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# Sandwich panels from cork and polyester in presence of epoxy resin as interfacial adhesive

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**This work presents an experimental study to determine the mechanical properties in bending, tension, compression and shear of a new sandwich material based on natural materials (jute and cork). The sandwich material is made basically of natural materials whose soul is agglomerated cork white (located in Jijel, East of Algeria) and the skins are woven jute with ortho phthalic polyester resin. Agglomerated white cork granules with medium density were used (cork boards with thicknesses of 10, 20 and 30 mm). The bending tests were performed on standard samples that were cut elaborate sandwich plates. The sandwich material prepared was tested for 3 and 4 flex points which indicate the stress, strain, bending stiffness, shear strength and failure mode. It was also found that a core thickness of 10 mm has better results compared to 20 and 30 mm. The results of this study allow us to develop a variety of agglomerated cork white product in for the development of low-density sandwich panels for use in the field of insulation and field of construction.**

**Key words:** Cork, jute, resin, sandwich, mechanical characteristics.

## INTRODUCTION

The use of composite materials is increasingly spreading. Their main characteristics include low density, high strength, high stiffness and excellent hardness, which are the requirements in areas such as aerospace, automotive, navigation, construction, etc. Sandwich materials are among the most widely used composite materials. These materials generally consist of: two soles or skins, low thickness with high strength and a much thicker core with low density.

Sandwich structures have increasingly become structural and non-structural components in construction. Sandwich structures are usually based on two thin face sheets with high stiffness and strength, and light-weight core that maintain the distance between the faces and sustains deformation, often with insulation properties. By varying the material and thickness of core and face sheets, it is possible to obtain sandwich structures with different properties and performance (Steeves and Fleck, 2004; Allen, 1969; Zenkert, 1997).

The properties of interest for core materials include, among others, low density and good thermal and acoustic insulation characteristics (Zenkert, 1997; Vinson, 1999). Commonly used core materials are honeycombs, foams and balsa wood, but other alternatives of cellular core structures are being proposed. The cork is a natural cellular material with a set of properties that largely fulfills

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the requirements for sandwich cores. It has an alveolar structure similar to a honeycomb, with closed cells, low density and excellent insulation properties (Pereira, 2007; Pereira et al., 1987; Gibson et al., 1981). It is also a renewable raw material from a sustainable production system, therefore, contributing to the present intent of increasing the ‘‘greenness’’ of construction.

Cork agglomerates are cork-based products that are marketed for several applications, mainly for surfacing, flooring and insulation purposes. The so-called compositions of corks are made with cork granules of variable dimensions that are joined together by using adhesives (e.g. polyurethane, melamine) (Gil, 2009). Although, the composition of cork agglomerates retain most of the properties of the cork material, as summarized in Pereira (2007), the mechanical strength of a specific composite cork product is also related to the properties of the adhesive.

The mechanical behavior of agglomerated cork was characterized for compression (Moreira et al., 2010; Gameiro et al., 2007), tensile (Moreira et al., 2010), shear (Reis and Silva, 2009), three-point bending (Reis and Silva, 2009; Kim and Wallace, 2010; Silva et al., 2010), creep in compression (Mano, 2007), as well as for dynamic compression (Reis and Silva, 2009; Gameiro and Cirne, 2007) and vibrations (Moreira et al., 2010). A few studies already considered cork agglomerates as core materials in sandwich panels. Static bending and shear tests on carbon/epoxy-cork sandwich samples showed that the cork performance depends mainly on density and grain size, with the maximum force, shear strength and modulus increasing with grain size (Reis and Silva, 2009). A comparison between the mechanical behavior during impact of sandwich plates with foam core and cork core showed a larger maximum impact force for the cork core panels with a higher capacity to absorb the impact energy with low depth damage (Castro et al., 2010). Micro-agglomerated cork materials were incorporated as cores in sandwich structures with aluminum alloy face sheets and tested under compression and high pulse wave, which showed that the impulse transmitted to the structure decreased with the core thickness with a threshold core thickness separating sandwich and plate behavior (Sousa-Martins et al., 2013).

This study focuses on the development of sandwich panels with face sheets of laminates with jute fiber and epoxy resin and agglomerated cork as core, including multilayered design. Three types of sandwich panels were produced and tested under compression, tension, bending and shear. The influence of the thickness of the soul of sandwich panels on the mechanical behavior of the sandwich panels was analyzed.

The underlying objective is to use natural local materials to the production of sandwiches with panels of ecological footprint and environmental production of sandwich panels which are light and show good insulation performers, low cost, for partitioning use in construction or interior walls of separation.

In this context, we mechanically characterize a new composite sandwich core of cork and laminate jute/polyester.

This study will focus on the use of a white agglomerated cork medium density with different thicknesses.

## EXPERIMENTAL PROCEDURES

The development panel sandwiches were made by the compression method (hydraulic press 28 bar with a temperature of 80°C). The skins are made of jute 3 ply folds and the core sinter base cork in density average thickness of 10, 20, and 30 mm.

