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Study of the damage by acoustic emission of two laminate composites subjected to various levels of loading in three points bending

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1. Introduction

Due of their importance like structural elements, the laminated plates cause a great interest for the study of damage evolution and its mechanisms of rupture while based on numerical and experimental approaches. Many research tasks were undertaken on the behaviour of the composite structures, in particular the damage caused by loadings of various types [1-8]. The present study treats the experimental follow-up of the damage of two laminates $[-30/0/30]_{10}$ (material 1) and $[-60/-30/0]_{10}$ (material 2) during their loadings in 3- points bending in static and cyclic tests. These materials are composed with glass fibres E and epoxy resin.

2. Materials

The materials used in the study are laminate composites manufactured by RTM. To check on the one hand the orientation and number of layers of the reinforcement, and on the other hand the rates of resin and the reinforcement of these materials, we had recourse to the pyrolysis technique, envisaging cutting of the five samples roughly in equals surfaces, followed by a weighing each of them in gram noted M1. The specimens are fixed in a furnace of renewed ignited air, the calcinations takes place at 600°C during 10 hours. After cooling, the residue of glass is weighed in mass in gram noted M2, the resin loss by calcinations is M=M1-M2. The resin rate in percent is then R%=(M/M1)% and the fibre rate of glass in percent is thus F% =100-R. The results obtained are reported in Table 1.

Table 1

Results after pyrolysis

Designation	Rate of		
	Reinforcement in mass *F*, %	Resin in mass *R*, %	Reinforcement in volume, %
$[-30/0/30]_{10}$	66.70	33.30	46.74
$[-60/-30/0]_{10}$	66.29	33.71	45.83

3. Experimental set-up

Experimental tests were carried out on a standard hydraulic machine INSTRON 8516 that can be used in static and fatigue tests. The force is mesured by a load cell. The capacity of machine is ± 100 kN, the tests were caried out with a load cell of ± 5 kN. The displacement of the actuator is ± 75 mm, in a frequency range up to 100 Hz. The machine is interfaced whith a detected computer for controlling and data acquisition. The damage evolution is followed by acoustic emission using the system EPA NCV-2.

3.1. Static tests

The three points bending tests where performed according to standard I.S.O.178 T : (1993) shown in Fig. 1. The dimensions of specimens were: h = 12 mm, L = 240 mm, l = 192 mm, b = 15 mm, crosshead speed of static and cyclic tests was 2 mm/min.

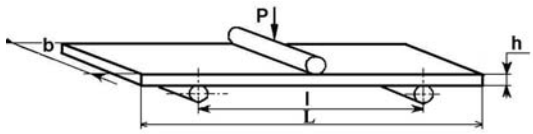
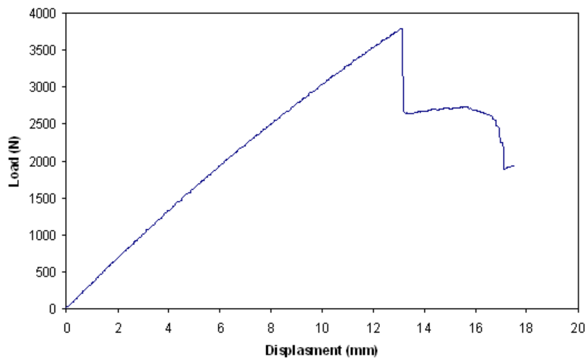


Fig. 1 Three points bending tests set-up



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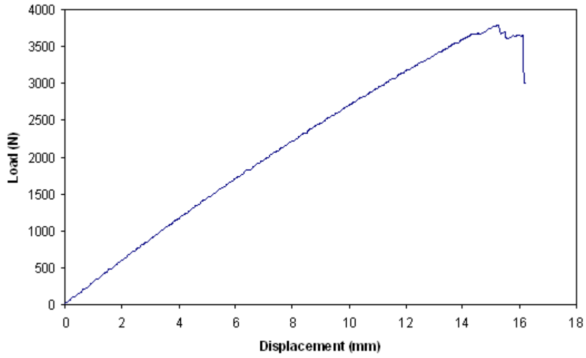

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Fig. 2 Load-displacement curves: a - material 1, b - material 2

The Fig. 2 represents a load-displacement curves during load in tree points bending in static tests until rupture.

