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COMPARATIVE STUDY OF BEHAVIOR TO DELAMINATION ON DCB SPECIMENS IN NATURAL AND INDUSTRIAL COMPOSITES

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A B S T R A C T

This paper concerns the evaluation of mechanical damage in two composite materials. The first material is an industrial glass-epoxy composite, the second is a natural composite of solid wood.

The opening mode (mode I) and the delamination mode (mode II) represent the two most aggressive solicitation types that a composite material can meet. For this reason, we carried out bending tests leading to delamination on glass-epoxy DCB (double cantilever beam) and tensile tests on wooden DCB specimens of Eucalyptus gomphocephala.

Damage process follow for the epoxy glass through the acoustic mission allowed us to define the lifetime stages of the material. The observation of internal defects in damaged specimens by optical and scanning electronic microscopy allows to schematize the progression of the microcracks in the two composites.

INTRODUCTION

Composite materials are usually constituted of at least two elements having different roles and mechanical properties. Wood is also considered to be a composite material given the diversification of its anatomy and the natural complexity of its structure. It is composed of many types of cells that are formed during the development of the tree; wood formation is influenced by genetics. The influence of environmental conditions such as water, temperature, wind and chemicals products in the soil on the wood characteristics in the tree makes it a highly heterogeneous composite material [1].

The glass-epoxy composite offers many advantages in applications that require strength and fatigue life. These advantages encourage industrials to use it in structural applications, such as aeronautics, space and automotive industry.

Eucalyptus gomphocephala wood has a major socio-economic function in Morocco. Indeed, besides the use of its wood in the pulp and paper industry, it also provides firewood and coal. The timbers part from Eucalyptus wood remains fairly limited in view of its great sensitivity to aggression forms.

Composites damage process is often governed by delamination. Several studies [2, 3, and 4] that treat delamination problem show the important role of interlaminar stresses in this damage process. It has also been noticed [5-12] that often the initiation of delamination is caused by geometric discontinuities and manufacturing defects.

In the case of unidirectional composite, the failure of the first fibers creates stress concentration zone and can cause a sudden failure. However, the initiation of delamination does not systematically lead to catastrophic failure [13, 14].

In these various applications, structures are subjected to static as well as dynamic loads, and durability becomes often the criterion of material choice. Durability can be assessed only by knowing degradation mechanisms. The aim of this work is to reproduce damage phenomenon involved in Eucalyptus gomphocephala wood degradation and the glass-epoxy composite by a fractographic observation of surfaces fracture and acoustic mission follow.

To achieve concrete results very close to reality, we perform a simulation of static tests. Due to the heterogeneity of composites, their damage is the result of

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the accumulation of several types of microcracks: Fiber-matrix decohesion, matrix failure and fiber failure. The accumulation of these micro-damage phenomena progresses continuously until a certain critical stage leading to macroscopic failure of the specimen or the structure.

Experimental methodology

Material

Eucalyptus wood

The E.gomphocephala used is from the household arboretum of "Maamora". The choice of trees was made in a simple and random manner, according to the following criteria:

- Diameter greater than 40 cm at a height of 1.30 m from the ground.
- Homogeneity along the trunk.
- Absence of defects: parasitic attacks, fungi, decay, hollow, trunk slender and does not show deformations.
- The tree has the minimum number of branches to decrease the nodes number.
- Important total height.

After slaughter, the logs were dried in the open air for a week. All the specimens have been cut from the same ridge so that the sides have the dimensions of 320 millimeters (longitudinal direction) of 80 millimeters (radial direction) and 30 millimeters (tangential direction). Dimensional characteristics of DCB specimens are given by figure 1.

The specimens were then notched; notches have been produced along the longitudinal direction in TL plane, so that the rings are parallel in TR plane. The notch was made at the beginning with a band saw (thickness = 1 mm). To increase the acuteness of mechanical notch and initiate easily the crack, we have used a very fine razor blade.

We have limited the number of specimens to 25 specimens with different notches lengths, given the major dispersion in wood material; we have devoted 5 specimens per batch, knowing that one lot corresponds to a different notch length (from 30mm to 70mm).

