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Experimental Investigation of Mechanical Behaviour and Damage of Bio-Sourced Sandwich Structures Based on Date Palm Tree Waste and Cork Materials

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ABSTRACT

The date palm is a giant plant that must be cleaned annually, which can be the first source various raw materials compared to other woods that are cleaned once every four years, such as cork. In Algeria, there are millions of palm trees that produce a significant amount of raw materials annually, but unfortunately they are not exploited in industry. This paper presents an experimental study on mechanical behaviour of four bio-sourced sandwich materials differentiated by their core types. The skins of these sandwiches are made composite material composed of rachis fibers and epoxy resin; however the cores are made of: 1) raw petiole and petiole agglomerate with two sizes (0 -1 mm and 1-3 mm) and 2) cork agglomerate for comparison. The comparison between these sandwiches is based on the overall stiffness which is determined by three point bending tests. The results obtained for all sandwich materials show that the overall stiffness of the Petiole agglomerate with the size (0mm-1mm)/rachis fibers-epoxy resin is higher than the other sandwiches. Thus, we have carried out a complementary damage study to this last sandwich material based on delamination tests. It turns out through this study the good resistance of this new sandwich to delamination compared to other previously studied materials.

1. INTRODUCTION

Composite materials have appeared since the years of the 20th century, it is another type of material that quickly competed with metals in several fields of application [1, 2].

Advantage of these materials is possibility of choosing resin formulation or the reinforcements according to the situation in which the part will find itself during its use [1]. A very popular application of these materials is used of sandwich structures which combine lightness with good flexural properties. Sandwich structure is a special form of laminated composites. It consists of two thin skins and a light thick core between them. Application of sandwich structures in aeronautic fields and civil construction has been increased, in particular due to their very low weight which leads to a reduction in the total weight and high flexural rigidity, shearing and good corrosion resistance [3].

For the sake of environmental protection and public health, materials from renewable bio-sources must be used as reinforcement of composite materials [4], increasingly in many fields. Date palms are thrown away large amount of waste every year, for this we can exploit as composite materials or sandwich structures. Several researchers have studied the mechanical behavior of bio-composites [5-7] and of bio-sandwiches [8, 9].

Polymers reinforced by synthetic fibers are used in many applications that would be very difficult to do without. But beyond their many advantages, they generate bulky waste which poses enormous problems linked to their treatment at the end of their life [10].

The needs of the world today to preserve the environment made many researchers turn towards searching for new natural resources [4]. Among the areas of research that have been presented in recent years, a set of research on the development of composite materials by including natural materials in the composition of composites as alternative materials. Several researchers have studied the mechanical behaviour for the improvement of unsaturated polyesters properties of bio-composites [7, 11, 12], they discussed the possibilities of developing a natural waste, produced from date palm in the northern Algerian Sahara, associated with the polymer matrix of a thermosetting polyester resin. The use of these natural materials can be due to their outstanding mechanical and physical properties, as well as their high availability in nature at low cost and the biodegradability. This is seen in the palm groves, where the date palm tree produces an estimated amount of waste of up to 82 thousand tons per year in the region of Biskra (Algeria) [13].

For this purpose, Boudjemaa et al. [14] presented an experimental study on the thermo physical, chemical and dielectric characteristics of two components of date palm wood (Petiole and Bunches) at Biskra region (Algeria). This natural material issued in the manufacture of thermal insulators for buildings. To characterize the microstructure and chemical composition of the samples, they used scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS) analysis of the wood of date palm tree. The thermal conductivity and the diffusivity were carried out by a periodic method and the relative permittivity was obtained from capacitance measurements carried out at room temperature.

Masri et al. [12], studied the effect of lignin on composite materials (LPC) based on date palm tree waste (leaflets and lignin) and expanded polystyrene. This composite (LPC) is composed of short fibers of leaflets as reinforcement and recycled expanded polystyrene as matrix. Four types of composite (LPC) used in this work, they fixed the percentage of reinforcement and varied the percentage of matrix and lignin, (70, 30, 0), (70, 28.5, 1.5), (70, 27, 3) and (70, 25.5, 4.5). Flexural modulus and maximum stress are determined by three point bending tests. This study demonstrated the effect of the proportion of this natural material on the mechanical properties of the compound.

In previous study [15], we conducted an experimental investigation to determine the toughness of sandwich structures used as rear insulation sheet in flat plate solar collectors (FPC). We used sandwiches (glass fibers-unsaturated polyester/cork agglomerate) differentiated by initial crack (30, 40, 50, 60 and 70mm). Delamination tests are carried out on specimens Double cantilever beam (DCB) to determine energy release rate (G_{IC}), which is expressed by the toughness. By modified beam theory method., we determined this factor (G_{IC}). Through this previous study, we concluded:

Energy release Rate at initiation of a crack specimens remains almost constant despite the variation of the initial crack. Therefore, the rate of energy release is considered to be intrinsic to the material. The delamination test shows a good adhesion (skins - core).