The adhesion between the agglomerate cork and polyester resin is low and to improve the adhesion between the skin and the soul epoxy resin film was deposited on the soul before filed jute tablecloths for development sandwich panels.

Several tests on the cork-based sandwich panels obtained as soul and jute/polyester resin as reinforcement are made on a universal machine of the type Zwick 250, piloted by computer with the acquisition testXpert V9.0 software, with a sensor of 250 kN force. The following tests were performed: compression perpendicular, perpendicular traction, pure compression and buckling, three and four points bending and shear test, according to French standards, respectively, NF T54-602 (1983), NF T 54-603 (1983), NF T54-604 (1986), NF T54-606 (1987), and NF T 54-605 (1983). Figure 1 shows the bending tests 3 and 4 points.

Several tests conducted the same type of sandwich to see the influence of thickness. Figures 4, 5 and 6 shows several curves (moving force) sandwiches with different thicknesses of cork (10, 20 and 30 mm). Some sandwiches designated S10, S20 and S30 according to the corresponding thickness will be presented in the next sections.

The normal stress σ3 and σ4 respectively for 3 and 4 bending points are expressed in N/mm². These constraints are also called tensile strength or compression soles according to standard NF T 54-606, they are represented by the following Equations 1 and 2:

$$\sigma 3 = \frac{P1d1}{2es\,(h+ea)b} \qquad (1)$$

$$\sigma 4 = \frac{P2d2}{4es(h+ea)b} \qquad (2)$$

where σ: (MPa); P1: maximum effort (N); P2: maximum effort (N); d1: distance between supports (mm); d2: distance between supports (mm); es: thicknesses soles (mm); ea: thickness of the soul (mm); h: height (mm); b: width (mm).

### Compression perpendicular test

The test of the compression in the perpendicular direction carried out was with samples of 50 × 50 $mm^2$ (length × width) (Figure 1) at a constant crosshead speed of 4 mm $min^{-1}$. The elastic modulus was determined entre 2.5% deformation (ε1) and 7.5% (ε2). The stress at 10% (σ10) was calculated matching ε = 10%. The maximum stress (σmax) achieved during the test was about 1 MPa and the crush value (Delta h max) for this load corresponds to a maximum deformation of about 70% (εmax). After the test, the samples were kept in the laboratory environment for 14 days, after-the thickness of the panel was measured to calculate the relaxation

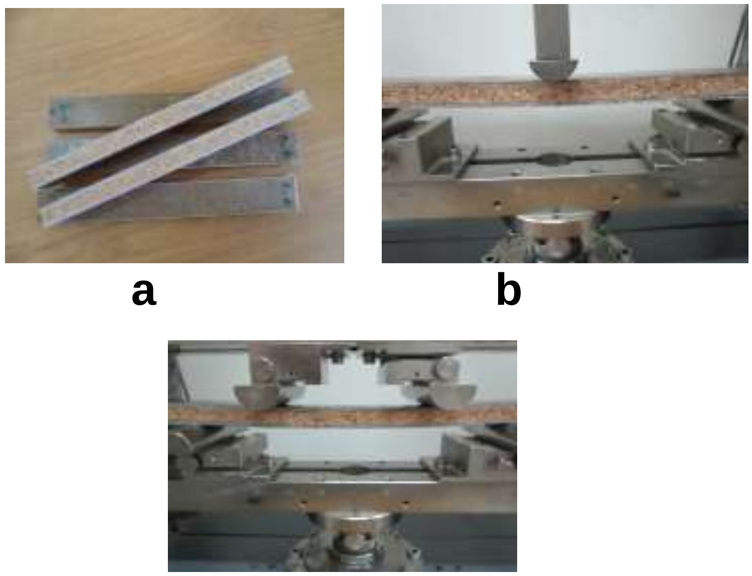



**Figure 1.** Bending tests: (a) specimens sandwiches; (b) three-point bending; (c) four-point bending.

rate (η). The following mechanical properties were calculated from the stress-strain curves:

$$\varepsilon max = \frac{\Delta hmax}{h_0} \times 100 \quad (3)$$

$$Ea = \frac{F2 - F1}{\Delta h2 - \Delta h1} \times \frac{h_0}{S_0} \quad (4)$$

$$\eta = \frac{hf2 - hf1}{hf1} \times 100 \quad (5)$$

### Perpendicular tensile test

The trial focused on determining the tensile strength perpendicular to a sandwich structure; according to standard NF T 54-603 (November 1983) (Silva et al., 2010). The test consists in subjecting the specimen to a normal tensile strength to the soles of the sandwich, transmitted to the test pieces by means clustering of fastening devices consist of thick fastener sun deformable blocks, glued on with epoxy resin thesis insoles year. Dimensions of tensile specimens 50 × 50 $mm^2$ (length × width) were manufactured according to the standard. The tests were performed used universal Zwick machines of the type with a traveling speed of the constant load set at 1.2 mm/min according to standard.