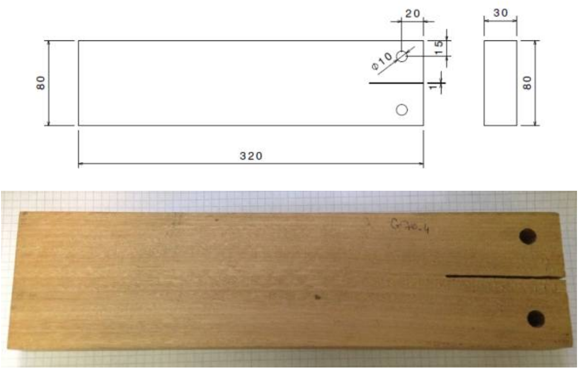


Figure 1 Geometrical properties of DCB specimen on solid wood

Glass-epoxy

Tested composite is glass fiber-epoxy made from S-2 prepreg fiberglass and Ferro-CE-9000-9 epoxy resin (HT-424). Specimens (Figure 2) were cut from plates that were manufactured according to the recommended polymerization cycles. The thickness of 5 mm was achieved by a stack of 26 layers that sequence is [± 45, O4, ± 45, O4, ± 45, O4, ± 45, O4, ± 45]. All the plates used for this study were subjected to an ultrasonic inspection according to the "C-scan" method. It was thus possible to verify that their internal structure was an example of manufacturing defects.

Principale and Tests Arrangements

For wood Eucalyptus, tensile tests were performed on a universal machine MTS 810. This machine allows achieving tensile and fatigue tests on different samples shape, with a maximum loading capacity of 100 KN. The machine belongs to the laboratory of control and mechanical characterization of materials and structures in the national higher school of electricity and mechanics (ENSEM CASABLANCA-Morocco).

The experimentation consists to submit wood DCB specimens on tensile tests (Figure 3), after having established the appropriate computer programs relating to machine control. Tests were carried out at a uniform velocity of 0.5 mm / min and with controlled displacement, and as soon as there is specimen failure, we record the load-displacement curve.

We used 5 batches of specimens from the same E.gomphocephala tree. Each batch represents a notch length and contains 5 BCD specimens. The notch lengths vary between 30 and 70 mm with a pitch of 10 mm. An unnotched specimen was also tested for reference.

Figure 3 Notched DCB specimen under tensile test

To illustrate the delamination in mode II of glass-epoxy, three-point bending assembly was used (Figure 4). 7 DCB specimens were tested. Interlaminar failure should occur simultaneously at mid-thickness in the two sheared areas of the specimen.

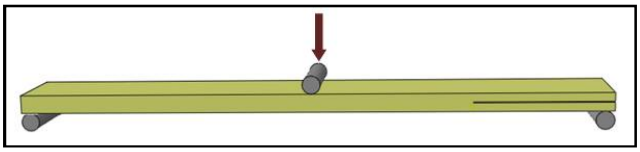


Figure 4 Schematic diagram of three-point end notched flexure (3-ENF) test

ANALYSIS AND RESULTS DISCUSSION

Strength at failure

The representation of variation of strength at failure in function of notch length for E.gomphocephala wood gives in Figure 5 curve. Strengths at failure varies linearly in function of notch lengths, it follows a decreasing rate when the notch becomes larger. This can be explained by the loss of strength in the longitudinal direction which is accentuated with the defect size.

The summary of mode II delamination results of glass-epoxy DCB specimens is shown on Figure 6. By comparing the mean values of critical strength at failure P_u obtained for each specimen, we can wonder if the difference between them (7.96 kN vs 9.76 kN) is significant. Analysis results demonstrate that the maximum shear strength of this composite is in the range of 52.56 to 63.32 MPa for 95% of tests.

However, the acoustic mission reveals the moment of damage initiation of the composite in the two zones of loaded specimen. The acoustic mission almost non-existent at loading beginning progresses as the load-displacement curve (arrow) increases. The recording of acoustic mission the rate located in the priming-delamination range has events rates which may be associated with either the resin cracking or the separation between the resin and the fibers and the fibers failure. We notice that at the moment of the sudden load drop (unstable phase of propagation), there is a sudden decrease in the number of events related to the instantaneous Interlaminar failure in mode II. This corresponds to a first delamination in one of the two zones of bending specimen. The same phenomenon occurs shortly afterwards, in the other zone of the test piece. The same phenomenon occurs shortly afterwards, in the other zone of specimen.

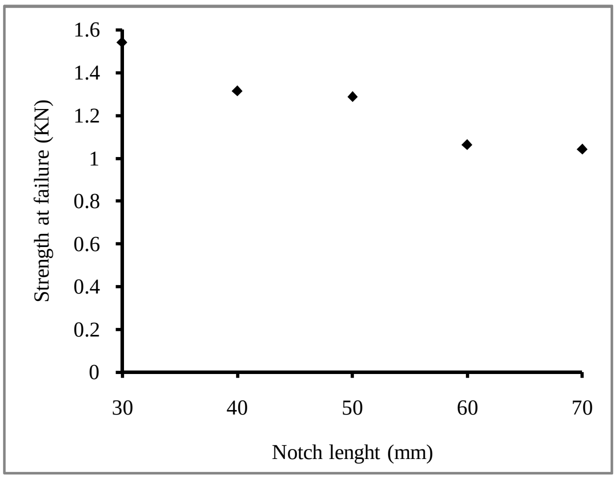


Figure 5 Variation of the critical strength at failure in function of notch length for E.gomphocephala wood

