Non Uniformity of Composite Materials Reinforced with Carbon and Carbon-Kevlar Fibers Fabric

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In this paper we study the influences on mechanical behavior of nonuniformity that appear in bars reinforced with carbon fibers fabric, and respectively carbon-kevlar fibers fabric. We studied the manner in which nonuniformity produced by interruption of a layer or two layers of reinforcement affects the modulus of elasticity, tensile strength and elongation at rupture. In addition to these mechanical properties, we have experimentally determined the coefficient of uniformity for samples with matrix of epoxy resin, reinforced by carbon and carbon-kevlar fibers fabric and which having one and two layers with interruptions. By changing the dimensions of interruptions from layers we analyzed the effect of these nonuniformity on the mechanical properties studied.

Keywords: composite materials, uniformity coefficient, elasticity modulus, tensile strength

Traditional composites, laminates, reinforced with fibers are made up of multiple laminae, each of which is a uniform combination of materials in which the direction of the reinforcement with fiber is constant. The design possibility of the traditional laminae is limited to the selection of components materials and fiber orientation for the individual layers, as well as to specifying the sequence of layers in the laminate.

The composites of “mosaic” type differs of traditional laminates by the fact that each layer consists of several pieces, each of them having its own type of orientation, length and distribution of the fibers. One such technique for obtaining composites extends the design possibilities and provides a means of adopting the local properties and reduce the stress concentrators that occur in places like the free edges of the laminate. A simply joining of some such layers may lead to obtain a composite with a modulus of elasticity close to that of a unidirectional composite reinforced continuous but which has a breaking strength reduced by 50% [1-2]. Using such elements in regular assemblies that are intertwined, led to increased tensile strength up to 90% from that of composites with continuous reinforcement [3-4]. In [5-6] was shown that the reducing the cohesion between neighboring elements may reveal a mechanism for slowing the fracturing speed, resulting the composite materials with improved damage tolerance.

The elastic properties and of strength of the composite materials can be influenced also by the various defects which arise after the manufacturing process. This aspect is important in the case of large series production of pieces from composite material, reinforced with fibers, in which the distribution of the fibers in matrix has a non-uniform character. The transfer of resin, the structural reactions and the effects on the interfaces of separation are the reference sizes in large scale production of composites and each parameter should also be considered as a potential factor in the thinking of the degree of non-uniformity. In 7 is showed that in the case of composites obtained by blend of components, which have the contact on interfaces, the jumps of properties may be sufficiently large so that to mask the unexpected changes in the variables of production process.

The medium global properties of composite materials and their non-uniformity may be determined by several experimental methods, such as:

-obtaining of the characteristic curves in tensile stresses and the comparison of these properties with those of reference materials obtained under ideal conditions;

-using the technique reply to impulse-frequency.

In [8] is presented the result of a program which develop a “rapid screening assay” for determining in plane of the fibers distribution, in composites structures which are reinforced unidirectional, using the measurement of the response to vibration and the Galerkin method. Elastic constants and density are supposed to be functions in relation to volumetric ratio of the fibers, while the distribution of volumetric proportion of the fibers is given by a polynomial function. The concept of effective density is used to obtain the approximate solution of polynomial function coefficients. The results show that the fundamental mode of vibration gives better results in predicting physical properties than higher order modes.

In [9-13] are studied also other influences of non-uniformity on the behavior of composite materials. In [14] are studied non-uniformities which are occurring in the composite bars reinforced with fiber glass fabric. Is presented a coefficient which estimate non-uniformities for composite bars which has two areas with different volumetric proportions of reinforcement.

A matriceal method for the study of the elastic properties of composite materials is given in paper [15].

Theoretical considerations

It is considered a composite bar with constant width subject to a tensile test. Among the elastic and strength properties which can be obtained, the most representative

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are elasticity modulus and tensile strength. Both of these characteristics depend on the mechanical properties of the constituents (matrix and reinforcement), of their spatial distribution, and of manner in which they interact. In the literature there are relations for calculating the elasticity modulus and tensile strength for composite materials. These relationships, however, are based on certain assumptions which usually suppose ideal conditions for obtaining the composite materials and which do not take into account the defects that may occur.