The breaking stress in tension perpendicular was calculated using the Following formula:

$$\sigma_P = \frac{F_R}{S_0} \quad (6)$$

where FR is the strength at break (N) of the sandwich structure; FM is the maximum force (N); $S_0$ is the initial area of the cross section of the specimen ($mm^2$). The longitudinal compression tests, with or without buckling were carried out to determine the compressive strength for the two boxes-have-been specified in the standard (NF T 54-604, 1986) (Mano, 2007) compression pure, if the sample length is up to twice the total thickness of the sandwich structure; compression with buckling if the sample length is entre 10 to 12 times the total thickness of the sandwich structure.

**Figure 2.** Specimen sandwich in the compression test.

Figure 2 shows Specimen sandwich in the compression test structure, compression with buckling if the sample length is entre 10 to 12 times the total thickness of the sandwich structure.

The samples were cut with a width of 50 mm and a length of 70 and 380 mm, respectively for pure compression and compression buckling. Both ends of rectangular samples were carefully machined to be flat, parallel and perpendicular to the load. The tests were performed at a constant crosshead speed of 0.21 and 1.35 mm $min^{-1}$ respectively for pure compression and compression buckling, respectively. The maximum stress in the compression or deformation of the sandwich structure is expressed in MPa such that:

$$\sigma_M = \frac{F_M}{S_0} \quad (7)$$

where F is the maximum force (N), and S0 is the initial section of the test piece ($mm^2$).

a b c

**Figure 3.** Test pieces for the tensile test up according to standard (NF T 54-603). Longitudinal compression test with or without buckling.

**Module bending stiffness of the sandwich D**

NF T 54-606 standard allows, from results of mechanical tests and three four-point bending on sandwiches, defining the flexural rigidity modulus D, the shear modulus N and bending shear modulus Ga soul. Equation 3 gives the value of the modulus of flexural rigidity D (Nmm²).

$$D = \frac{P1\ d1\left[1-\left(\frac{11 d_1^2}{8 d_2^2}\right)\right]}{48 w_1 \left[1-\left(\frac{2 p_1 d_1 w_2}{p_2 d_2 w_1}\right)\right]} \quad (8)$$

Equation 4 defines the shear modulus in bending N expressed in Newtons.

$$N = \frac{P1\ d1\left[\left(\frac{8 d_1^2}{11 d_2^2}\right)-1\right]}{4 w_1 \left[\left(\frac{16 p_1 d_1^3 w_2}{11 p_2 d_2^3 w_1}\right)-1\right]} \quad (9)$$

Equation 5 defines the module of coulomb that the core is related to N by the following equation. It is expressed in Newton's per square millimeter.

$$Ga = N 4ea/(h+ea)2\ b \quad (10)$$

**Three-point bending**

The three-point bending is a mechanical test carried out by placing a beam on two simple supports. According to NF T54-606 Norme (1987), contact between the beam and the support point is considered and located on the ends of the beam. Concentrated in the middle of the beam, the load is applied. The contact between the load and the beam is also considered as a contact point (Tadeu and Santos, 2003).

When the load is gradually increased without exceeding the limit of practical strength; the beam is deformed along a determined arrow, depending on the nature of the constituent components of the beam.

**Test device**

Bending tests 3 and 4 points are made on a universal machine type Zwick 250 kN. The test was computer-controlled with a 2 mm/min and with a force sensor of 2.5 kN (Figure 3).

Data acquisition is performed with 9.0 V of testXpert software that records the displacement versus force.

**Figure 4.** Three-point bending tests.

**Four-point bending test**

This test is performed on the same machine as the three-point bending. According to NF T54-606 Norme (1987), the 4-point bending in particular allows to create a pure bending moment in the central area.

In this case, the same single support is used, but a single two loads concentrated load is applied instead. When the load increases gradually, without exceeding the limit of practical resistance, the beam deforms along and a determined depending on the nature of the constituent components of the beam arrow.

**Shear test**

The shear tests were performed on a Zwick Universal type machine controlled by a computer 250 kN (testXpert software V 9.0) with a test sample at a speed of 1 mm/min, while equipped with a force sensor of 2.5 kN (Figure 15).

