World Academy of Science, Engineering and Technology
International Journal of Materials and Metallurgical Engineering
Vol:8, No:2, 2014

Study of the Green Composite Jute/Epoxy

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Abstract**—**Work presented is interested in the characterization of the quasistatic mechanical properties and in fatigue of a composite laminated in jute/epoxy. The natural fibers offer promising prospects thanks to their interesting specific properties, because of their low density, but also with their bio-deterioration. Several scientific studies highlighted the good mechanical resistance of the vegetable fiber composites reinforced, even after several recycling. Because of the environmental standards that become increasingly severe, one attends the emergence of eco-materials at the base of natural fibers such as flax, bamboo, hemp, sisal, jute. The fatigue tests on elementary vegetable fibers show an increase of about 60% of the rigidity of elementary fibers of hemp subjected to cyclic loadings. In this study, the test-tubes manufactured by the method infusion have sequences of stacking of 0/90° and ± 45° for the shearing and tensile tests. The quasistatic tests reveal a variability of the mechanical properties of about 8%. The tensile fatigue tests were carried out for levels of constraints equivalent to half of the ultimate values of the composite. Once the fatigue tests carried out for well-defined values of cycles, a series of static tests of traction type highlights the influence of the number of cycles on the quasi-static mechanical behavior of the laminate jute/epoxy.

Keywords**—**Jute, epoxy resin, mechanical, static, dynamic behavior.

I. Introduction

In a preoccupation of environmental protection and public health, the composites tend to integrate an ecological character. This study relates to the characterization of a laminate containing natural reinforcement (a fabric of jute) and of epoxy resin. Among all natural fibers, the jute has interesting mechanical characteristics in terms of tensile strength, with interesting properties in inflection [1]. The work undertaken by C. Baley [2], [10], [38], [39], shows that the properties of natural fibers change considerably, this variability occur from their harvests by the identification of the physiological and biochemical aspect on the species of harvests of the jute stem [3]. Khöler et al. [4] show that the genetic variability of jute fiber is related to nature even jute. One of the principal problems in the manufacture of jute fabric resides in the optimization of thread to use, indeed, the optimization of the process of fiber opening is significant to obtain fibers of good mechanical properties [5], [6].

The behavior of jute fiber is controlled by two parameters the reorientation according to the axis of the request of the fibrillate and the slip of those the ones compared to the others [7]-[9]. Hearle et al. [10] show that the angle microfibrillaire characterizing the jute is influenced by the percentage of cellulose in the jute (61% to 71%). Work of [5] shows that this angle microfibrillaire generally about 8° influences the mechanical behavior of the jute.

For the improvement of the mechanical characteristics of the jute, like its behavior in a wet medium, several works were interested in the treatments of the surface of the jute [11]-[20].

These treatments that modify the interphase also produce the morphological changes according to this one [12], [21]. They are carried out based on alkaline, of silane or of alkaline and silane [12]-[18], the hemicellulose and lignin contained in jute fiber are soluble in an alkaline solution, they will dissolve during the treatment alkaline what will cause a reduction in the mass of fibers. Other treatments are done under radiation UV present an increase of 58% at the flexural strength [19], [20], [22]. The mode of rupture of the reinforcement in the laminate differs thanks to the treatments from fibers, the rupture of untreated fibers is clear, on the other hand, that of fibers treated with silane is less clear thanks to the cohesion of the fibrillate [37]. The laminated plates containing jute are the subject of a certain number of works. The most used matrices are the thermoplastics such as polyethylene (EP) [23], [24], polypropylene (PP) [25], [26], polystyrene (PS) [27], [28], vinyl polychloride (PVC) [29], [30] and the polyester [31], [32], [36] for economic reasons. The choice of a structural polymeric resin does not pose a problem of provisioning but constitutes a barrier to the recyclability of the unit. However, the ecologically or naturally labeled resins do not answer the schedule of conditions of the end product because of the weak mechanical properties which characterize them. Moreover, they are rigid and breakable like the polylactone, PLA with the jute [33], dissolve in water like the natural polysaccharose, TPS [34]. Moreover, the migration of water in the resin can lead to a disturbance of the interface fiber/matrice [35]. The influence of the sequences of stacking on the mechanical properties (traction, inflection and of interlaminar shearing) of the untreated woven hybrid composites jute/polyester was studied in experiments by Sabeel et al. [31]. The results show that incorporation of glass fiber can improve the mechanical properties of the laminate. The tests of absorption of water realized on a composite material containing jute-fiber reinforcement of glass and an isophthalic resin polyester by Sabeel [32] show that the absorption of water decreases with the increase in the mass rate of glass fibers in material. This is explained by the fact, that the impermeable glass fibers act as barriers and prevent the direct contact between the jute and water [32], [28]. Work of Alvarez et al. [36] show that the studies relating to the thermal degradation of the composite of the jute/vinylester type are still limited for these materials, and this, in spite of their development in the field of the car. In waiting for a more powerful ecological resin, our choice was made on a thermohardening resin of epoxy type. The method

