EXPERIMENTAL ANALYSIS OF THE RUPTURE OF POLYESTER-WOOD COMPOSITE UNDER DYNAMIC LOADING

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The work is devoted to experimental study of polyester-wood composite under dynamic loading. Based on a thermodynamic approach, the objective is the evaluation of the specific energy of interfacial delamination in a multi-layer composite material under dynamic loading causing damage to it by cracking. For modeling of dynamic loading, it was used an experimental device based on the principle of the Charpy test which is to measure the residual energy of a mass movement following a shock at speeds generally between 1 and 4 m/s, on a test piece cut of standardized dimensions requested in bending. Some of the available energy is consumed by rupture of the test piece. The results of this work showed that for a dynamic test, the fracture energy is function of the speed and impact energy of fall of the load. These results may be useful in the design of multilayer composite structures subjected to dynamic loads.

KEY WORDS**:** polyester-wood composite, dynamic loading, fracture energy interfacial delamination, specific energy of delamination, Charpy test, cracking.

Introduction

One of the factors limiting the use of composites in civil engineering is linked to their high sensitivity to degradation of technological origin and operating conditions hat can induce the initiation of interfacial delamination and/or the accumulation of damage causing a decrease in their strength characteristics. These composite structures undergo changes at high speed of deformation during impact or explosion accelerating the spread of cracks and damage. Structures and composite systems sizing so appeals to various tools, such as the prediction of initiation of microcracks by using the theory of damage [1], the holding of structures cracked using the mechanics of breaking (linear or nonlinear) [2], [3], the theory of buckling, loads limits, or even resistance to fatigue. In the latter case claiming cyclic and/or vibration stresses, is more often overlooked the effect of frequency.

Quick stress are often referred to as "dynamic" when the effects of inertia can no longer be neglected, and the kinetic energy involved is not negligible with regard to the energy of deformation. The dimensioning of structures becomes much more difficult to perform. Under these conditions, an experimental analysis for the understanding of the phenomena of impact fracture becomes evident. These tests are all or nothing or undersigned structure. There are enough systematically deformation $10s^{-1}$ speeds for which testing machines have a close enough architecture that are used to characterize the behavior and fracture of materials under quasi-static loading, although the inertia of the testing machine makes the difficult discharge. Secondly, for loads greater than $100s^{-1}$, typically used a montage of Hopkinson-Kolsky bar [4], [5] allowing, depending on the device, apply a load of compression, traction or torsion. Beyond $1000s^{-1}$, one of the privileged means of investigation is loaded by shock [6] obtained either by impact of plates using powder or gas launchers, explosive.

Number of studies on the behaviour of composites under dynamic loading conducted, inter alia, in [7], [8], [9]. However the small number of experimental data related to rupture and evaluation of the characteristics of resistance to cracking composites under dynamic loading slows the development of standards for damage of composite structures.

The present work proposes an experimental method of evaluation of interfacial delamination specific energy of a composite polyester-wood, under dynamic loading following a normal failure mode.

1. Materials and methods

1.1. Description of the test

The purpose of the test material is a polyester-wood composite (fig. 1), whose mechanical properties under static and long term loadings were the subject of a study in [10], [11].