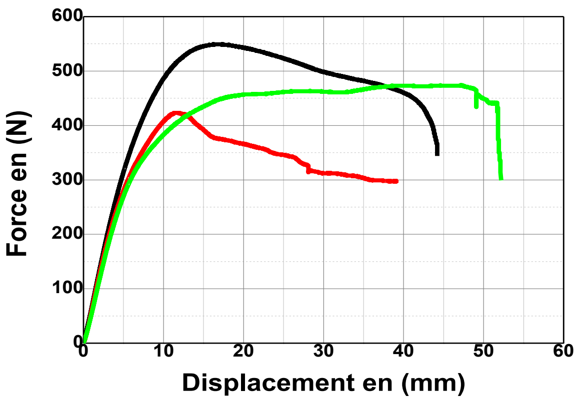



**Figure 5.** 3 points bending sandwich cork 10 mm.

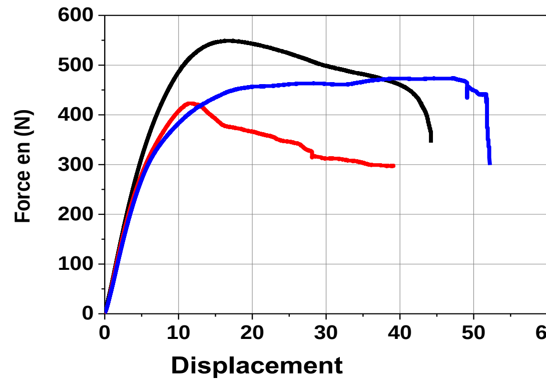



**Figure 7.** 3 points bending sandwich cork 30 mm.

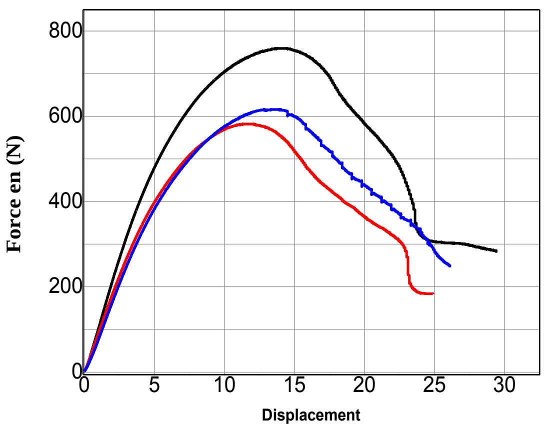



**Figure 6.** 3 points bending sandwich cork 20 mm.

**Figure 8.** Bending tests three items, after fracture.

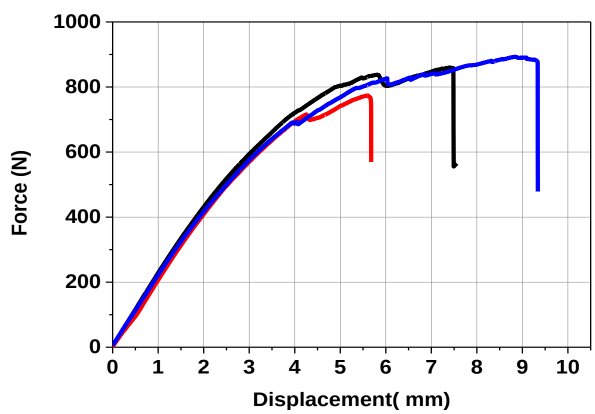



**Figure 9.** 4-point bending sandwich of 10 mm cork.

**Compression with buckling**

The three sandwiches have the same behavior towards the longitudinal compression test (with buckling) which is illustrated from the same shape of the curves S10, S20, and S30.

The maximum stress, compression, for each of the variants is: 10.27 MPa for an elongation of 3.42%, for the sandwich S10, 6.47 MPa for an elongation of 3.07% for the sandwich S20, and 4.14 MPa for an elongation of 2.191% for the sandwich S30.

These values show that the increase in thickness of the core causes a reduction of the maximum compressive stress. Therefore, the maximum stress corresponding to S10 is greater than 5% relative to that corresponding to S20 and the latter is greater than 18% relative to that corresponding to S30.

For the sandwich panel skins jute/polyester agglomerated cork and soul, subjected to longitudinal compression test, there is a separation between the skins (laminated jute/polyester) and soul (agglomerated cork) (Figure 7).

Most tests have shown a release of the skins of the core (cork) and producing a separation rupture which finishes with a break skins and a cork buckling subsequently break thereof (Figure 8). This behavior is justified by the poor adhesion of the laminated jute/polyester as sandwich skins and the cork core and the epoxy resin film deposited on the cork did not alter adhering a significantly causing delaminating (Figures 9, 10, 11 and 12).

**Pure compression**

***Compression test***

The curves show the first phase, the linear increase of the applied load corresponding to small deformations, followed by a nonlinear.

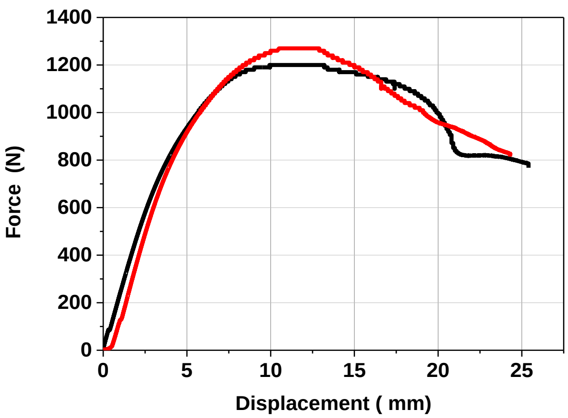
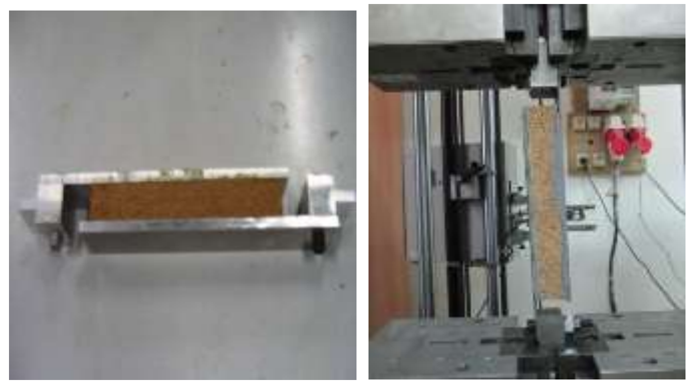



