEOL scanning electron microscope model JSM-840, to study the interaction between the fabrics and the plaster matrix.

3.2. Adhesion fiber-matrix test.

The adhesion tests determine the strength of adhesion fiber-matrix. To check the strength of the matrix fiber bond, a thread from the jute fabric with different adherence lengths with the gypsum matrix is tested under tension. For the adhesion tests an Ibertest model ELIS-50-W is used. Table 3 shows the specimens used for adhesion tests, three cases were studied, with three different adhesion lengths of the jute thread in the gypsum matrix.

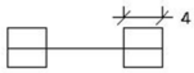
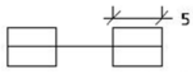
Specimen	Adherence length (cm)	
P10	3 cm	
P11	4 cm	
P12	5 cm	

Table 3. Samples for adherence test

3.3 Flexural and compression tests

Test conditions follow the recommendations of the standard EN 1015-11: 2000: Methods of test for mortar for masonry - part 11: determination of flexural and compressive strength of hardened mortar. For the flexural and compressive tests, an Ibertest model ELIS-50-W testing machine is used.

The dimensions of the specimen used for the flexion and compression tests are 160x40x40 mm and 40x40x40 mm respectively. Table 2 shows the specimens used for flexural and compressive tests.

The elastic range of the stress-strain curves of the compressive test are used to determine the Young's modulus of each specimen:

$$E = \frac{\sigma}{\varepsilon} \qquad (1)$$

Where E is the Young modulus, σ is the normal stress tension and ε is the strain.

Figure 2 shows the flexural and compression set up of two specimens, one with jute fabrics and another without them.

Fig. 2. Flexural and compression test

3.4 Ultrasonic test.

The Young's modulus of the composite is calculated with the wave velocity propagation:

$$v = \frac{1-2\,(\frac{V_T}{V_L})^2}{2-2\,(\frac{V_T}{V_L})^2} \qquad (2)$$

$$E = \frac{V_L \rho (1+v)(1-2v)}{1-v} \qquad (3)$$

Where ν is the Poisson ratio, V_L is the longitudinal velocity, V_T is the transversal velocity and ρ is the density. Fig 3 shows the ultrasonic test set up. The longitudinal and transversal velocity of the ultrasonic waves were measured using a Matest model C372N/AA/0019 transmitter-receiver equipment that records and digitizes the wave. Figure 3 shows the test set up for measuring the Young's modulus.

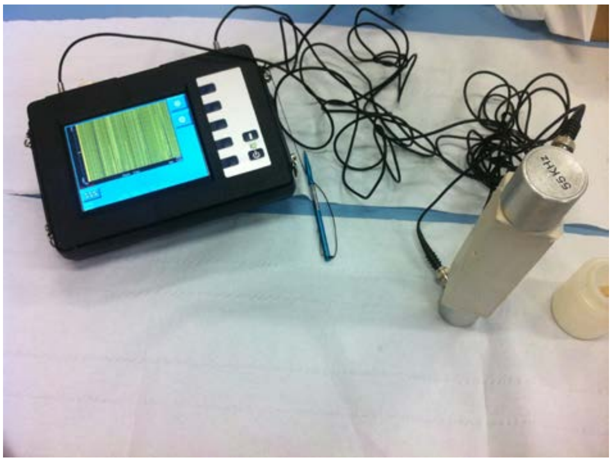


Fig. 3. Ultrasonic equipment**.**

4. Results.

4.1 Scanning Electron Microscope

Scanning Electron Microscope (SEM) images reveal that the adhesion of jute to plaster is ensured due to the morphology of the jute fiber. The rough surface of the jute fibers enhance the adhesion between them and plaster crystals. Figure 4 shows the jute fibers with the plaster crystals added in their surface.

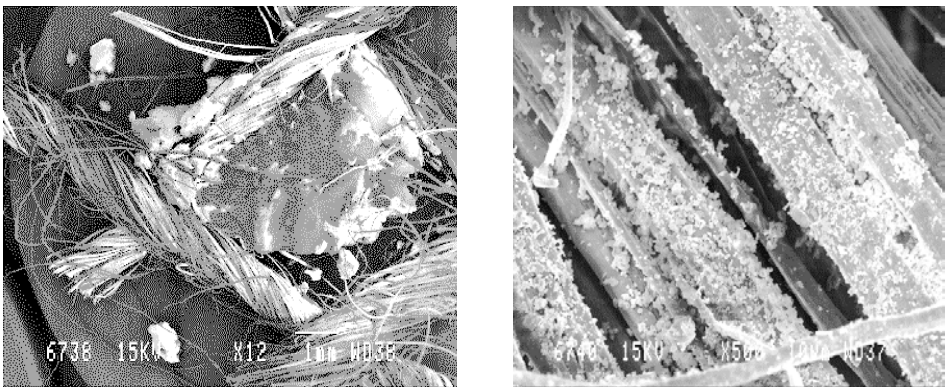


Fig. 4. SEM images of the jute thread and the plaster crystals.