The calculation of the mechanical characteristics in 3 points static bending is based on the Eq. (1) for bending stresses σ_f and on the Eq. (2) for the values of the bending modulus E_f.

$$\sigma_f = \frac{3\,F\,l}{2\,b\,h^2} \tag{1}$$

where F is load at the rupture applied; l is support length; b is width of the specimen, and h is thickness of the specimen.

$$E_f = \frac{\sigma_{f2} - \sigma_{f1}}{\varepsilon_{f2} - \varepsilon_{f1}} \tag{2}$$

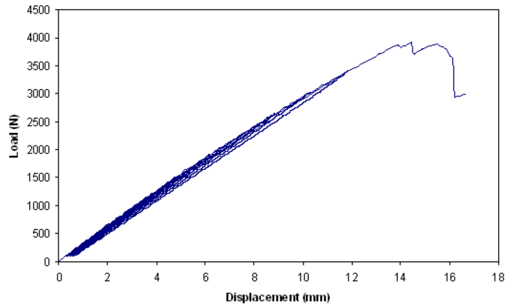
σ_{f2} and σ_{f1} are the bending stresses measured at deflection s_2 and s_1; ε_{f2} and ε_{f1} are respectively the bending strains at 0.0025 and 0.005 corresponding to the deflection s_2 and s_1 such as

$$s_i = \frac{\varepsilon_{fi} L^2}{6h} (i = 1; 2) \tag{3}$$

For material 1, the modulus equal to 23857.96 MPa while for material 2 the modulus is 20141.25 MPa.

3.2. Cyclic tests

The specimen undergo a growing load by the step of 10 % of the static load at rupture. For each step an unloading is applied until zero value, only the last cycle is maintained until rupture. The load-displacement curves in load and unload - displacement obtained are presented in Fig. 3.



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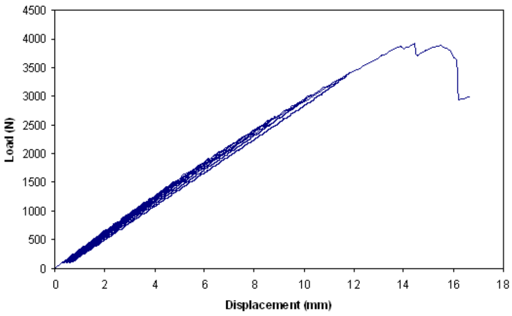

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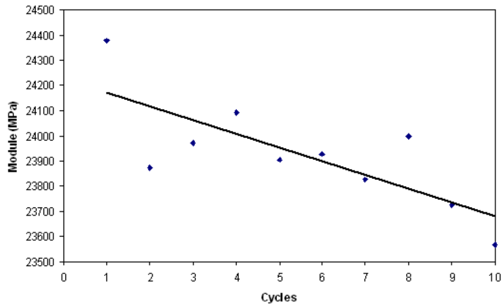
Fig. 3 Load, unload – displacement curves: a - material 1, b - material 2

4. Results analysis

The bending modulus in load and unload are obtained according the Eq. (2). The corresponding values are presented in Tables 2-5. The modulus evolution according of the cycles number under loading and unloading is represented on Fig. 4.



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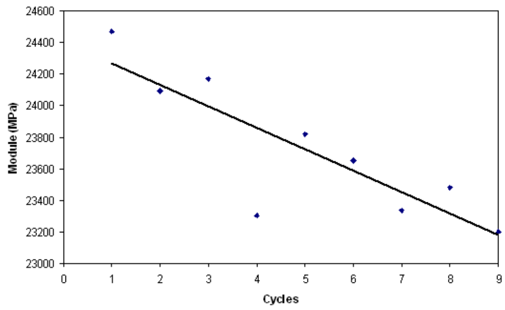

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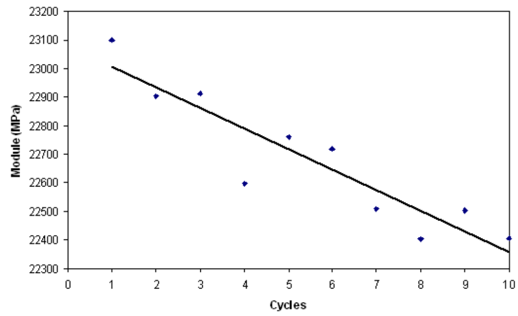