Afterwards, we demonstrated how to exploit the leftover palm waste by elaboration an other composite material based on this waste. These composite materials are constituted by granules of the petiole, which are deferential by the sizes of these granules (0 to 1, 1 to 3 and 3 to 5) mm [16]. Then, we studied a physical, thermal and mechanical properties of these three types of composite materials. Results obtained, from a mechanical point of view, we see an inverse variation of the mechanical behavior of these composite materials according to the size of granules. Physically it has a low density in the range (0.16-0.56) g/cm^3 and also showed low thermal conductivity, in the range (0.109-0.122) W/m^2 K^{-1}. These weak properties make it possible to these compsit materals as an effective insulator.

Benzidane et al. [17] have also used wood and date palm tree fibers to produce sandwich panels. The short fibers of the rachis (5%, 10%, and 15%) are used as epoxy skin reinforcement. Three parameters are studied to optimize the design of the core: the orientation (longitudinal, transverse, radial), the length of the pieces of 'wood' (30 mm, 100 mm), and the thickness (10 mm, 15 mm, 20 mm). The sandwich efficiency is studied by three points bending tests combined to linear elastic beam theory and failure mode analysis. The results obtained show that materials with a mass fraction of 15% fibers present the most rigid materials for the skins. In addition, the manufacture of sandwich panels using short fibers as reinforcement for the skins and raw wood petiole as the core is a very effective option for technical and cheap waste recovery.

In this context, the main objective of this work is to investigate the mechanical behaviour and damage of new sandwich structures based on waste of date palm tree. These sandwiches differentiated by the types of the core (raw petiole, petiole agglomerate and cork agglomerate), while they are composed of the same skins (rachis fibers and epoxy resin).

In similar applications the sandwich panels must be resistant to bending and delamination strain, this is what conducts us to focus in this study on delamination and three-point bending tests.

Since the raw petiole is of small sizes, it cannot be used as sandwiches in large sheets and plates, unlike these new sandwiches that can be manufactured on demand. On the other hand, cork requires large costs, and its extraction from trees takes three to five years, unlike the remains of palm trees which are cleaned every year, and do not cost anything. Unfortunately, tens thousands tons are destroyed per year and no industrial exploitation to these waste materials that can build continuous industrial production.

Waste date palm used in this work consists of two components of the palm, rachis fibers and petiole.

Rachis is a basic element of a palm. is it also made up of petiole, spines and the leaflets (Figure 1).

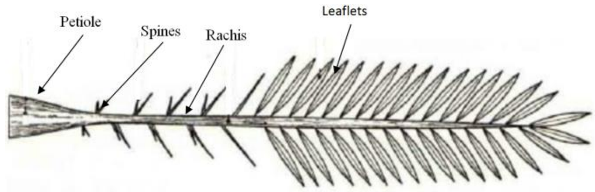

Figure 1. Palm's components [13]

All specimens used in our studies were fabricated at the department of Mechanical Engineering of Biskra University (Algeria).

Rachis fibers are used with epoxy in skins of sandwich and Cork/Petiole with different size were used as cores.

Elasticity modulus is determined by three point bending tests of composite material (rachis fibers-epoxy resin), which used as skins in sandwiches studied. Overall stiffness was determined on the different types of sandwiches by three point bending tests too, then, the toughness is determined by delamination tests breaking in mode I. The tests carried out after selection of the most rigid type of sandwich compared to the other types of studied sandwich. The results that will be obtained will make it possible to recover palm waste and use them as an essential component of sandwich structures. The results also determine the potential and areas of use of this bio-sourced sandwich.

2. MATERIALS AND METHODS

As mentioned previously, we used two natural materials to prepare the core of the bio-sourced sandwich, petiole wood and cork agglomerate, and for the skins we used a bio-synthetic (epoxy resin) as a matrix and rachis fibers as reinforcements.

2.1 Natural materials

2.1.1 Palm

Two parts of the palm have been used in this work; rachis fibers and petiole wood.

a) *Rachis fibers:*

To obtain the rachis fibers by mechanical extraction, we go through the following steps: After harvesting the palms, the rachis is cut into pieces and soaked in distilled water for 10 days to facilitate the separation of their fibers (water retting technique). These resulting fibers are subjected to rolling, finally we manually extract the rachis fibers. After natural drying, some of these long fibers are cut in an electric blade grinder for 60 seconds. Short fibers obtained are subjected to intensive sieving on a succession of metal sieves (vibrating sieve) for 20 minutes to obtain the different fiber sizes:

Size 1: d<0.8 mm, size 2: d<0.2 mm, and size 3: 0.315<d<0.5mm.

Finally, the chosen fibers are washed with steam to ensure their cleanliness and then are dried in an electric oven for 48 hours at 60°C. In this work we choose the size 3 (0.315 < d <0.5 mm). we can summarize these steps through the protocol shown in Figure 2.