4.2 Adherence test

Regarding adhesion to the plaster matrix, it is concluded that this characteristic depends on the contact length between the matrix and the fiber reinforcement. In all cases the thread slips, without breaking under the tension force. The interlaminar shear strength between fiber and matrix is lower than the tensile strength of the fiber. The best adherence results were achieved with the specimen P12, with a contact length of 5 cm and adherence forces of 33 N. Figure 5 shows the force-displacement graph for the adherence test.

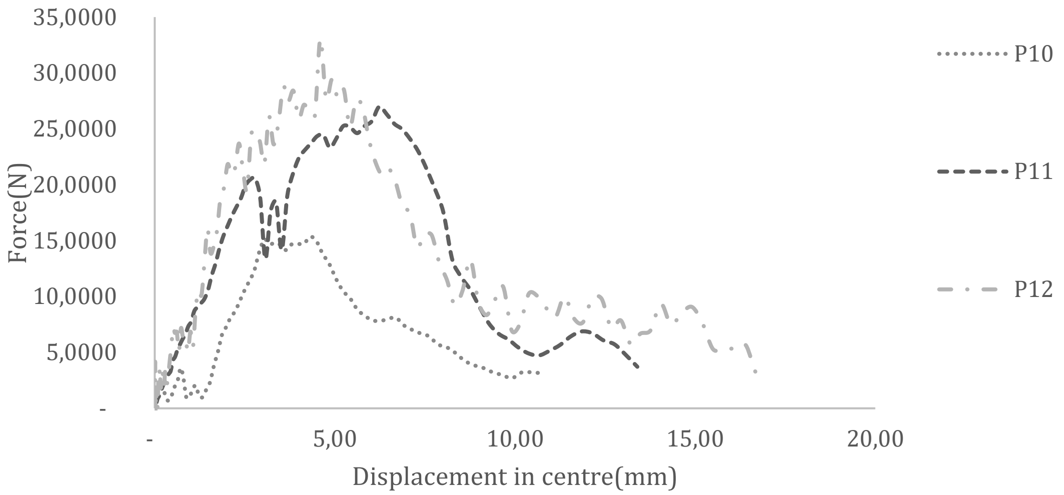


Fig. 5. Adherence test results.

4.3 Flexural test.

All the specimens have a maximum bending load between 2 and 2.5 kN. Otherwise, the maximum deflection increases with the addition of jute fiber and fabric, there is an enhancement of the composite tenacity. The composites with added jute retain flexural strength after the matrix cracking, especially the ones with jute fabrics. The addition of jute fibers improve the plasticity of the composite, especially the 3 cm length ones of the P2 and P3 specimens. The location of the jute fabrics at different heights of the cross sections has an important effect in the flexural behaviour. The specimens P6 and P9, with a fabric layer in the tension zone of the cross section shows the better results of the flexural test. Figure 6 shows the results of the bending test.

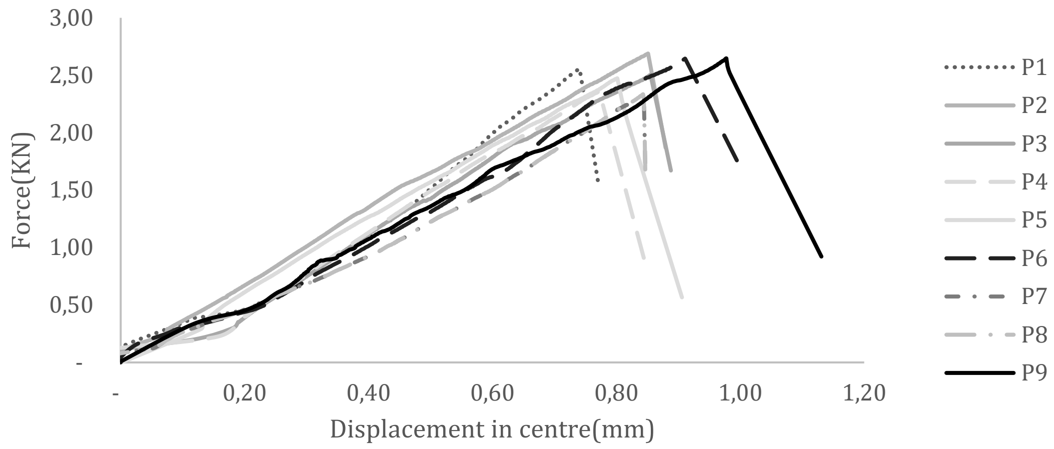


Fig. 6. Flexural test results.