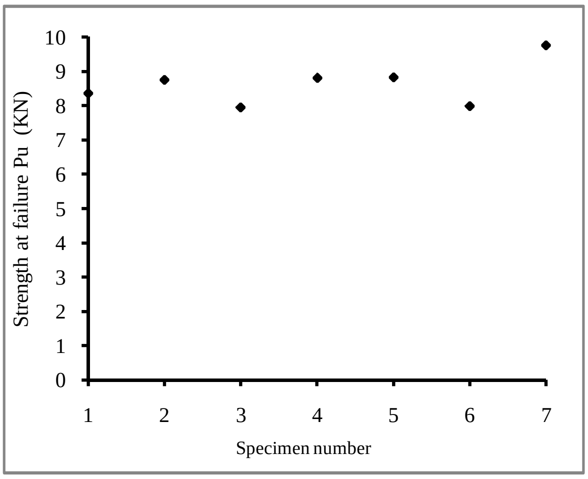


figure 6 variation of the critical strength at failure in function of specimen number for glass-epoxy

Acoustic mission follow of epoxy-glass damage

The objective of acoustic mission follow consists of detecting in real time, by continuous monitoring, microcracks that are born and propagate in specimens during the monotonic loading. The adopted priming criterion on a microscopic scale is the appearance of the first event in acoustic mission diagram. Figure 7 illustrates a simultaneous presentation of the two curves of double-embedded specimen, one of charge-displacement and the other of the acoustic mission rate for glass-epoxy.

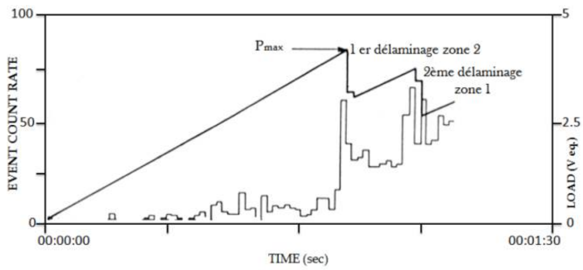


Figure 7 Correlation of acoustic mission rate with an increase in the static load. The discontinuities observed in the load curve correspond to the successive delamination in the two shear zones of the glass-epoxy specimen.

The elastic linear behavior of this material gives no indication of the irreversible priming beginning.

Figure 8 shows the final histogram of the events after delamination in the two zones. It is noted that although the damage has propagated in the solicited areas of specimen, the location of events by acoustic mission system corroborates well with these.

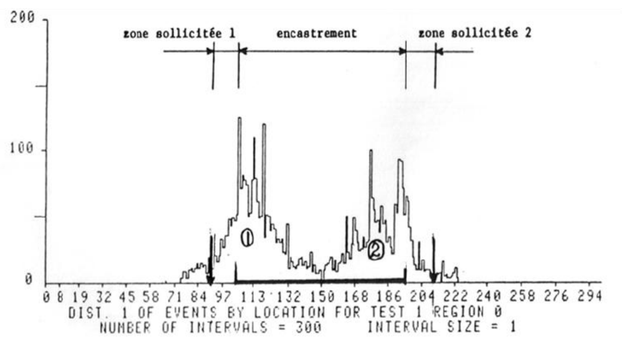


Figure 8 Linear location of acoustic mission in zones 1 and 2 at the end of a mechanical test

The results of the mechanical test shown in Figure 8 show load drop caused by the delamination, which is controlled very clearly by the sudden increase in the number of events in the two solicited zones. Moreover, the appearance of the first events around 30% of P_u suggests that damage develops much earlier than expected in the material. The validity of these results was verified by using, during or after the test, another non-destructive method is the ultrasonic immersion control (C-Scan) as well as by the microscopic observation techniques (destructive method).

Visualization of damage in glass-epoxy and Eucalyptus gomphocephala wood

Optical microscopic examination of glass-epoxy surface fracture (macrocracks observed in longitudinal section) indicates that the cracks propagate from the edge of the embedment practically in a straight line between layers [0° and +45°]. They cross layers [± 45 °] in the middle of the solicited zone to stop at the support point between the layers [-45° and 0°]. The cracking model is illustrated by the photo of Figure 9 obtained on a DCB specimen loaded in static flexion.

Electronic scanning microscope examination of beveled specimens allows to follow damage evolution of the damage in static bending which occurs between the layers [±45° et 0°]. Figure 10.a) indicates bare fibers, fractures and cracks in the matrix parallel to the fibers. The evolution of microcracks marked by tongues in a rich resin zone is illustrated in Figure 10.b).