Figure 2. Rachis fibers preparation protocol

b) Petiole:(raw petiole, petiole agglomerate)

We used petiole in its raw state and in the petiole agglomerate state.

Raw petiole is an orthotropic material, these properties vary according to direction considered (parallel, perpendicular to the fiber of the petiole).

Djoudi et al. [16], determined the mechanical characteristics of this material by the compression tests presented in Table 1.

Table 1. Values of elasticity modulus of raw petiole

Direction of specimen	Elasticity modulus (MPa)
Longitudinal	224 ± 69
Transverse (thickness)	67 ± 14

Two types of petiole agglomerate used in this work differentiated by granule size (0-1) mm and (1-3) mm.

To prepare these granules, first, the raw petiole can be planed, and then it is sieved to get the size (0-1) mm, but in the second type, the raw petiole is cut into (1-3) mm pieces (Figure 3).

2.1.2 Cork

We used a cork agglomerate in the core of the second sandwich with the same skins, which we have already used in the first sandwiche.

- Cork agglomerate is 15 mm thickness to be used as core;

It was treated at industrial company "Taleza cork" at Skikda, (Algeria). Its density is 280 kg/m^3 and a thermal conductivity(λ) is 0.0375W/m^2 K^{-1} [1, 14, 17]. Several researchers studied and characterized the cork properties.

Table 2 presents the values of the longitudinal and transverse elasticity modulus of medium density of cork agglomerate obtained by compression tests [1]. This material is isotropic transverse.

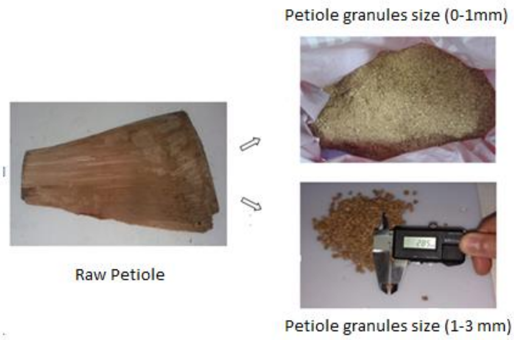

Figure 3. Different sizes of petiole granules used

Table 2. Values of elasticity modulus of cork agglomerate

Direction of specimen	Elasticity modulus (MPa)
Longitudinal	5.41 ± 0.53
Transverse (thickness)	20.93 0.18

2.2 Matrix

Matrix used in this work is resin epoxy. It is a thermosetting matrix (Epoxy Resin Scapa Polymeric 41). It is used for insulation in electrical cables. This is made up of two mixing liquids, epoxy resin and hardener (Figure 4).

Its density is 1.03 g/cm^3. It was prepared by mixing of two liquids at an ambient temperature of about 30°C for 5 min.

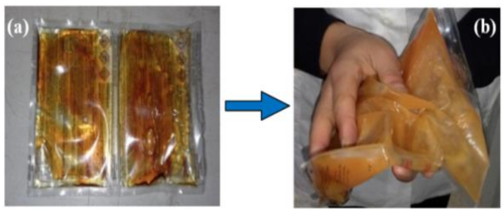

Figure 4. Epoxy resin, (a) before mixing, (b) after mixing

2.3 Composite material

After preparing the rachis fibers and the petiole (raw petiole, petiole granules with (0-1mm) size and petiole granules with (1-3mm) size from the date palm waste. As well as the cork agglomerate, they were used to prepare the skins and the cores several sandwiche structures as follows:

• (RFE) Composite material with 3mm of thickness, it's composed of rachis fibers of size 3 as reinforcement and epoxy resin (Scapa Polymeric 41) as matrix.

• Two type of Petiole agglomerate with 15 mm of thickness differentiated by granule's sizes (0 - 1 and 1 - 3) mm.

• Raw petiole and cork agglomerate with 15 mm of thickness.

Where these bio-materials were used in several sandwiches structures as follows:

- S_{P01}: Petiole agglomerate in the core with size (0-1) mm between two skins of composite material (RFE).

- **S_{P03}**: Petiole agglomerate in the core with size (1 -3) mm between two skins of composite material (RFE).
- **S_{RP}**: Raw petiole in the core between two skins of composite material (RFE).
- **S_{CA}**: Cork agglomerate in the core between two skins of composite material (RFE).

2.3.1 Composite material (RFE)

Rachis-Fiber-epoxy (RFE): It is composed of epoxy resin as matrix and rachis fibers as reinforcement. the steps to prepare this composite are, 10% of rachis fibers size 3 are mixed with 90% of epoxy resin, then next this mixture is filled in a mold of (150x130x03) mm^3, afterwards, material is dried, later unmold, this bio-composite material (Figure 5).