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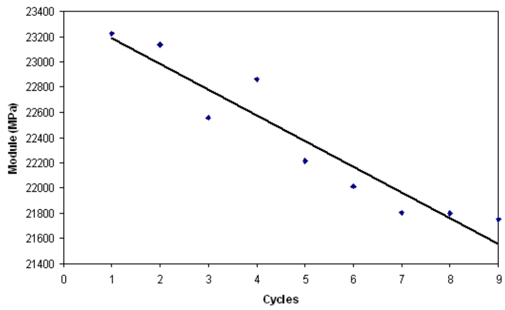


d

Fig. 4 Modulus by step of load as the function of cycles number: a - loading of material 1 , b - unloading of material 1, c - loading of material 2, b - unloading of material 2

The results obtained show that the increase in the number of cycles in loading or unloading involves a linear reduction of the modulus of elasticity of the two studied materials; this reduction is probably related to the appearance of microcracks. These microcracks influence the mechanical behaviour of the specimen and particularly in terms of macroscopic properties such as module degradation. The fact that rigidity of the material is affected during the loading-unloading it is essential to measure the elastic modulus in order to be able to quantify the damage [5, 6], thus giving an idea on the evolution of the total damage of the material. Damage is determined by

$$D = 1 - \frac{\widetilde{E}}{E} \tag{4}$$

where $\widetilde{E}$ is the Young modulus of damaged material, E is the Young modulus of intact material.

The evolution of the damage parameter D during the loading – unloading tests in 3 points bending is a direct technical characteristic. It is obtained by measuring the Young modulus of the damaged material from the curves load–displacement (Table 2-5).

Table 2

Modulus and damage by step of loading of the material 1

Cycle	1	2	3	4	5
$\widetilde{E}$	24380	23873	23970	24093	23903
D	0.0000	0.0208	0.0168	0.0117	0.0195
Cycle	6	7	8	9	10
$\widetilde{E}$	23927	23825	23997	23726	23567
D	0.0186	0.0227	0.0157	0.0268	0.0333

Table 3

Modulus and damage by step of unloading of the material 1

Cycle	1	2	3	4	5
$\widetilde{E}$	24468	24091	24170	23302	23817
D	0.000	0.0154	0.0122	0.0477	0.0266
Cycle	6	7	8	9	
$\widetilde{E}$	23652	23335	23479	23199	
D	0.0333	0.0463	0.0404	0.0519	

Table 4

Modulus and damage by step of loading of the material 2

Cycle	1	2	3	4	5
$\widetilde{E}$	23100	22903	22911	22597	22761
D	0.0000	0.0085	0.0082	0.0218	0.0147
Cycle	6	7	8	9	10
$\widetilde{E}$	22717	22509	22401	22502	22406
D	0.0166	0.0256	0.0303	0.0259	0.0300

Table 5

Modulus and damage by step of unloading of the material 2

Cycle	1	2	3	4	5
$\widetilde{E}$	23228	23136	22561	22858	22213
D	0.0000	0.0040	0.0287	0.0159	0.0437
Cycle	6	7	8	9	
$\widetilde{E}$	22013	21806	21796	21750	
D	0.0523	0.0612	0.0616	0.0636	

5. Mechanisms of damages and rupture

To confirm the results of mechanical behaviours obtained at experimental tests in 3 points static and cyclic bending, we have applied an experimental procedure of acoustic emission. It is based on a system of acquisition (EPA) including 2 ways. This system is composed of a chart PCI-2 and a microcomputer. Signals of acoustic emission are converted by 2 piezoelectric differential sensors of R10 type, resonating at 250 (325) kHz and with contact surface of 10 mm diameter. These signals are then amplified by a preamplifier with 40 or 60 dB gains, in a band of frequencies between 175 and 1000 kHz. The signals are then converted by the chart PCI-2 which digitizes them and proceeds to the extraction of the acoustic emission parameters. The data resulting from the charts are transmitted to the microcomputer, in real time of acquisition; storage and post processing are done using a program prepared under MATLAB. Fig. 5 shows the set-up of acquisition of acoustic events

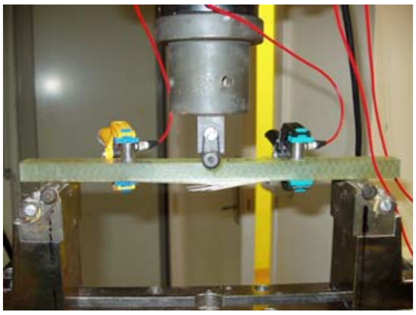


Fig. 5 Set-up for the acoustic events

5.1. Results

Figs. 6 and 7 represent respectively the mechanisms of damages and rupture observed under the optical microscope and located by acoustic emission during 3 points static and cyclic bending of materials 1 and 2.