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of development of the laminate made by infusion presents many advantages, it is simple of design, economic and not very expensive, in addition to that makes it possible to manufacture plates (laminated) large-sized.

The mechanical behavior reinforcement fabric of dry jute is significant insofar as the temperature of polymerization of the resins is likely to be done with values that can deteriorate the mechanical characteristics of the jute. For that, tensile tests are carried out on samples of the fabric of dry jute carried at various levels of temperatures. The goal is to see the influence of the temperature of heating on stress the rupture of dry jute fabric. In the second shutter, we characterized the mechanical properties in traction of the laminate before and after fatigue tests to see the influence of the number of cycles on the mechanical behavior of the material. The shearing and tensile tests before fatigue tests defined the breaking stresses. We consider 0.5 σ_{rup} for the fatigue tests. The rupture is carried out with 21000 cycles for the specimens $[0/90]_4$. Following the directive of the European Parliament and Council of UE (2002/95/CE) relating to the limitation and the use of certain dangerous substances in the electric and electronic components, we carried out an analysis of heavy metals in the laminate through a non-destructive testing. This analysis allows to quantify the substances accused (expressed as a percentage limited) with knowing lead Pb, hexavalent chromium Cr+6, mercury Hg, polybromobipheniles PBB, cadmium Cd and polybromodipheylethers PBDE.

II. Experimental Procedure

The tensile tests of the jute fabric samples are carried out on a multipurpose machine Zwick of the type Z250/SNÄ equipped with a sensor of the force of 2,5 kN. It is controlled by a computer (Software TestXpert V12.0). Five test-tubes are tested for each temperature of the reinforcement (20, 50, 80, 100, 150 and 180°C) with a speed of test of 2mn/mm (Fig. 1).

Fig. 1 Tensile test of the jute fabric

The development of the laminate jute/epoxy is carried out by the method known as `by infusion', the fabric is prepared and cut-out with dimensions 300x300mm, the studied sequences of stackings are of type $[0/90°]_4$, $[+45°/- 45°]_4$. Fig. 2 represents the laminate jute/epoxy plates are cut out with a diamond saw following standard NF IN ISO 527-1.

A. Tensile Tests

For the identification of the mechanical properties of the laminate jute/epoxy (Young modulus, Poisson's ratios and breaking stresses), shearing and tensile tests are carried out in accordance with the standard IN ISO 527-5. Fig. 3 represents the shearing and tensile tests carried out on test-tubes of size 250 x 50 x 2.5mm provided with heels.

Fig. 2 Samples jute/epoxy reinforcement fabric of jute

Fig. 3 Tensile test of the laminate

B. Fatigue Tests

The fatigue tests on the samples $[0/90°]_4$ are carried out on a Zwick machine of the vibrophore type (Fig. 4). The static force is equal to 0.5 σ_{rup} and the dynamic force 5 kN. The number of cycles which definite the rupture of the samples (21 000 cycles) is divided into seven equal parts. The fatigue tests are done on samples from 3000 to 21000 cycles. Then, the samples having sudden 3000 cycles are tested in traction until the rupture, the same thing for those having sudden 6000, 9000, 12000, 15000, 18000, and 21000 cycles.