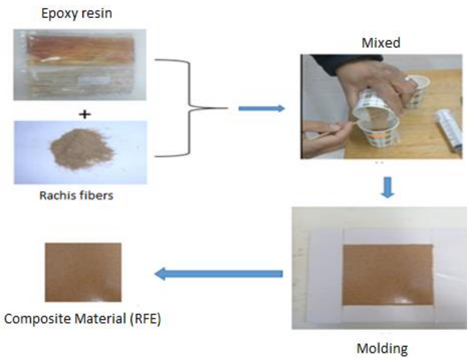

Figure 5. Composite material preparation protocol

2.3.2 Composite material (Petiole agglomerate)

To prepare petiole agglomerate plate, (20%) petiole granules (0-1 or 1-3) mm are mixed with (80%) natural glue (white glue) used as matrix, then this mixture is poured into a mold of (150x130x15) mm^3 in dimension. This bio-material is compacted, pressed and dried in an oven at a temperature of 50° for 24 hours. The specimens of the plates obtained and specimens of raw petiole and cork agglomerate are cut in parallelepiped shape (140x20x15) mm^3 (Figure 6).

We have determined the mechanical behaviors of these materials which are used as cores in the bio-sourced sandwich material, these proprieties were presented in previous study [16]. Table 3 presents the modulus of elasticity (E) of these materials determined by compression tests.

Table 3. Values of elasticity modulus (E) of petiole agglomerate differentiated by granules size

Petiole agglomerate		E (MPa)
Size (0-1) mm	Longitudinal	62.73±19.97
	Transverse	118±33.72
Size (1-3) mm	Longitudinal	97.56±19.86
	Transverse	116.58±16.03

2.3.3 Sandwiches structures

The combination between the skins (RFE) and the cores (raw petiole, petiole agglomerate and cork agglomerate) in this work is done according to collage. We can follow these steps:

Amount 10% of rachis fibers are mixed with 90% of epoxy resin, then next this mixture is filled in a mold of (150x130x03) mm^3, then specimens of the core are placed on this composite to obtain the first skin, afterwards this material is dried, later unmold the semi sandwich (sandwich with one skin).Then we prepare another plate of the composite to be used as the second skin of the sandwich, then we place the semi-sandwich (the face without skin) on this plate to obtain the second skin and also leave it to dry. Finally, unmold the specimens of sandwich (Figure 7).

Figure 6. Petiole agglomerate preparation protocol

Figure 7. Sandwiches preparation protocol

Figure 8. Placement of aluminum film between the core and the second skin

For the delamination tests, an aluminum film is added before the location of the semi-sandwich on the second skin to create an initial crack (Figure 8).

2.4 Mechanical tests

To determine the mechanical properties and the efficiency of these new bio-sourced sandwich, several tests are performed on “INSTRON” universal machine type 5969, with computer-controlled acquisition Bluehill3, with 05 KN force sensors and 1[mm /min] constant crosshead speed.

2.4.1 Three-point bending tests of skins

These tests make it possible to determine the elasticity modulus in composite material (RFE) used as skins in our sandwiches. We consider a composite material (RFE) with (B) in width, (L) in length and with (t_f) in thickness (Figure 9). These tests were carried out on specimens according to standards ASTM 790-81.2005. They were performed by applying the load (P) in perpendicular direction in the middle of the upper face of the specimen. It was placed on two supports with 60 mm of distance. Elasticity modulus is calculated from the linear part of a curve load (P) – deflection (f), We can calculate by this formula:

$$E_f = \frac{\Delta P}{\Delta f} \cdot \frac{L^3}{4B.t_f^3} \quad (1)$$

With: $\frac{\Delta P}{\Delta f}$ is the slope of linear part of curve P=f(f).

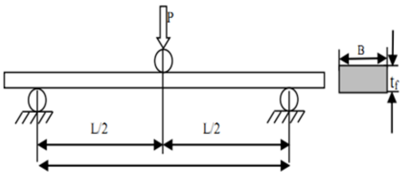

Figure 9. Geometric dimensions of a specimen used as skin by three-point bending [1]

2.4.2 Three-point bending tests of sandwiches

These tests determine the overall stiffness (D_G) in different types of sandwiches structures that have been prepared (S_{P01}, S_{P03}, S_{RP} and S_{CA}). We consider a sandwich with (b) in width, (l) in length, two identical skins with (t_f) in thickness and a core with (t_c) in thickness (Figure 10). These tests were carried out on specimens according to standards ASTM C393-62.1988 [18]. They were performed by applying the load (P) in perpendicular direction in the middle of the upper skin of the specimen. It was placed on two supports with 80 mm of distance Overall stiffness is calculated from a linear part of a curve load (P) – deflection (f). We can calculate by this formula:

Elastic deflection can be expressed by the following formula [1, 18]:

$$f = \frac{Pl^3}{48D_0} + \frac{Pl}{4S} \quad (2)$$

$$f = \left[\frac{l^3}{48D_0} + \frac{l}{4S}\right] P \quad (3)$$

$$f = [F_G]P \;\; ou \;\; P = [D_G]f \quad (4)$$

With D_G is a slope of the linear part of the curve P=f(f).