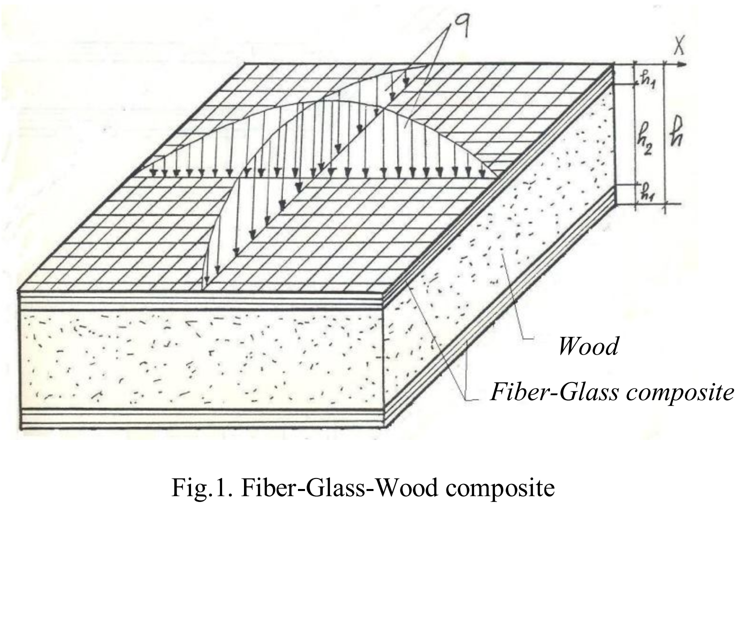


Fig.1. Fiber-Glass-Wood composite

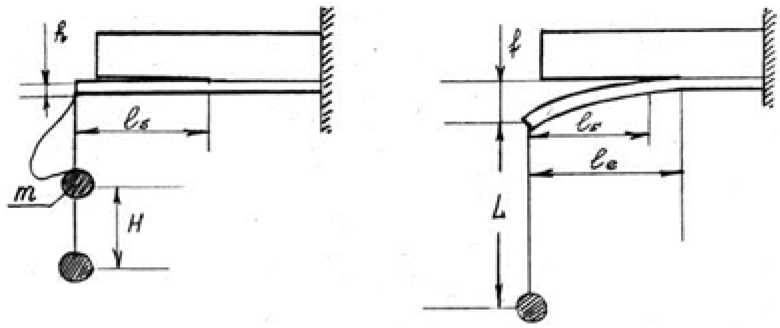
Modeling of dynamic loading, it is used an experimental device based on the principle of the Charpy test, which consists in measuring the residual energy of a mass moving from shock at speeds generally between 1 and 4 m/s, on a test piece cut to standardized dimensions requested flexural. Some of the available energy is consumed by the rupture of the test piece. The schematization of the test is shown in figure 2.

The specific energy of breaking U_g is defined as energy A_g necessary to the emergence of a new area of cracking D_s:

$$U_g = \frac{A_g}{D_s}. \tag{1}$$

For composites, the specific energy of quasi-static test failure has a value between 10^2 and 10^3 J/m^2. As part of this work the object of study test piece is a bi-layer composite: the top layer is a laminated wooden pine with dimensions $a \times b \times c$ - respectively the length, width and thickness. The bottom layer is a glass/polyester composite laminate with dimensions $a \times b \times h$ - respectively the length, width and thickness including the numeric values are reported in tables 1 and 2. The adhesive used for gluing of layers is a bi-component thermosetting epoxy, which the thickness does not exceed 0,1 mm, because only the thermosetting resins can withstand updates under significant loads and are, therefore, suitable for use as structural adhesives [12] only. The hardening of the adhesive is obtained by room temperature for 24 hours. The test piece embedded in the test machine has initial cracking and undergoes a load with a free fall of the mass movement, leading to an increase of interfacial crack.

Before the start of the test, an initial cracking of length l_s is made on the test piece (fig. 2a) which is then embedded in the testing machine. At the left end of the bottom layer is fixed a load of mass m with a wire of length L. This experimental device allows to consider that the wire is imponderable and absolutely rigid. The mass m is set so that the deformation of the bar is zero. This position of the mass corresponds to the zero potential. For loading, the mass is at a height H above the zero level (corresponding to the zero potential). The height H corresponds to the lower limit of the potential energy stored leading to the evolution of the crack. The balance of the system after loading is shown in figure 2 where the position of the mass m is given by the arrow f of the lower layer and the crack length increases from l_s to a value l_e.



a) b)

Fig.2. Diagram of the experimental device for dynamic loading

1.2. Modelisation

The potential energy of the mass at the time t_0 will be:

$$U_H = mgH,\ g = 9{,}81 m/s^2. \tag{2}$$

The expression (2) corresponds to the energy deployed to increase the cracked surface D_S. So be it:

U_b - the potential energy accumulated by the inflected layer; A - the energy dissipation during the vibration of the lower layer; $U_f = mgf$ - the change in the potential energy of the mass (f is the arrow on the bottom layer).

We consider that the energy dissipation A is comparable to U_b.