Medium elasticity modulus is considered to be elasticity modulus of a homogeneous material, which if has the same size and spatial distribution as the composite bar, will have the same specific deformation. In this hypothesis we obtain:

$$E_{med} = \frac{\int_0^l \frac{1}{g(x)} dx}{\int_0^l \frac{1}{E(x) \cdot g(x)} dx}, \tag{1}$$

where:

l is the length of the bar;

E(x) is the function which gives the variation of the elasticity modulus of composite material;

g(x) is the function which gives the variation of bar thickness along its length.

Shall be considered that the bar fracture occurs when the fibers are broken in section which has the lowest tensile stiffness. In this hypothesis the tensile strength is supposed to be:

$$\sigma_r = \frac{\sigma_f}{E_f} \cdot \frac{(E\,g)_{\min}}{(g)_{\min}}, \tag{2}$$

in which:

- σ_f is fracture resistance of the fibers;
- E_f is elasticity modulus of the fibers;
- $(E_g)_{min}$ is the minimum value of the product E(x) . g(x);
- $(g)_{min}$ is the value of the sample thickness in section in which the product E(x) . g(x) has a minimum value ($(g)_{min}$ is not the minimum value of thickness).

A coefficient which estimate the properties of composite material is that of uniformity defined by:

$$c_u = \frac{\sigma_r \cdot E_f}{\sigma_f \cdot E_{med}}. \tag{3}$$

Values of uniformity coefficient close to 1 indicates that the material is homogeneous, without discontinuities in the reinforcement distribution, while lower values indicate the presence of some defects. Even if it does not show the nature and position of defects, a low value of uniformity coefficient indicates either the presence of some areas where material properties are damaged or that these defects are concentrated in a small area.

Experimental part

We made composite plates which have matrix of epoxy resin and reinforcement of carbon and carbon-kevlar fibers fabric. Each plate is made from five layers of fabric. At these plates, one or two-layer have discontinuities with different-sized. In addition, we have made the reference plates, which have five layers, with the same reinforcement, but which does not present discontinuities. From each plate were cut off the sets of samples. The sets of samples reinforced with carbon fibers fabric were abbreviated with C00, C10, C12, C14, C16, C18, C20, C22, C24, C26, C28, and sets of samples reinforced with carbon-kevlar fibers fabricwith CK00, CK10, CK12, CK14, CK16, CK18, CK20, CK22, CK24, CK26, CK28. The first number is the number of layers with discontinuities, and the second number represents the discontinuity length expressed in centimeters. For example, C24 is the set of samples reinforced with carbon fibers fabric, which have two layers with discontinuities, the lengths discontinuities for both layers being 4 cm.

The samples were requested to be tested to tensile strength the zone length which was requested being for every sample of 16 centimeters.

In figure 1 is shown the traction device and associated measuring equipment.

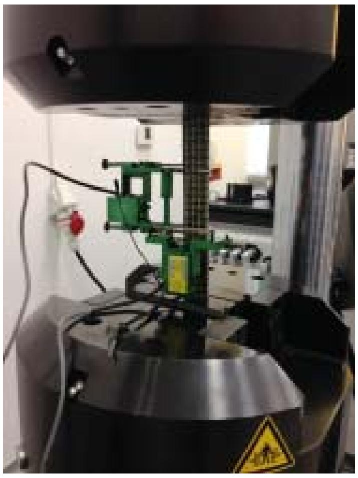

Fig. 1.

In figure 2 is presented the distribution of renforced components and resin for a sample reinforced with carbon fibers fabric without discontinuities in the reinforcement distribution.

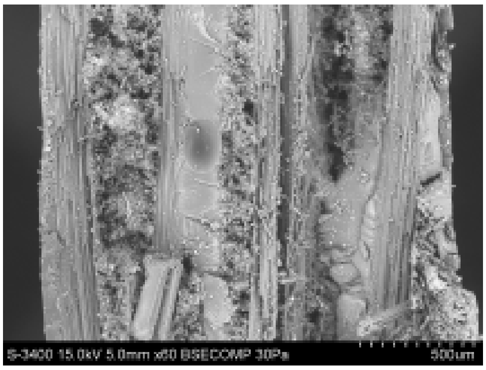

Fig. 2.

In figure 3 are shown, by comparison, the characteristic curves for three representative samples, reinforced with carbon fibers fabric: a sample of set without discontinuities, a sample of set with a discontinuous layer and a sample of set with two discontinuous layers.

In figure 4 are shown, by comparison, the characteristic curves for three representative samples, reinforced with carbon-kevlar fibers fabric: a sample of set without discontinuities, a sample of set with a discontinuous layer and a sample of set with two discontinuous layers.