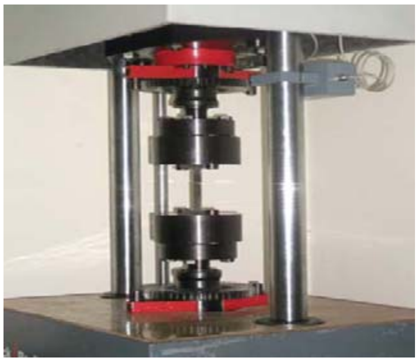

Fig. 4 Fatigue test of the laminate

C. Analyze Heavy Metals in the Laminate

One often thinks of conceiving systems, sets, subsets containing materials generally answering constraints imposed at the beginning and taking into account of the intrinsic characteristics of these metals, unfortunately, generally one does not think (or little) about how to make them disappear once they will have fulfilled their functions. We carried out an analysis of heavy metals in the laminate which we designed, so as to quantify and metals and their percentage to be able to define the field of application, and this, through a non-destructive testing. From an apparatus of the Axio type colored (Zeiss), with an objective of 2.5, a clear bottom, a considered light, with transmission by transparency, a numerical camera IC3 (3 million pixels).

III. Results and Discussion

The tensile tests carried out on the jute samples show the influence of the temperature on the mechanical behavior of the jute (Fig. 5). Two distinct zones arise: a zone of stability thermal energy of the ambient temperature (20°C) until 150°C with a variation of the maximum constraint of 10.8 to 12.2 MPa, and a zone of thermal degradation starting from 150°C until the temperature of carbonization of the jute. With the temperature of 180°C, the breaking stress falls of 57% of its initial value to reach 5.3 MPa, the jute then changes color (of clear brown with dark brown) and the wire constituting fabric are fixed between them. This thermal stress is determining in the choice of the resin to use; certain resins are polymerized at high temperatures. Our choice is related to an epoxy resin of type *STR(R)* with hardener *STR(D)*. The reinforcement being out of natural fiber, during the development of the laminate we notice a good cohesion between the reinforcement and the matrix due primarily to absorption in heart of the jute, from where, total absence of presence of air pockets inside the laminate. Fig. 6 below shows the regularity in the provision of the reinforcement compared to the matrix.

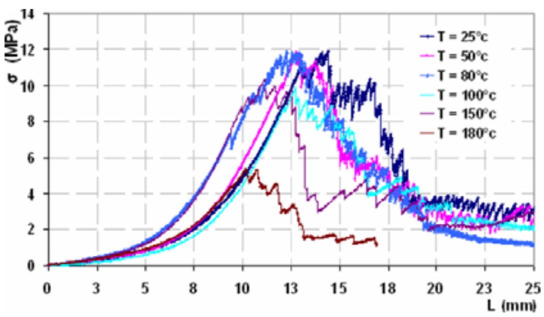

Fig. 5 Influence temperature on the breaking stress of the woven jute

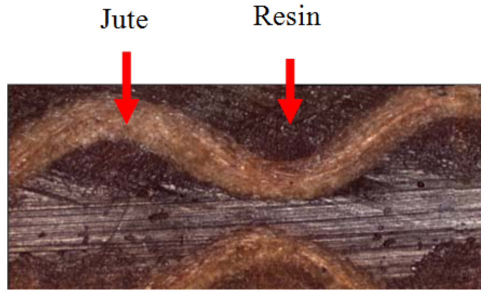

Fig. 6 Sight of profile of the laminate with reinforcement

Fig. 7 shows a real rupture of the laminate in traction. The results obtained in traction show that the laminate jute/epoxy samples have an identical linear behavior up to a value of 20 MPa. The behavior of the laminates is nonlinear until the rupture which is in the vicinity of 42 MPa (Fig. 8).