This formula is valid only for the beginning of bending tests when the deflection is relatively small. Five specimens used in each type of sandwich to determine overall stiffness.

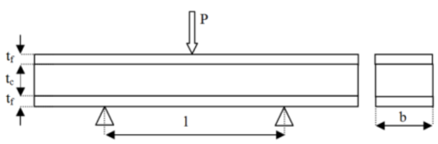

Figure 10. Geometric dimensions of a sandwich by three-point bending

2.4.3 Delamination tests of sandwiches (S_{P01})

During this study, we were found that the sandwiches of the type (SP01) are the most rigid compared to the other sandwiches studied, and since the sandwiches are laminated composite materials that can be damaged by delamination between the skins and the core. Delamination tests is the breaking in mode I. It determines the toughness in this type of sandwich (SP01) (Figure 11).

Specimens used in these tests are double cantilever beams (DCB) type. In geometrical dimensions, we consider a specimen (DCB) with (b) in width, (l) in length, (e) in thickness and (a) is initial crack lengths (see Figure 12).

These specimens are differentiated by initial crack lengths (a=30,40,50, and 60) mm. They are obtained by placing, a thin aluminum between the core and the upper skin.

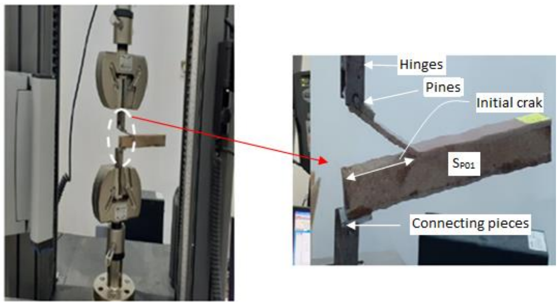

Figure 11. Delamination test in (DCB) specimen of (S_{P01})

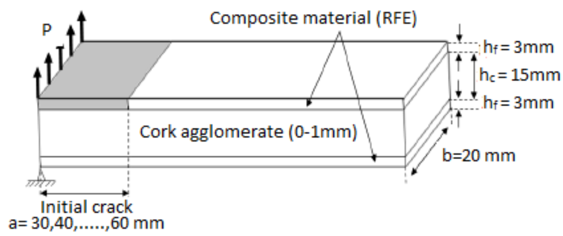

Figure 12. Geometrical dimensions of (DCB) specimen

Toughness in these studies defined by energy release rate (G_{IC}) at the priming point. It is the point of the end in linear part of curve [P=f(δ)], with (P) a load applied to the end of the specimen, and (δ) is the opening of the lips of this specimen. It is determined by [1, 15]:

$$G_{IC} = \frac{P^2}{2b}\frac{dC}{da} \quad (5)$$

When (*P*) is the applied load in initiation point,
(C): The compliance, it's presented by:

$$C = \frac{\delta}{P} \quad (6)$$

(δ) is the crack's opening displacement in initiation point

There is a difficulty to determining the ratio (dC/da). We have used in this paper the modified beam theory (MBT) to determine strain energy release rate (G_{IC}).

The graph $C^{1/3} = f(a)$ is theoretically a straight line.

$$C^{1/3} = m\,(a + |\Delta|) \quad (7)$$

These parameters (Δ) are obtained from the compliance at the initiation crack of several specimens differentiated by the size of the crack between the upper skin and the core.

IΔI is the magnitude of the intercept of $C^{1/3}$= f(a) with the (a)-axis (Figure 13).

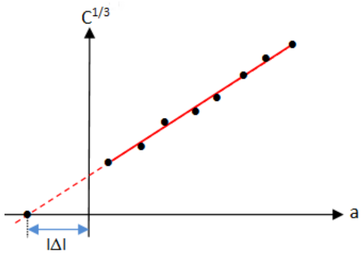

Figure 13. Value of IΔI by curve $C^{1/3}$=f(a) [1, 15]

Finally, to calculate strain energy release rate (G_{IC}), we use the relation

$$G_{IC} = \frac{3P^2C}{2b(a+|\Delta|)} \quad (8)$$

3. RESULTS AND DISCUSSION

3.1 Three-point bending tests of skins

Figure 14 presents Load-deflection curves in three-point bending testes of composite material (RFE) used as a skin in our sandwiches. They are started with a linear increase (0A), then a non-linear increase (AB) and finally they are reduced (BC) of a load (BC). We can calculate the modulus of elasticity in the linear part by formula (1). Table 4 presents the values of this parameter in composite material (RFE).