Figure 10. 4-point bending sandwich of 20 mm cork.



a b

**Figure 13.** (a) Plate cork attached to two; (b) Test setup for shear traction machine non-deformable metal supports.

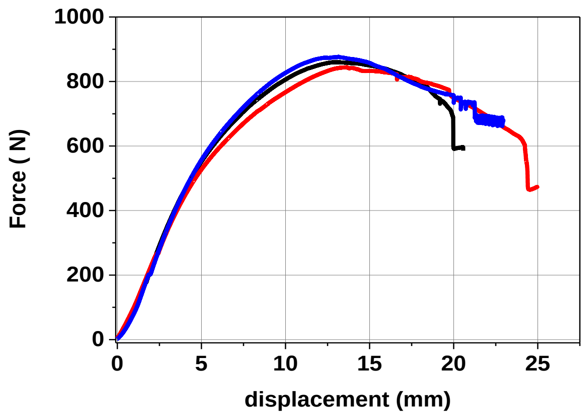



**Figure 11.** 4-point bending sandwich of 30 mm cork.

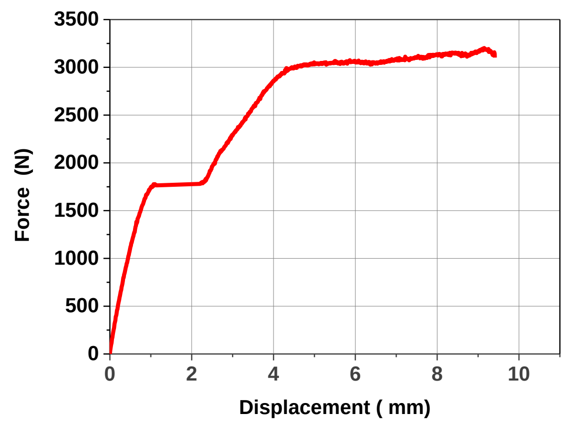



**Figure 14.** Shear sandwich (10 mm).

a b

**Figure 12.** Bending tests. Four points: (a) before fracture, (b) after fracture.

## Shear test

The shear tests were performed on a Zwick Universal type machine controlled by a computer 250 kN (testXpert software V 9.0) with a test sample at a speed of 1 mm / min while equipped with a force sensor of 2.5 kN (Figure 13). The tested samples were cut with a wire saw according to NF T 54-605 with dimensions: 250 × 50 × 30 mm. The sample is attached to the mechanical jaws of the machine with the two non-deformable metal supports. During loading, the displacement and applied load are recorded.

Several pieces of sandwich materials S10, S20 and S30 are tested. Figures 13, 14, 15 and 16 show the achieved assembly for testing shear.

## Perpendicular compression

Table 1 gives the values of the three normal bending stress and four points and σ 4 σ 3 and the flexural rigidity D and the shear stiffness of the modulus N and the core coulomb Ga, for different sandwich structures, with 10, 20 and 30 mm thickness of the core.

Table 2 gives the principal properties of panel sandwiches after the test of compression perpendicular, such as modulus of elasticity (Ea), maximum deformation (εmax [%]), maximum stress (σmax [%]), and relaxation rate η [%].

In all tests, the curves followed the same trend: an elastic deformation zone to values of about 4.73 and 4.91% for S20 and

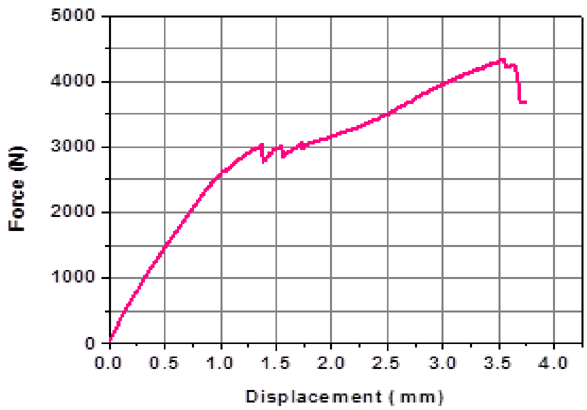



**Figure 15.** Shear sandwich (20 mm).

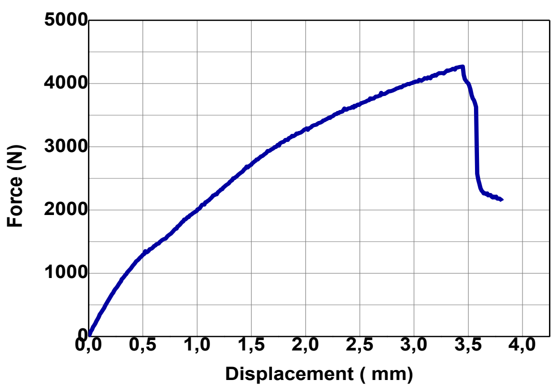



**Figure 16.** Shear sandwich (30 mm).

S30, respectively, corresponding to 0.896 MPa stress values and 0.915 MPa, respectively, followed by a large platter with a lower slope for deformations of 40 to 50%, with a sharp subsequent rise to higher stresses with deformations for crushing and the cells collapse. The trial was stopped at a stress of 40 and 54 MPa, which corresponds to a deformation of 60 to 64% for S20 and S30, respectively (Figure 17). The effect of the maximum compressive stress in expanded cork agglomerate of the soul of sandwich is as shown in Figure 18.