The energy balance before and after loading will be written in the following form:

$$U_H = U_b + A - U_f + g_{dyn} D_S. \quad (3)$$

Considering that the crack propagation speed is quasi constant (with the exception of the beginning and the end of cracking), we obtain the expression of the specific energy of delamination in the following form:

$$U_{g\,dyn} = \frac{(U_H + U_f - U_b - A)}{D_S}. \quad (4)$$

2. Results and discussions

Experimental results are presented in table 1 for the load of mass m = 2,6g and in table 2 for the load of mass m = 10,5g. The loading speed has the expression $v = (2gH)^{0,5}$, H - the distance of fall (fig. 2), g - the acceleration due to gravity, I - moment of inertia of the delamination surface.

Table 1. Treatment of experimental data for the load of mass m = 2,6g

№ test	E, Pa	a, м	b, м	h, м	I, м^4	m, kg	H, м	ls, м	le, м
1	4,00E+09	0,0999	0,0511	0,001	4,26E-12	0,0026	0,66	0,025	0,031
2	4,00E+09	0,0999	0,0511	0,001	4,26E-12	0,0026	0,76	0,031	0,035
3	4,00E+09	0,0999	0,0511	0,001	4,26E-12	0,0026	0,96	0,035	0,04
4	4,00E+09	0,0999	0,0511	0,001	4,26E-12	0,0026	1,16	0,04	0,045
5	4,00E+09	0,0999	0,0511	0.0	0.0	0,0026	0.0	0.0	0,045

Continuation of Table 1

№ test.	D_l, м	f, м	U_b , J	P_{stat},	U_{rup}, J	Ds, м^2	$U_{g\,dyn}$ J/м^2	v, м/s	$U_{g\,dyn}/U_{g\,stat}$
1	0,006	1,49E-05	1,89E-07	0.0	1,68E-02	0,000307	54,8	3,59	8,76
2	0,004	2,14E-05	2,73E-07	0.0	1,94E-02	0,000205	94,7	3,86	15,1
3	0,005	3,19E-05	4,07E-07	0.0	2,45E-02	0,000256	95,7	4,33	15,3
4	0,005	4,54E-05	5,79E-07	0.0	2,96E-02	0,000256	115,0	4,77	18,4
5	0.0	0,008	0.0	1,2	0.0	0.0	$U_{g\,stat}$=6,25	0.0	0.0

Table 2. Treatment of experimental data of the load of mass m = 10,5g

№ test	E, Pa	a, м	b, м	h, м	I, м^4	m, kg	H, м	ls, м	le, м
1	4,00E+09	0,1004	0,0414	0,001	3,45E-12	0,0105	0,1	0,004	0,02
2	4,00E+09	0,1004	0,0414	0,001	3,45E-12	0,0105	0,12	0,02	0,036
3	4,00E+09	0,1004	0,0414	0,001	3,45E-12	0,0105	0,2	0,036	0,052
4	4,00E+09	0,1004	0,0414	0,001	3,45E-12	0,0105	0,25	0,052	0,067
5	4,00E+09	0,1004	0,0414	0,001	3,45E-12	0,0105	0,3	0,067	0,084
6	4,00E+09	0,0999	0,0511	0.0	0.0	0,0105	0.0	0,05	0.0

Continuation of Table 2

№ test	D_1, м	f, м	U_b, J	P_{stat}, N	U_{rup}, J	D_s, м^2	$U_g$dyn ,J/м^2	v, м/s	$U_{g\,dyn}/U_{g\,stat}$
1	0,016	1,99E-05	1,03E-06	0.0	1,03E-02	0,000662	15,5	1,40	2,41

2	0,016	1,16E-04	5,98E-06	0.0	1,24E-02	0,000662	18,6	1,53	2,89
3	0,016	3,50E-04	1,80E-05	0.0	2,06E-02	0,000662	31,1	1,98	4,82
4	0,015	7,48E-04	3,85E-05	0.0	2,58E-02	0,000621	41,5	2,21	6,43
5	0,017	1,47E-03	7,59E-05	0.0	3,10E-02	0,000704	44,0	2,42	6,8257
6	0.0	0,01	0.0	1,1	0.0	0.0	$U_g$stat =6,45	0.0	0.0

In the last line of tables are shown results of static tests. The coefficient of variation for such tests does not exceed 15%. As it is shown in these tables, the dynamic work of rupture is higher than the value of the static work and depends largely on the speed of impact of load, its mass and energy accumulated at the time of the impact. Thus, for a dynamic test, the fracture energy is function of the speed and impact energy of fall of the load.

$$U_{g_{dyn}} = U_{g_{stst}} F(m, v, U), \tag{5}$$

where F is a function of correction that can be evaluated as a first approximation by statistical means. In figure 3, it presents the relationship between the fracture energy and the energy of falling of the load at the time of the impact.