Table 4. Values of modulus elasticity (E_f) of composite material (RFE)

Specimens	Elasticity modulus E_f (Mpa)	CV (%)
(RFE)	1356.37±22.32	1.65

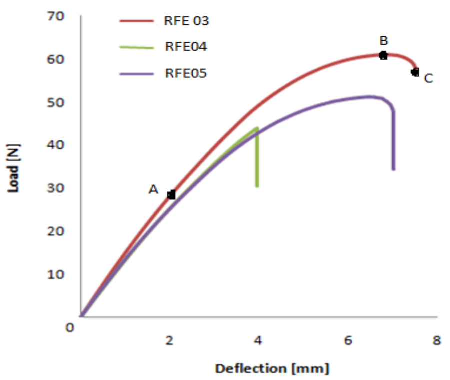

Figure 14. Load (N)-Deflection (mm) in three point bending tests of composite material (RFE)

This material (RFE) is isotropic because its properties are the same in all directions. The modulus of elasticity of our composite (RFE) is 1.356 GPa, while, it is 5.394 GPa in the plywood and 7.455 Gpa in the laminate of 04 layers (Glass fiber - polyester resin) [18]. It is clear that, the composite material (RFE) is more fragile than plywood and laminate (fibers glass-polyester resin). More ever, we can conclude that the composite (RFE) is more rigid compared with other composites of the same composition but differentiated by the fiber content (4%, 7% and 14%) [13].

3.2 Three-point bending tests of sandwiches

Figure 15 presents Load-deflection curves in three-point bending testes of different type of sandwiches (S_{P01}, S_{P03}, S_{RP} and S_{CA}). We note that there is a similarity in the four curves displayed. they are started with a linear increase (0A), then a non-linear increase (AB) and finally they are reduced until the rupture (BC). For this, we can determine the overall stiffness in the four types of sandwiches, which is defined by the slope in the linear part. Table 5 presents the values of the overall stiffness in different type of sandwich's studies.

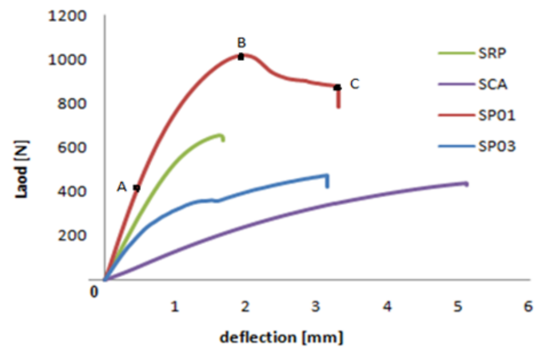

Figure 15. Load(N)-Deflection (mm) in three point bending tests of sandwich's specimens differenced by type of a core

Overall stiffness in sandwiches which contains the petiole in the cores (S_{P01}, S_{P03} and S_{RP}) are higher than a sandwich with the agglomerated cork in the core (S_{CA}), and overall stiffness in sandwich which contains the agglomerated petiole with size (0-1) mm in the core (S_{P01}) is higher than the other two sandwiches (S_{PO3} and S_{RP}).We say that the overall stiffness of sandwiches that contains petiole agglomerate in the core increases when as its particles are small, and this is due to its good cohesion with the matrix (white glue) added to it. Overall stiffness of S_{P01} is 818,90 MPa, it is greater than the toughness of another sandwich (cork agglomerate/glass fibers -polyester resin) (290.70 MPa) which was investigated in our previous study [18].

Table 5. Overall stiffness (D_G) values in different sandwiches

Sandwiches	D_G (Mpa)	CV (%)
S_{P01}	818.90±32.77	4.00
S_{P03}	485.99±17.06	3.51
S_{RP}	569.11±46.06	8.09
S_{CA}	106.73±13.94	13.06

3.3 Delamination tests of sandwiches

Figure 16 presents a Load-displacement curves of delamination testes of (SP01) sandwiches differenced by initial cracks (a= 30, 40, 50 and 60 mm). We note that there is a similarity in the four curves displayed of sandwiches.

They are started with a linear part, then a non-linear increase and finally a load drop. We can determine the energy release rate (G_{IC}) at the priming point in the different sandwiches, by extracting the values of (P and δ) from curves at this point and including them in the formula (08). We can calculate value of IΔI. It is the magnitude of the intercept of $C^{1/3} = f(a)$ with the (a)-axis (Figure 17). According to the curves, the greater value of the initial crack (a), the greater the displacement value (δ) and the decreasing the value of the load (P). Table 6 presents the values of energy release rate (G_{IC}) in several sandwiches differentiated by initial cracks.