The compression behavior of two sandwich panels (S20 and S30) showed some differences, but the shape of the stress-strain curve is quite similar, the S10 sandwich panels have shown a module larger than the sandwich panels S20 and S30 (2.3 and 2.4 MPa). Relaxation rate after 14 days was lower for SN20 panels S30 and S10 relative to the panels (80 and 70%, respectively).

### Compression with buckling

The three sandwiches have the same behavior towards the longitudinal compression test (with buckling) which is illustrated from the same shape of the curves S10, S20, and S30 (Figure 19).

The maximum stress, compression, for each of the variants is: 10.27 MPa for an elongation of 3.42%, for the sandwich S10, 6.47 MPa for an elongation of 3.07% for the sandwich S20, and 4.14 MPa for an elongation of 2.191% for the sandwich S30.

These values show that the increase in thickness of the core causes a reduction of the maximum compressive stress. Therefore, the maximum stress corresponding to S10 is greater than 5% relative to that corresponding to S20 and the latter is greater than 18% relative to that corresponding to S30.

For the sandwich panel skins jute/polyester agglomerated cork and soul, subjected to longitudinal compression test, there is a separation between the skins (laminated jute/polyester) and soul (agglomerated cork) (Figure 20). Figure 21 shows the stress strain curve of sandwich panels in pure compression longitudinal. The testing of shear at early separation and total detachment of the skin of the sandwich is illustrates in Figure 22.

Most tests have shown a release of the skins of the core (cork) and producing a separation rupture which finishes with a break skins and a cork buckling subsequently break thereof (Figure 20). This behavior is justified by the poor adhesion of the laminated jute/polyester as sandwich skins and the cork core and the epoxy resin film deposited on the cork did not alter adhering a significantly causing delaminating.

### Pure compression

The curves show the first phase, the linear increase of the applied load corresponding to small deformations, followed by a nonlinear phase short until the maximum load is reached; then a decrease of the load applied to the separation of the skins of the core is observed.

The maximum longitudinal compression stress (pure) for three variants is: 29.46 MPa for an elongation of 1.5 mm, for the sandwich S10; 9.31 MPa for an elongation of 1.2 mm for the sandwich S20; 6.18 MPa for an elongation of 1 mm, for the sandwich S30.

These values show that the increase in thickness of the core causes a reduction of the maximum compressive stress. Therefore, the maximum stress corresponding to S10 is greater than 68.4% relative to that corresponding to S20 and it is greater than 33.6% relative to that corresponding to S30.

## RESULTS AND DISCUSSION

### Influence of the thickness of the sandwich on the breaking strength

The curves (force-displacement) sandwiches are similar but with different thicknesses (10, 20 and 30 mm) show linear behavior for the S20, then the nonlinear phase to failure to 1200 N for a displacement of 14 mm. The S30 has a linear behavior, then the rupture is 810 N for a displacement of 15 mm. For S10 breaking is 850 N for movement 9 mm.

### Analysis of the mode of failure in bending three and four points

Breaking recorded four-point bending on sandwiches is noticed on the web (transverse fracture) (Figure 12). By looking more closely at this cross, as the force is exerted on the sample, there is a crack, which appears above the lower flange, which propagates along the thickness of the sandwich (Figure 12). This failure mode is completely

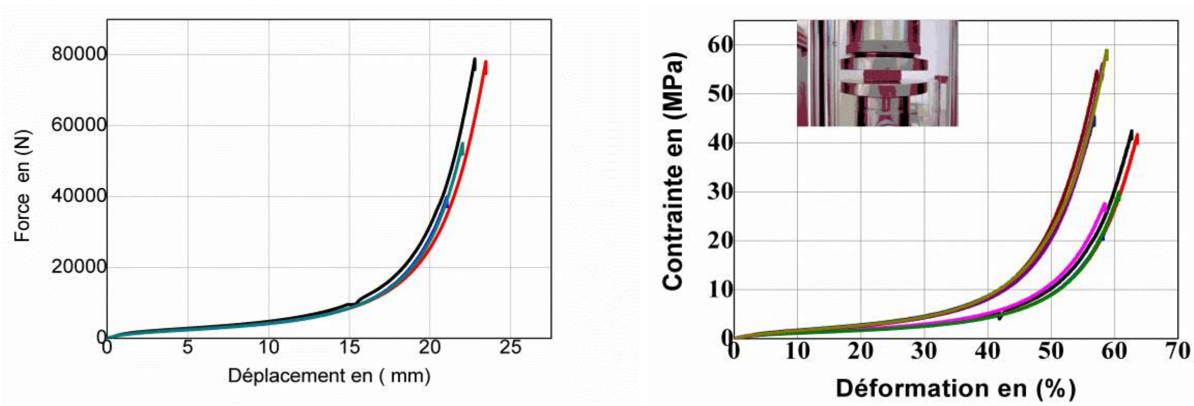
**Table 1.** Values obtained by calculation according to the equations given by the standard NF T 54-60.