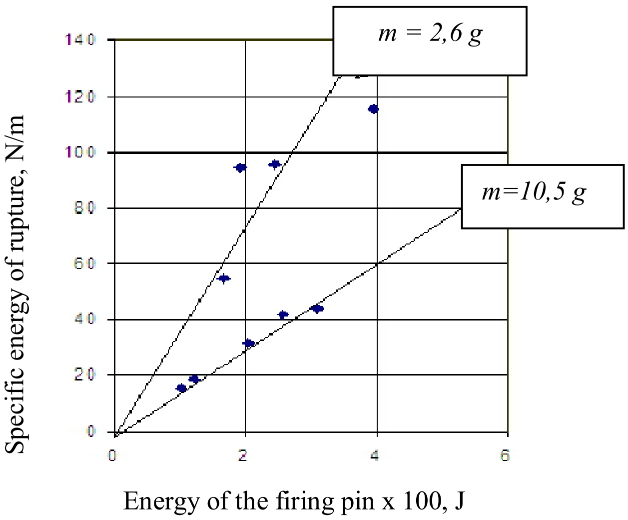
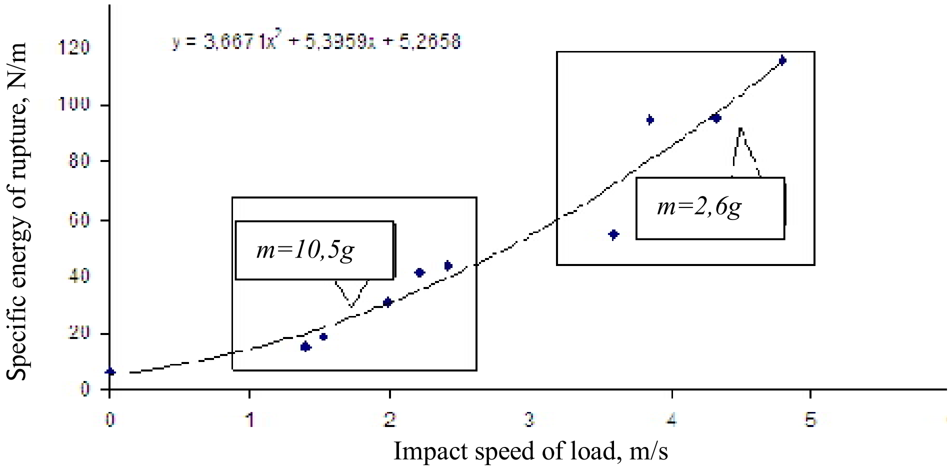


Fig. 3. Diagram specific energy of breaking - energy of the firing pin

Two cases are studied: a load of mass m = 2,6g and m = 10,5g. For the same energy accumulated by the firing pins, loading by the small mass leads to a higher of the fracture energy value which is correlated with the speed of the firing pin at load time. As a first approximation we can consider that the relationship between the fracture energy and the energy of the firing pin is quasi nonlinear. This is valid both for the small charge for the great (fig. 3). The relationship between the fracture energy and the loading speed is presented in figure 4. The static value of the fracture energy corresponds to the speed zero. To the right of the same figure was the results of the firing pin of mass m = 10,5g; top those of mass m = 2,6g. Regarding the small mass, the energy is more important (fig. 3). It should be noted that at each point in the chart, the energy of the firing pin is different.

As seen (fig. 4) the experimental data are approximated by a quadratic function satisfactorily. Visibly, in an acceptable interval (slow loading) results for the large mass will be in a range of small loading speeds.