In the same way Figs. 8 and 9 represent respectively the mechanisms of damage and ruptures observed under the optical microscope and located by acoustic emission for material 2 $[-60/-30/0]_{10}$.

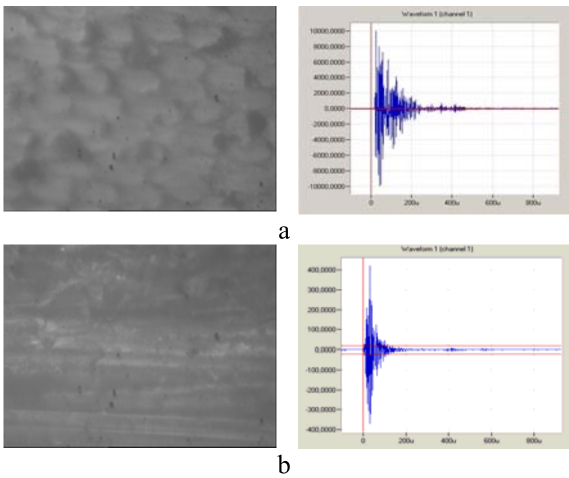
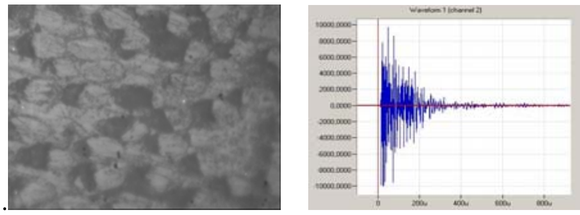


Fig. 6 Mechanisms of damage and rupture in static bending of the material 1: a - interface rupture, b - interfolds rupture



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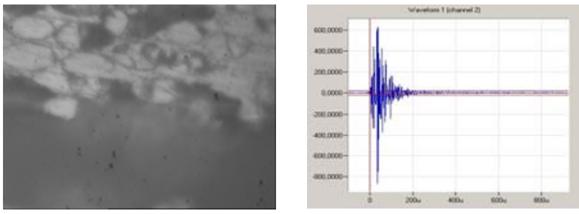

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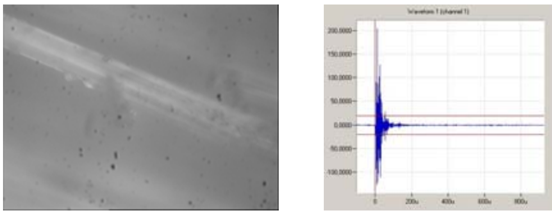
Fig. 7 Mechanisms of damage and rupture in cyclic bending of the material 1: a - interface rupture, b - interfolds delamination



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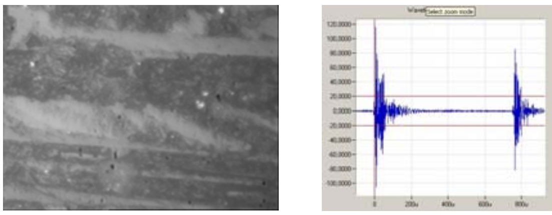

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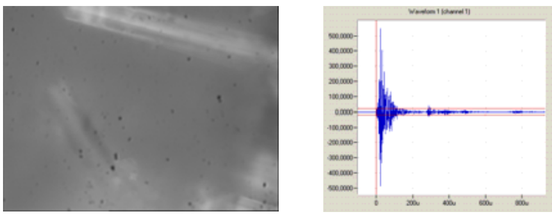
Fig. 8 Mechanisms of damage and rupture in static bending of material 2: a - rupture of fibres extended to 0°, b - interfolds delamination



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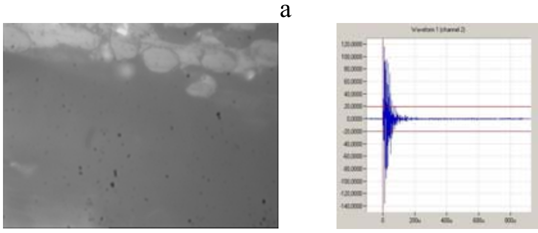

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Fig. 9 Mechanisms of damage and rupture in cyclic bending of material 2: a - rupture of fibres extended to 0°, b - interfolds delamination

5.2. Results analysis

A perfect correspondence resulted between the mechanisms observed under optical microscope and those obtained by acoustic emission which are principally of three types: in static and cyclic load, i.e. rupture of fibres, rupture of the interface, and delamition rupture.