| Sandwich | τ(Mpa)3ts | τ(Mpa)4ts | σ(Mpa)3pts | σ(Mpa)4pts | D (Nmm²) | N(N) | $G_a$(N/mm²) |
|---|---|---|---|---|---|---|---|
| S10 | 0.4016425 | 0.72697282 | 12.6642099 | 11.5027344 | 661461383.5 | 11223.3571 | 13.86419354 |
| S20 | 0.29515557 | 0.45242001 | 11.1505835 | 8.51694301 | 41876059.79 | 651435.072 | 581.8117141 |
| S30 | 0.18170106 | 0.32158918 | 9.72400223 | 8.66350172 | 3851960310 | 5383.85467 | 3.717517577 |

**Table 2.** Main properties of sandwich panels.

| *Panneaux sandwiches* | Ea [MPa] | σ10 [MPa] | σmax% | εmax [%] | η [%] |
|---|---|---|---|---|---|
| S10 | 6.8 | 1.94 | 37.90 | 23.27 | 68.54 |
| S20 | 2.4 | 1.46 | 41.50 | 62.61 | 89.35 |
| S30 | 2.2 | 1.38 | 54.10 | 58.22 | 93.82 |

SN20 and SN40 in compression perpendicular: Module apparent elasticity (Ea), deformation ε = 10% (σ10) maximum deformation (εmax) and the relaxation rate η [%] (Sousa-Martins et al., 2013).




a b

**Figure 17.** Stress-strain curve of the sandwich panels (S10, S20 and S30) during compression in the perpendicular direction.

a b

**Figure 18.** Image of a specimen of S30 sandwich panel before (a) and after (b) compression in the perpendicular direction.

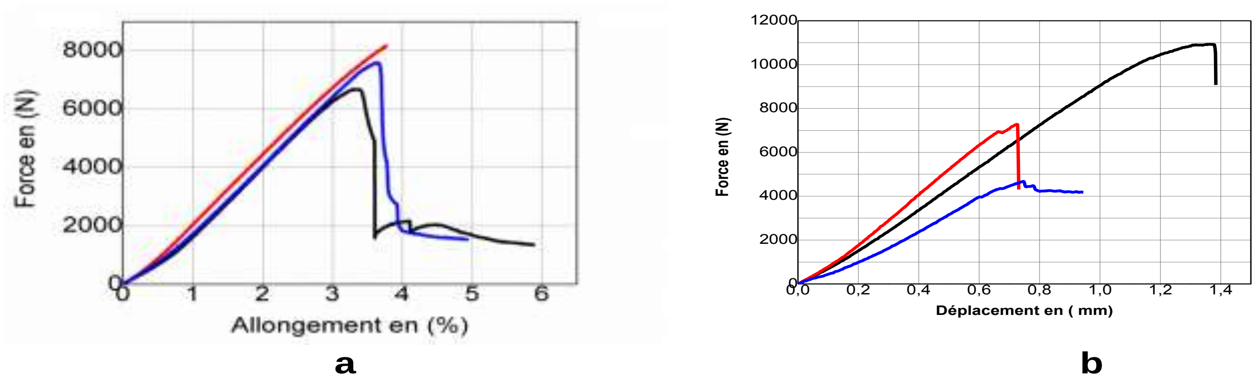



**Figure 19.** Stress-strain curve of sandwich panels (a): S10 and (b): S20 and S30 during the compression in the longitudinal direction with buckling.