Energy thresholds necessary for the evolution of cracking are presented in figures 5 and 6. Figure 5 corresponds to the mass *m=2,6g* while that figure 6 corresponds to the mass *m=10,5g*. To evolve the crack, it will take the firing pin's small mass accumulation of largest energy need more large mass.



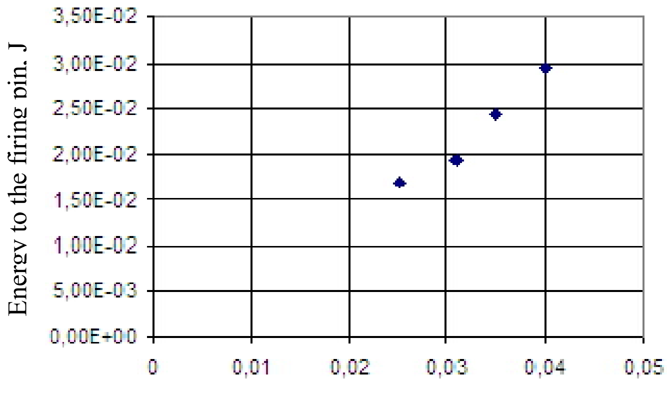


Fig. 5. Energy necessary to the evolution of the crack (*m* = 2,6*g*)

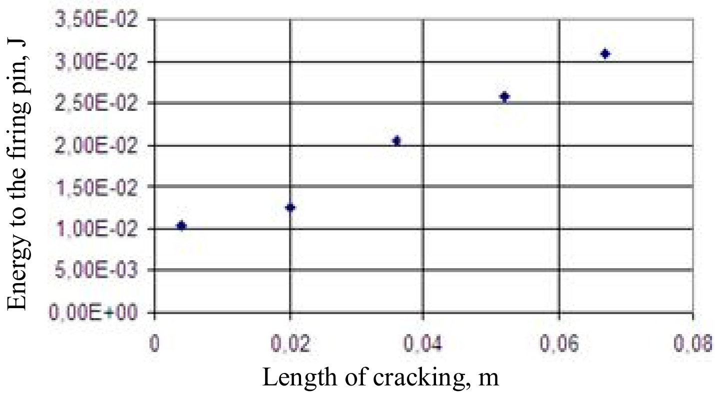


Fig. 6. Energie necessary for the evolution of the crack (*m* = 10,2*g*)

3. Conclusion

Following the dynamic experimental study on composite test piece, we can retain the following:

1) The specific energy of interfacial delamination under dynamic loading is greater than that obtained under static load.

2) For a constant energy accumulated by a firing pin, firing pins of lower mass lead to a higher specific breaking energy value.

3) During an impact between solids of different masses, but having gained equal amounts of energy, the solid of greater mass are more dangerous because their energy from deployed delamination is less important and approximates the quasi-static value.

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ЭКСПЕРИМЕНТАЛЬНЫЙ АНАЛИЗ РАЗРЫВА ПОЛИЭФИРНО-ДРЕВЕСНОГО КОМПОЗИТА ПРИ ДИНАМИЧЕСКИХ НАГРУЗКАХ

E.T. Olodo, E.C. Adjovi, S.L. Shambina

Работа посвящена экспериментальному изучению полиэфирного древесного композита под действием динамической нагрузки. В основе лежит термодинамический подход, целью исследования является оценка удельной энергии межфазного расслоения в многослойных композиционных материалах в условиях динамической загрузки, т.е. оценка влияния этих нагрузок на растрескивание образца. Для моделирования динамической нагрузки, было использовано экспериментальное устройство, основанное на принципе испытании по Шарпи (Charpy test). Эксперимент заключался в измерении остаточной энергии движения тела в результате ударного изгибного воздействия (со скоростью в среднем от 1 м/с до 4 м/с) на предварительно расщепленный образец стандартных размеров. Некоторая часть имеющейся энергии потребляется для разрушения образца. Исследования показали, что при динамических испытаниях энергия разрушения является функцией скорости и энергии удара от падения нагрузки. Эти результаты могут быть полезными при разработке многослойных композитных конструкций, находящихся по действием динамической нагрузки.

КЛЮЧЕВЫЕ СЛОВА: полиэфирно-древесный композит, динамическое нагружение, удельная энергия межфазного расслоения, испытание по Шарпи, трещины.