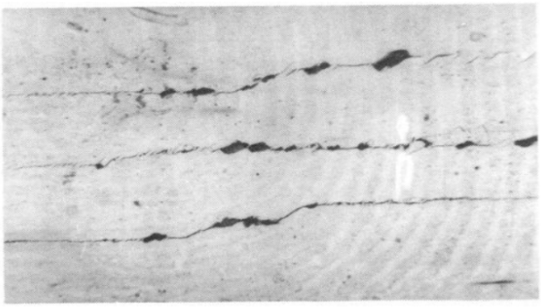


Figure 9 Marco-cracks observed in the longitudinal section of glass-epoxy DCB specimen in a static bending test

The analysis of fracture surface of E.gomphocephala wood shows that broken specimen was subjected to rapid failure; the examination of its fracture surface by an optical microscope shows a detachment of the fibers caused by the solicitation perpendicular to the fibers direction. Cracks propagate through the cellular tissue and form elements of irregular shapes and sizes. Cracks bypass the cell wall and cross the intercellular cement, this is an intercellular failure.

The pre-existence of cracks in the wood mass Figure 11.a) can also be noticed because of the weakening of joints between cells. These degradations are caused by the effects of high humidity and temperature gradients

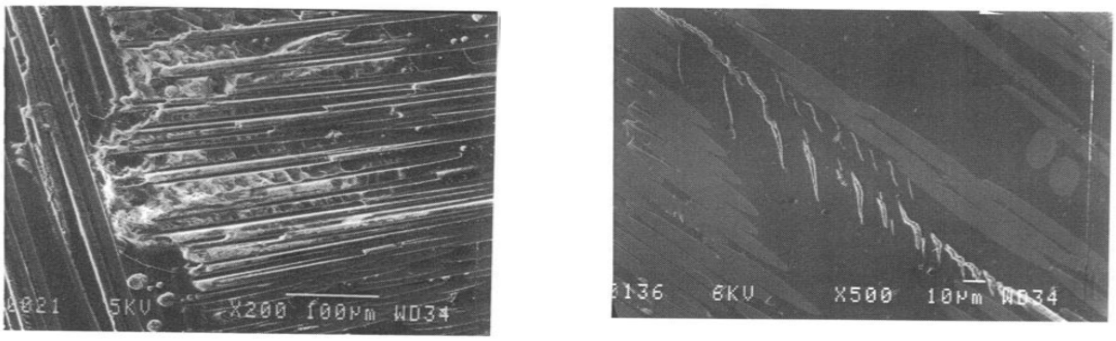
The existence of these cracks in wood due to the drying process constitutes an initial damage of the material [15] that influences its mechanical properties. The crack effect on strength depends on the crack size, its position and the direction of solicitation.

At the bottom of notch, cracks start at many places, but only one that propagates until the total failure of the specimens (Figure 11.b).

CONCLUSION

In this work we studied and compared damage mechanisms of two composite materials with different origins, industrial glass-epoxy composite and natural composite of E.gomphocephala wood. According to this study, several conclusions can be removed:

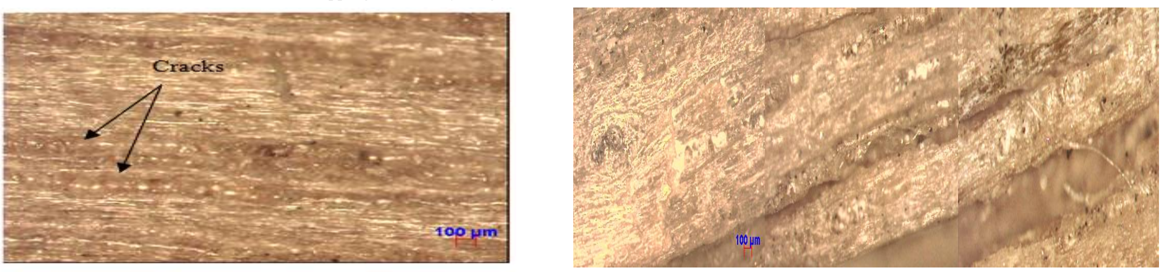
By using acoustic mission in a static test on glass-epoxy we noticed that the lifetime is translated by the first point of priming which is manifested by the appearance of the first burst of acoustic mission.



a b

Figure 10 Delamination in mode II in a static bending test for glass-epoxy

a. Fibers loss between the layers [± 45 °]
b. Crack stopping marked by tongues in a resin rich zone



(a) b

Figure 11 DCB specimen of E.gomphocephala wood

a. Fracture surface
b. Cracks propagation from the bottom of the notch

DCB wood specimens that are all manufactured from the same tree have a different behavior in front of solicitation. Wood material has a very marked natural anisotropy along the fibers direction.

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