In table 1 are shown the values of elasticity modulus, tensile strength, elongation at break and the uniformity coefficient for composites reinforced with carbon fibers fabric. Values shown are the medium values for samples in each set.

In table 2 are shown the values of elasticity modulus, tensile strength, elongation at break and the uniformity coefficient for composites reinforced with carbon-kevlar

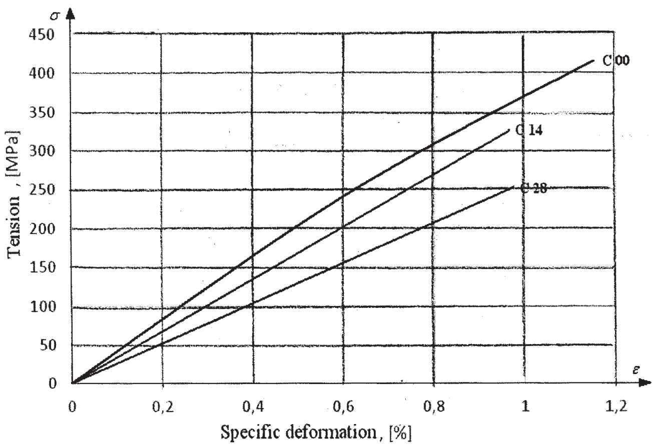

Fig. 3.

Table 1

set of samples	elasticity modulus (MPa)	tensile strength (MPa)	elongation at break (%)	uniformity coefficient
C00	35832	415	1.16	0.832
C10	35261	321	0.91	0.656
C12	34532	318	0.93	0.662
C14	33075	324	0.97	0.704
C16	32640	323	0.99	0.711
C18	32097	331	1.03	0.741
C20	35945	249	0.69	0.494
C22	32540	243	0.75	0.536
C24	29785	240	0.81	0.577
C26	28076	254	0.90	0.650
C28	26440	256	0.98	0.701

fibers fabric. Values shown are the medium values for samples in each set.

Results and discussions

Generally the properties of the composite materials depend on the constituents properties, by proportion and their spatial arrangement. Analysis of experimental results shows that the ratio between the discontinuity length of layers and the sample length subject to the tensile test has a special importance on mechanical behaviour of laminated composites with layers discontinued. This ratio will be denoted by β. The studied mechanical characteristics, namely the elasticity modulus, tensile strength and elongation at break are influenced as follows:

a) elongation at break increases with β increases;

b) tensile strength is not practically influenced by the values of the parameter β; for composites reinforced with carbon fibers fabric, the average of tensile strength for samples with a discontinued layer is 323.4 MPa, i.e. 78% from tensile strength of samples without discontinuities, and for samples with two discontinued layers the average of the tensile strength is 248.4 MPa, namely 60% from the tensile strength of samples without discontinuities; for composites reinforced with carbon-kevlar fibers fabric, the average of tensile strength for samples with a discontinued layer is 244.2 MPa, i.e. 79% from tensile strength of samples without discontinuities, and for samples with two discontinued layers the average of the tensile strength is 210.2 MPa, namely 61% from the tensile strength of samples without discontinuities; this indicates that the tensile strength decreases with increase of the number of discontinued layers and it is proportional to the number of layers which remaining intact (4 layers out of 5, for samples with one discontinued layer or 3 layers out of 5, for samples with two discontinued layers);

c) elasticity modulus decreases while β increases.

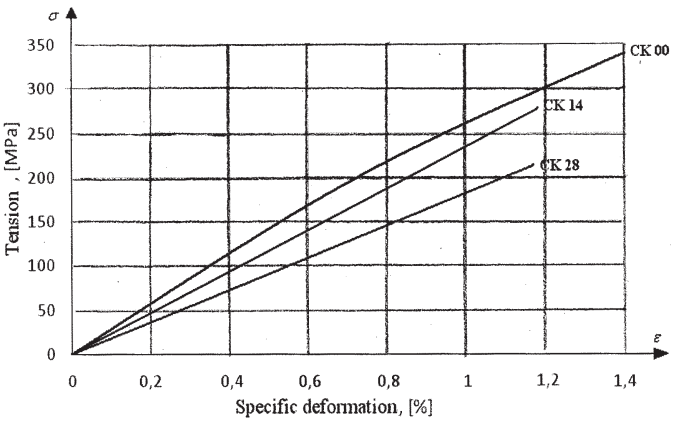

Fig. 4.