6. Conclusion

This study enabled us to see the influence of the type of loading on the mechanical behaviour of two laminate composites. The cyclic loading of materials studied in 3 points bending showed a linear reduction of the bending modulus with the increase in the number of cycles in loading and in unloading. The sequence of stacking has little influence on the values of the modulus determined starting from the curves of experimental in statics and cyclic tests. The mechanisms of ruptures and damage observed are primarily: rupture of fibres, rupture of the interface and delamination. The follow-up of the damage evolution by acoustic emission led to the detection of rupture mechanisms and of damage during the loading of material. The microscopic observations confirmed the detected mechanisms.

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TRIJUOSE TAŠKUOSE ĮVAIRAUS LYGIO LENKIMO APKROVA VEIKIAMŲ DVISLUOKSNIŲ KOMPOZITŲ TYRIMAS AKUSTINE EMISIJA

R e z i u m ė

Straipsnyje aprašomi dvisluoksnių kompozitų, pagamintų RTM būdu ir statiškai bei cikliškai lenkiamų apkraunant trijuose taškuose iki suirimo, eksperimentinių tyrimų rezultatai. Šie bandiniai buvo pagaminti iš epoksidinės dervos ir E stiklo pluošto. Mechaniniai bandymai atlikti naudojant „Instron“ įrenginį su kompiuterizuotu 50 kN galios apkrovos moduliu. Suirimo procesas buvo stebimas akustines emisijos sistema EPA NCV-2, sujungta su bandymo įrenginiu; bandiniai buvo papildomai tiriami optiniu mikroskopu. Tyrimų rezultatai rodo, kad mechaniniais bandymais gautų rezultatų eksperimentinių kreivių pobūdis priklauso nuo pažeidimo tipo. Didėjant ciklinės lenkimo apkrovos ciklų skaičiui, dvisluoksnio kompozito tamprumo modulis, apkraunant ir nukraunant apkrovą sumažėja. Akustinė emisija įgalino nustatyti pažeidimų tipą ir suirimą veikiant ciklinei apkrovai.

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STUDY OF THE DAMAGE BY ACOUSTIC EMISSION OF TWO LAMINATE COMPOSITE SUBJECTED TO VARIOUS LEVELS OF LOADINGS IN THREE POINTS BENDING

S u m m a r y

We present on this paper an experimental study of the follow-up of the damage of two laminate composites manufactured by RTM during their loadings in 3 points bending in static and cyclic tests. These materials are composed E glass fibres and epoxy resin. The mechanical tests are carried out on a standard hydraulic machine INSTRON 8516 that can be used in static and fatigue tests. The machine is interfaced whith a detected computer for controlling and data acquisition. The evolution of the damage is followed by acoustic emission using the system EPA NCV-2 connected to the testing machine, then confirmed by optical microscopic observations. The results obtained show that the curves of mechanical behaviour are strictly related to the observed damages. In the case of cyclic bending, the increase in the number of cycles involves a modulus reduction for the two materials that in loading as well as in unloading. The Acoustic emission allows to locate the mechanisms of damage and rupture caused by the loading of these materials.

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ИССЛЕДОВАНИЕ ПОВРЕЖДЕНИЙ ДВУХСЛОЙНОГО КОМПОЗИТА ВОЗДЕЙСТВОВАННОГО В ТРЕХ ТОЧКАХ ИЗГИБАЮЩЕЙ НАГРУЗКОЙ ПРИ ПОМОЩИ АКУСТИЧЕСКОЙ ЭМИСИИ

Р е з ю м е

В статье приводятся результаты экспериментальных исследований двухслойного композита, изготовленного методом RTM при нагрузкой трехточесным статическим и циклическим изгибом. Образцы изготовлены из эпоксидной смолы и стекловолокна типа E. Испытания проведены испытательной установкой „Instron“, снабженной силовым устройством мощностью 50 kN и компьютеризированным модулем. Процесс разрушения наблюдался при помощи прибора акустической эмиссии типа PA VSV-2, подключенного к испытательному устройству, при дополнительном иследовании оптическим микроскопом. Полученные результаты показывают, что характер кривых, полученных при механических испытаниях зависит от типа повреждения образца. При увеличении числа циклов нагружения модуль упругости двухслойного композита уменьшается при его нагружении и разгрузке. Метод акустической эмиссии позволил установить тип повреждения и разрушения образцов при воздействии циклической нагрузки.

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