Fig. 7 Rupture in traction of the laminate

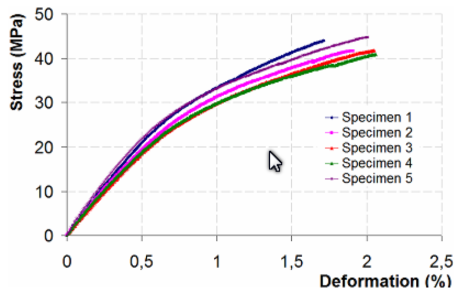

Fig. 8 Curves of the tensile tests

TABLE I
Values of the Modulus of Elasticity, the Modulus of Rigidity, Stresses the Rupture, and Poisson's Ratios

	E (GPa)		G (GPa)	Poisson's ratio		σ rupture (MPa)	
	Warp	Weft	-	ν_{lt}	ν_{tl}	Warp	Weft
Tensile test	4.5±0.6	4.8±0.8	-	0.24	0.27	42±3	43±4
Shearing test	-	-	1.45	-	-	23	

The results of the quasi-static mechanical tests are represented in Table I.

The fatigue tests carried out on the laminate jute/epoxy with different numbers cycles show the influence of the number of cycles on mechanical behavior in tensile test and shearing. In the tensile test, one notes a uniform degradation for the test-tubes having undergoes a number of going cycle from 3000 to 12000 cycles. Follows we have a saturation starting from 12000 cycles until the rupture with 21000 cycles (Fig. 9). In shearing, one notes a degradation of the breaking stress according to the number of cycles. One also notes a breaking stress of 35 MPa after 3000 cycles, then a fall with 24 MPa at 12000 cycles. Starting from this value, one notes a stagnation of the ultimate stress from 12000 to 21000 cycles. This difference between the values obtained in tensile test and shearing are due to the provision of the reinforcement inside the laminate. The provision of the fibers (0, 90) behaves better than those with (+45, -45).

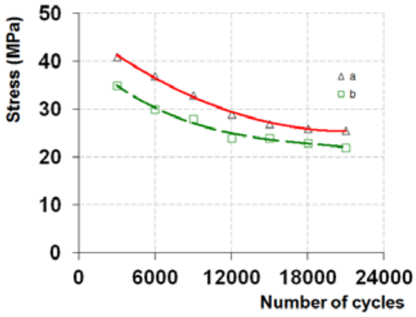

Fig. 9 Influence of the number of cycles on the breaking stress: (a) tensile test, (b) shearing

The European Parliament and the council of the UE approved the directive 2002/95/CE relating to the limitation and the use of certain dangerous substances in the electric and electronic components. The accused substances are (expressed as a percentage limited) Pb, hexavalent chromium (Cr^{+6}), mercury (Hg), polybromobipheniles (PBB), cadmium (Cd) and poly-bromodipheylethers (PBDE) (Fig. 10).

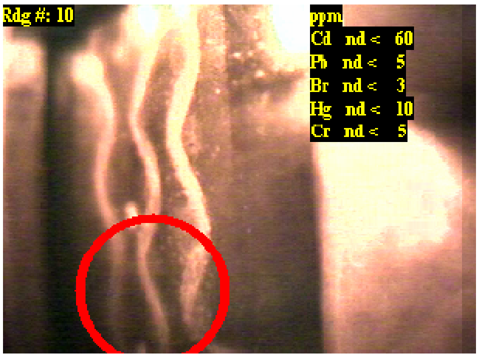

Fig. 10 Analyze presence of metals doors in the laminate jute/epoxy

IV. Conclusion

On the basis of an approach of topicality based on a logical of eco-design and of development of the renewable stock management, the study of the natural reinforcement is juicy initially enabled us to identify the influence of the temperature on behavior in traction of fabric is juicy dry. Stress the rupture of traction of dry fabric heated at a temperature higher than 150°C falls of 54% compared with that of a dry fabric at ambient temperature. In the second time, thanks to the mechanical tests (traction and shearing) carried out on laminates of the jute/epoxy type, to show certain variability mainly dependent on nature of fabric and its mode of weaving. The tests tensile on the laminate is juicy epoxy showed an identical behavior in two stages: a linear part up to 20 MPa and a nonlinear part until rupture with 42 *MPa*. One notes a clear rupture of the laminate in traction. One also notes the influence of the number of cycles on the breaking stresses in traction. We have a uniform reduction in the breaking stress from 3000 to 12000 cycles, then a slow degradation until the rupture. The analysis of the presence of metals doors in the laminate shows that this last fulfills the requirements imposed by the EEC in the field of the safety and health of the users of these metals.

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