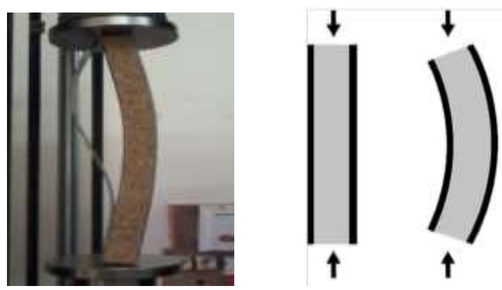


**Figure 20.** Image diagram of a sandwich test (S30) during the longitudinal compression test with buckling.

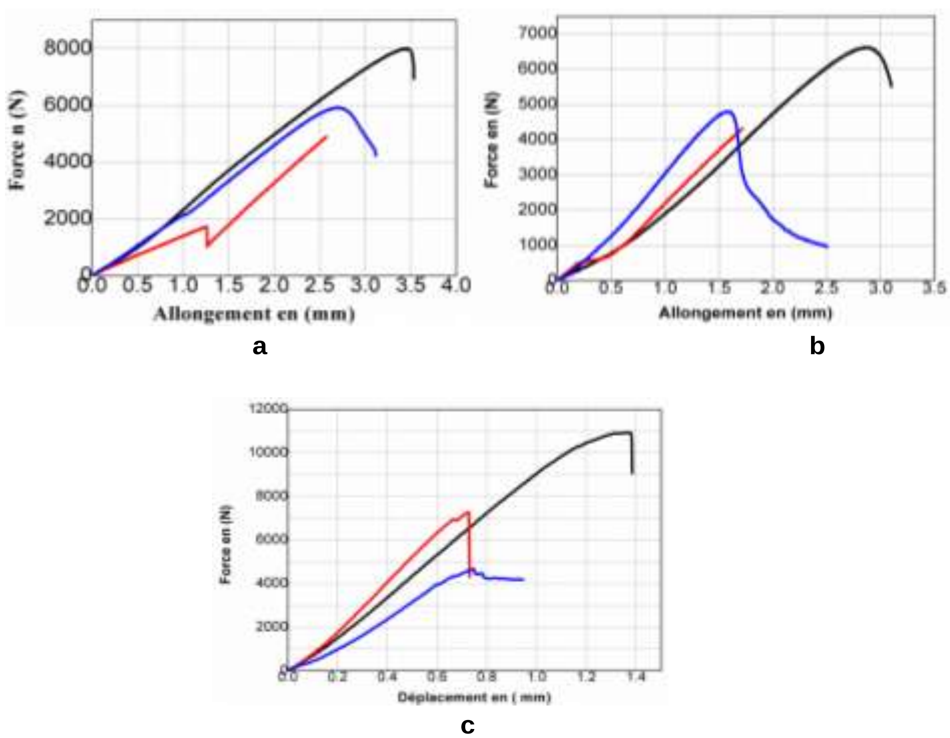



**Figure 21.** Stress-strain curve of sandwich panels S10, S20 and S30 in the pure longitudinal.

**Figure 22.** Testing of shear (a) early separation of the skins of the sandwich, (b) the end of testing with total detachment of the skin.

different from that obtained by three-point bending where the web fracture can be observed (Figure 7).

The results from three bending tests and four points, sandwiches on S10, S20 and S30, show that: the normal stress σ bending three points is higher for S10 by almost 12% and S20 by 23.22% compared to S30; the normal stress σ of four-point bending is higher for S10 with 26.18% and for S20 with 24.69% with respect to S30. Another thing was noted for the flexural rigidity (D) and the shear rigidity (N) where it was observed was the highest value given by the variants S30 and S20.

The results of the stress and the maximum shear modulus of sandwiches S10, S20 and S30 from the shear tests according to the NF T 54-606 are not significant as they were observed during the test and after some filling 250 [kgf], peeling skin (Figure 18b) of the soul that is due to poor adhesion between the cap and the polyester resin film and epoxy resin used between the laminates and sandwich core has resist this charge and it has not suffered the shear.

## Conclusion

Sandwich structures are designed to be subjected to bending efforts and applied in thermal insulation.

The use of natural fiber such as jute will certainly impact on the environment and adds value to the jute fibers (natural fiber) through a rational and effective implementation in the vast field of composite structures.

The 3 and 4-point mechanical bending tests as well as shear, on sandwiches made of cork with different core thicknesses exhibit good results and shows that the stress, strain, bending stiffness and shear strength of the failure mode are a function of the thickness of the core and the resin depend is likely used to avoid the polyester resin separation from the skins of the soul which was not observed in the case of sandwich-based epoxy resin. No delaminating was observed at the skins, while delaminating between the core and the skins was noticed. To address the problem of low adhesion between the polyester resin and cork epoxy resin film was added on the cork before developing sandwiches which give good results, especially in three and four points bending and even a treatment study on the polyester resin.

Analysis of the fractured surfaces of different sandwiches identified the influence of the thickness of the core. Based on the results found sandwiches with 10 mm thick soul shows the best features compared to those of 20 and 30 mm. Mechanical characteristics and the low mass density of these structures have their own sandwiches advantage suggesting applications particularly in the field of insulation (construction area).

The results of this study allow us to develop a variety of white agglomerated cork produced from jute, in the development of low mass density panels sandwiches in order to use it in the field of insulation (field of construction).

Finally, we believe that this preliminary study should be complemented by a study on the improvement of adhesion between the polyester resin and the surface of the cork using a natural resin to benefit ecological character which can bring significant mechanical improvements in the mechanical and environmental performance of such structures, to replace industrial resins. The use of natural materials available in Algeria such as jute and cork for the development of the composites industry is a key to meet the needs of the habitat. Our study concerns the use of a natural fiber (jute) as well as white agglomerated cork, which has good thermal and sound insulation properties.

Making a panel sandwich among all the natural fibers, jute has interesting mechanical properties in terms of tensile strength, with interesting properties in flexion (Belkacemi and Bezzazi, 2014; Mir and Bezzazi, 2011). In addition, imported raw jute is processed, spun and woven in Algeria, it is available and at low cost.

## Conflict of Interests

The authors have not declared any conflict of interests.

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