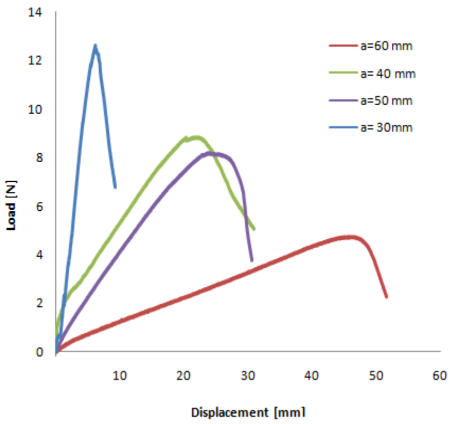

Figure 16. Load(N)-Displacement (mm) in delamination tests of (S_{P01}) specimens differenced by initial crack

Table 6. (G_{IC}) values in (S_{P01}) sandwiches differenced by (a)

a [mm]	P [N]	δ [mm]	C [mm/N]	G_{IC}[J/m²]
30	12.43	10.96	0.88	154810.00
40	8.67	19.58	2.26	167524.93
50	8.09	23.05	2.85	162623.11
60	7.86	24.13	3.07	148173.28
|Δ|	**b [mm]**	**G_{IC} (average)**		**CV [%]**
0.036	20	158282.83±8534.59		5.39

Toughness (energy release rate) values are almost equal in different sandwiches because this parameter is intrinsic to the material. It doesn't influence by the crack length. Toughness of the sandwich (petiole agglomerate /rachis fibers-resin epoxy) is 148173,28 J/m², it is greater than the toughness of another sandwich (cork agglomerate/glass fibers -polyester resin) 63545.3 J/m² [15].

It can be seen that, the sandwich (agglomerated petiole/rachis fibers-resin epoxy) which consists of a crack between the skin and the core supports a high priming energy than the sandwich (cork agglomerate/glass fibers -polyester resin).

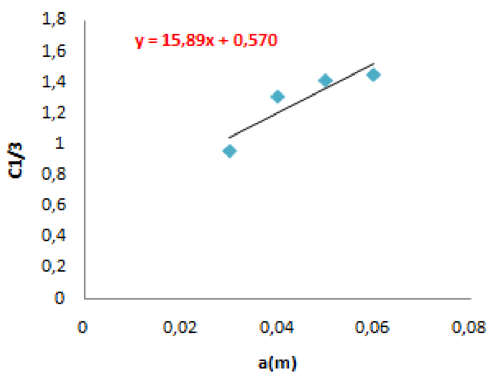

Figure 17. Curve ($C^{1/3}$-a) to determine IΔI

4. CONCLUSION

This study presents an experimental investigation on damage and mechanical behavior of bio-sourced sandwich materials differentiated by the composite materials used as core.

Thus, use used a composite material based on date palm waste (petiole) crushed in different sizes as core and compared their mechanical proprieties a composite based on cork agglomerate.

Tests carried out in this study are:

- Three-point bending tests on composite materials (rachis fibers - epoxy resin) to determine the modulus of elasticity in the skins.
- Three-point bending tests of the four types of sandwiches in order to determine their overall stiffness.

These tests have shown that the S_{p01} sandwich has the best mechanical properties (Petiole agglomerate in the core with size (0-1mm) between two skins of composite material (RFE)). This encouraged us to carry out a complementary investigation on the delamination test of sandwich $_{Sp01}$:

Delamination tests in mode I of the S_{P01} were carried out on beam's type, double cantilever beams (DCB). Sandwich to determine its toughness, this was made by insertion of Aluminum film between the upper skin and the core.

It turns out from the results of the investigation that, the studied sample presents a great overall stiffness.

In skins, elasticity modulus value of composite materials is 1.356 Gpa. This value is lower than that of a plywood and laminate composite material of 04 layers (glass fibers-polyester resin).

The overall stiffness of sandwiches that contains petiole agglomerate in the core decreases with the increase of its particles size; this is may be due the good cohesion with the matrix (white glue). The studied sandwich (petiole agglomerate/rachis fibers-resin epoxy) presents higher toughness values in comparison with toughness values of other sandwich from literature [15] (cork agglomerate/glass fibers - polyester resin).

It turns out that the studied material has very acceptable mechanical characteristics for the targeted applications. This makes it possible to exploit this bio-waste as an alternative wealth at a lower cost.

This work will be followed by a detailed comparative study of the thermal properties of different composite materials resulting from date palm waste for thermal insulation applications.

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REFERENCES

[1] Djemai, H. (2017). Contribution to the study of damage in sandwich composite materials. PHD Thesis, Mechanical Engineering, University of Biskra (Algeria). http://thesis.univ-biskra.dz/2806/1/Th%C3%A8se_03_2017.pdf.

[2] Djemai, H., Hecini, M., Djoudi, T., Djebloun, Y. (2018).