4.4 Compression test.

All the specimens have maximum strength values between 9 and 11 MPa. The jute improves the compression behaviour of the composite, especially after the failure of the plaster matrix. The fibers and the fabric improve the ductility and tenacity of the composite. On the other hand, the jute fabric layers in the plaster provide passive confinement stresses when the specimens are subjected to axial compression, and increases the ultimate strain capacity of the confined plaster. The specimens with jute fabric show better values of plasticity and tenacity than those with fibers, allowing higher strain values. Figure 7 shows the results of the compression test.

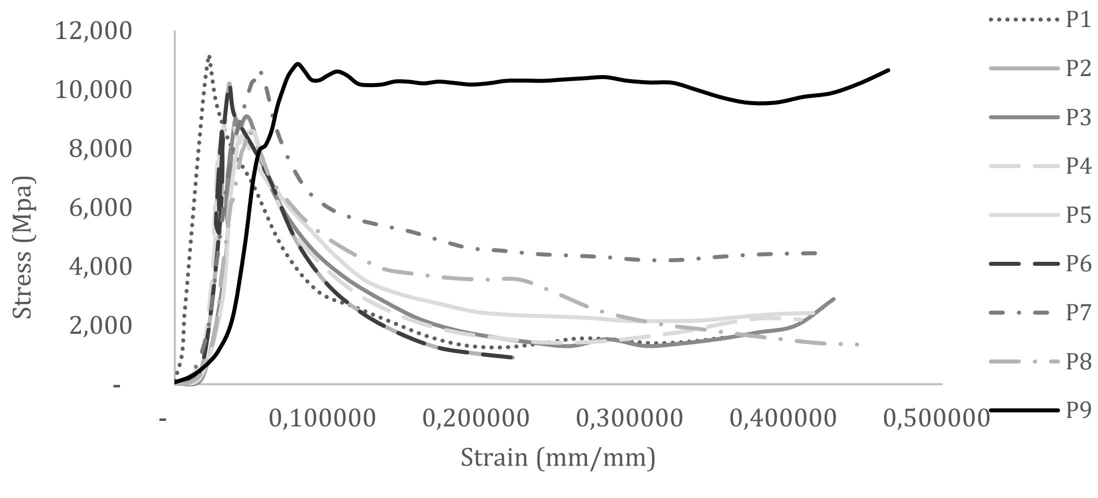


Fig. 7. Flexural test results.

4.5 Young's modulus.

The Young's modulus is determined statically with the compressive test and dynamically with the ultrasonic test. There are differences because the porosity or coarse granularity in the gypsum, can cause variations in sound velocity and affect the accuracy of ultrasonic Young's modulus measurement. Table 4 shows the results for both methods in each specimen and the K ratio dynamic/static modulus.

Specimen	Young Modulus Compression (Mpa)	Young Modulus ultrasonic (Mpa)	K
P1	6309,42	9069,64	1,44
P2	6736,84	9783,51	1,45
P3	6282,59	9028,64	1,44
P4	6451,13	9214,08	1,43
P5	6522,35	9344,88	1,43
P6	7320,33	10070,80	1,38
P7	7465,83	10404,13	1,39
P8	6858,85	9192,64	1,34
P9	6402,59	8721,64	1,36

Table 4. Young modulus

5. Conclusions.

In this work, the effect on the mechanical properties of jute fabric as reinforcement material for plaster has been studied. The mechanical adhesion between the jute fabrics and plaster is ensured due to the topology surface of the jute fibers. The specimens with jute fabrics presents better mechanical properties than those reinforced with loose fibers. The jute fabric improves the ductility and tenacity of the composite in bending and compression, providing structural stability to the specimens tested after the fragile rupture of the plaster matrix. The fracture mechanism and the elastic behaviour in the unreinforced plaster is modified from brittle to a non-linear.

Overall, the reinforcement of plaster with jute fabrics is concluded to be an efficient technique to increase the mechanical properties of plaster. Future work in this field should be directed at optimizing the jute fabric reinforcement, studying the durability of the reinforcement system and applying other types of natural fibers fabrics for reinforcement.

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