Table 2

set of samples	elasticity modulus (MPa)	tensile strength (MPa)	elongation at break (%)	uniformity coefficient
CK00	24576	345	1.40	0,803
CK10	24880	281	1.10	0,631
CK12	23922	268	1.13	0.639
CK14	23424	276	1.18	0.672
CK16	22228	267	1.23	0.684
CK18	21133	279	1.32	0.752
CK20	24202	208	0.85	0.492
CK22	22411	204	0.91	0.518
CK24	20896	211	1.01	0.575
CK26	19469	218	1.13	0.647
CK28	18025	210	1.17	0.664

In figure 5 are shown the theoretical variations of elasticity modulus according to β, for samples reinforced with carbon fibers fabric, which have a layer or two layers discontinued.

Comparatively are presented the experimental results for 5 values of parameter β, (β=0; β=0.125; β=0.375; β=0.5). In figure 6 are shown the theoretical variations of elasticity modulus according to β, for samples reinforced with carbon-kevlar fibers fabric, with one and respectively two discontinued layers. In addition, are presented the experimental results for the same 5 values of parameter β. It is observed that for β=0, the elasticity modulus, both for samples with a discontinued layer, but also for those with two discontinued layers, coincides practically with elasticity modulus for samples without discontinuity. Increasing the discontinuity length of layers leads to decrease the elasticity modulus, and this decrease is more pronounced for samples with two discontinued layers.

Conclusions

Material defects, irregular distribution of reinforcement, the variation in volumetric proportion, have their effect decreased ability of taking over the efforts. Uniformity coefficient is an indicator that evaluates the influence of various factors on the mechanical behaviour of composite materials. The main parameters which influence the uniformity coefficient are the volumetric proportion of reinforcement in zone of minimum resistance, the volumetric proportion of reinforcement in rest of the material, the zone size of minimum resistance and the ratio between the elasticity modulus of fibers and elasticity modulus of matrix.

It can be noticed that values of uniformity coefficient increase together with increasing the value of the parameter β. The lowest values of uniformity coefficient are obtained for β=0, this fact shows that the low values

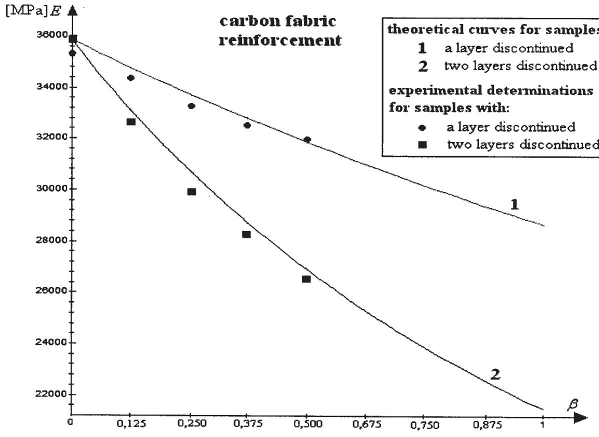

Fig. 5.

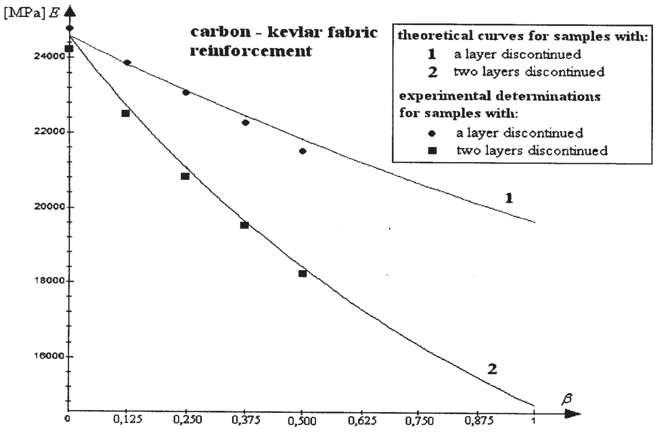

Fig. 6.

of uniformity coefficient indicating the presence of some concentrated defects.

In addition, it is observed that the elongation at break is proportional to the uniformity coefficient, and their ratio does not depend on the number of discontinued layers. This fact can be explained by composites behaviour, which is practically linear until the fracture.

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