Mechanical characteristic of two different sandwiches made from bio-source materials: International Symposium on Mechatronics and Renewable Energies ISMRE, El-Oued, Algeria. http://dspace.univ-eloued.dz/handle/123456789/1623.
[3] Sezgin, F.E. (2008). Mechanical behaviour and molding of honeycomb laminated fiber/polymer sandwich structures. PHD thesis, University of Urla-Izmir, (Turkey).
[4] Bourahli, M.E. (2014), Characterization of composite of glass epoxy. PHD thesis in Optics and Precision Mechanics, University of Setif (Algeria). http://dspace.univ-setif.dz:8888/jspui/handle/123456789/1148.
[5] Berkouk, A., Meghezzi, A., Chelali1, H., Soltani, M.T. (2021). Mechanical, morphological, thermal and dynamic study of composites of unsaturated polyesters-date palm leaf fiber DPLF. Journal of Composites and Advanced Materials, 31(6): 317-323. https://doi.org/10.18280/rcma.310602
[6] Masri, T., Ounis, H., Sedira, L., Kaci, A., Benchabane, A. (2019). Characterization of new composite material based on date palm leaflets and expanded polystyrene wastes. Construction and Building Materials, 164: 410-418. http://dx.doi.org/10.1016/j.conbuildmat.2017.12.197
[7] Touam, L., Derfouf. (2021). Effect of the Varying Percentage Diss Fiber on Mechanical Behaviour of the Based Polyester Bio-Composite, Journal of Composites and Advanced Materials, 31(3): 175-180. https://doi.org/10.18280/rcma.310309
[8] Hacheman B. (2013). Analyse expérimentale du comportement mécanique d'un matériau composite soumis à des sollicitations d'impacts by, experimental analysis of mechanical behavior of a composite material subjected to impact stresses. http://dlibrary.univ boumerdes.dz:8080/jspui/bitstream/123456789/1238/1/Hachemane%20Belkacem.pdf.
[9] Djoudi, T. (2019). Development and characterization of bio-sourced composites based on date palm fibers. PHD thesis in Mechanical Engineering, University of Biskra (Algeria). http://thesis.univ-biskra.dz/4689/1/Doctorat%20en%20%20sciences%202019%20G%C3%A9nie%20M%C3%A9canique%20Dr%20DJOUDI%20Tarek.pdf.
[10] Djbloun, Y., (2018). Contribution à la caractérisation des matériaux composites renforcés de fibres végétales. PHD thesis in Mechanical Engineering, University of Biskra (Algeria). http://thesis.univ-biskra.dz/3951/1/Th%C3%A8se%20Doctorat%20de%20Mr.%20DJEBLOUN%20Youcef.pdf.
[11] Berkouk, A., Meghezzi, A., Chelali1, H., Soltani, M.T. (2021). Mechanical, morphological, thermal and dynamic study of composites of unsaturated polyesters-date palm leaf fiber DPLF. Journal of Composites and Advanced Materials, 31(6): 317-323. https://doi.org/10.18280/rcma.310602
[12] Masri, T., Ounis, H., Sedira, L., Kaci, A., Benchabane, A. (2019). Characterization of new composite material based on date palm leaflets and expanded polystyrene wastes. Construction and Building Materials, 164: 410-418. http://dx.doi.org/10.1016/j.conbuildmat.2017.12.197
[13] Djoudi, T., Hecini, M., Scida, D., Djebloun, Y., Djemai, H. (2019). Physico-mechanical characterization of composite materials based on date palm tree fibers. Journal of Natural Fibers, 18(6): 789-802. https://doi.org/10.1080/15440478.2019.1658251
[14] Boudjemaa, A., Benchabane, A., Boudenne, A., Laurent, I., Magali, F. (2011). Renewable materials to reduce building heat loss: Characterization of date palm wood. Energy and Buildings, 43(2-3): 491-497. https://doi.org/10.1016/j.enbuild.2010.10.014
[15] Djemai, H., Labed, A., Hecini, M., Djoudi, T. (2021). Delamination analysis of composite sandwich plate of cork agglomerate/glass fiber-polyester: An experimental investigation. Journal of Composites and Advanced Materials, 31(4): 193-197. https://doi.org/10.18280/rcma.310402
[16] Djoudi, T., Djemai, H., Hecini, M., Ferhat, A. (2022). Physical, thermal and mechanical characterization of a new material composite based on fibrous wood particles of date palm tree. Journal of Composites and Advanced Materials, 32(1): 45-52. https://doi.org/10.18280/rcma.320107
[17] Bnzidane, M.A., Benzidane, R., Hammamousse, K., Adjal, Y., Sereir, Z., Poilâne,C. (2022). Valorization of date palm wastes as sandwich panels using short rachis fibers in skin and petiole 'wood' as core. Industrial Corps and Products, 177: 114436. https://doi.org/10.1016/j.indcrop.2021.114436
[18] Djemai, H., Hecini, M., Labed, A. (2016). On the characterization of sandwich panels for solar flat plate collectors' applications: Theoretical and experimental investigation. Journal of Applied Engineering Science & Technology, 2(1): 15-22.

NOMENCLATURE

E_f	Elasticity modulus, GPa
f	Deflection, mm
B	Composite material width, mm
L	Composite material length, mm
t_f	Composite material thickness, mm
D_G	Overall stiffness, Mpa
P	Applied load, N
b	Sandwich width, mm
a	Crack length, mm
C	Compliance, mm/N
G_{IC}	Toughness, J/m^2
$\|\Delta\|$	Magnitude of the intercept of C= f(a) with the (a)-axis.
δ	Displacement, mm