



Structure-Related Non-uniformities in Composite Bars Made of Hybrid Dammar-Based Resin and Reinforced with Natural Fiber Fabrics

Alexandru Bolcu^(✉) , Sabin Rizescu , and Nicolae Dumitru

Department of Applied Mechanics and Civil Engineering, University of Craiova,
165 Calea Bucuresti, 200620 Craiova, Romania
{alexandru.bolcu,sabin.rizescu,nicolae.dumitru}@edu.ucv.ro

Abstract. The paper presents the factors characterizing the non-uniformities that might occur during the technological process of making composite materials. These factors were analyzed in cases of two types of composite materials made of hybrid Dammar-base resin and reinforced with hemp and linen fabric, respectively. Multilayer composite-made specimens with one or more interrupted layers of 2 cm or 4 cm were built. In the aftermath of a certain tensile stress applied on each and every composite material specimen, the elasticity factor, the strength factor and the uniformity factor (even factor) were experimentally found out.

Keywords: bio-composite materials · non-uniformities · natural fiber

1 Preliminaries

The physical and mechanical properties of composite materials depend on many factors, the most important of which are:

- the physical and mechanical properties of the constituents;
- the volume ratio of each constituent;
- the spatial arrangement of the constituents;
- the adhesion between whatever two of the constituents on the separating surfaces between them;
- length of fibers used;
- the technological process of obtaining the composite material (pressures, temperatures, filler materials);

In addition to these factors, the mechanical behavior of composite materials is influenced by environmental factors (humidity, temperature, radiation, chemicals), the mechanical loads to which they are subjected (type of load, loading time variation, loading speed, load direction, time duration of the load).

An important issue concerning the mechanical properties of composite materials consists in the non-uniformities that might occur during the manufacturing process. In the case of fiber-reinforced composites, the uneven distribution of fibers in the matrix is the main factor influencing their mechanical behavior. Resin transfer, structural reactions, interface effects are phenomena to be considered when assessing the degree of non-uniformity (uneven degree). Due to the uneven distribution of the fibers, one may often experience some experimental discrepancies regarding the physical properties of the studied specimens.

The main methods to analyze the dynamic behavior of non-uniform composites are presented in [1–3]. In these studies, the elastic constants and density are assumed as being functions of the volume ratio of the fibers, while the distribution of fibers is given as a polynomial function. In [4] are studied non-uniformities occurring in composite bars reinforced with fiberglass fabric and a coefficient is introduced in order to assess the non-uniformities in composite bars having two parts, each of it having its own reinforce volume ratio. In [5] are studied non-uniformities occurring in composite bars reinforced with carbon fabric and with combined fabric of carbon and kevlar, respectively.

Of real interest is that non-uniformities and discontinuities may be used to obtain composite materials with controlled properties. The control of properties can be done by selecting the component materials and orienting the fibers in individual layers, as well as by modifying the sequence of layers in the laminate. In [6] the properties of composite materials are controlled by using so-called “mosaic” type composites. In these composites, each layer consists of several parts, each part having its own orientation, length and distribution of fibers. In [7] it was shown that using such elements into regular and intertwining assemblies, led to the possibility to produce composites with breaking strength of up to 90% of that of composites with continuous reinforcement, although simply joining such layers may decrease the breaking strength by 50%. Composite materials with improved damage tolerance have been made and that because a phenomenon of slowing down the cracking speed does occur. This phenomenon is related to reducing cohesion between the neighboring elements.

2 Theoretical Approach

In the specific case of a multilayer composite, if the breaking strength of a layer is reached, then it will break and a first damage to the bar will occur. After the break of the first layer, the efforts are taken over by the other layers, producing and the stresses change their values in all the layers. Thus, two breaking scenarios are to be considered. A first scenario involves reaching the breaking stress in other layers too, followed by a cascade breaking, causing the bar to break without an increase in the force that causes the stress. The second scenario assumes that, after redistributing the stresses in the layers, the breaking stress is not reached in any of the remaining layers. In this case the force causing the stress may increase, leading to an increase in stresses until the breaking strength is reached in one of the remaining layers, the breaking phenomenon being repeated. The breaking stress of the bar, noted σ_r , is considered to be the average stress in the section of the bar starting from the moment the cascade breaking starts occurring so the bar is led to destruction.

Concerning bars with different non-uniformities caused by defections occurring during the technological process of making the bar, the following factors characterizing the quality are defined [8]:

- the elasticity factor

$$f_E = \frac{E}{E_{ideal}}$$

where E is the elasticity modulus of the material of which the studied specimen is made of and E_{ideal} is the elasticity modulus of the material assumed as ideal, without non-uniformities.

- the strength factor

$$f_\sigma = \frac{\sigma_r}{\sigma_{r_{ideal}}}$$

where σ_r is the breaking stress of the material the studied specimen is made of and $\sigma_{r_{ideal}}$ is the breaking stress of the material assumed as ideal so that without non-uniformities.

- the uniformity factor (even factor)

$$f_u = \frac{f_\sigma}{f_E}$$

These three factors provide information on the properties of the material the studied specimen is made of. These properties are compared with the properties of the reference material that is assumed as ideal. Values close to “1” for these three factors indicate that the studied material has properties being very close to those of the reference material. The decrease in the values of these three factors indicates the presence of manufacturing defects or the fact that the studied material is different from the reference material. A situation when the strength factor and the elasticity factor have subunit and very close values might occur. In this case the uniformity factor gets close to the value “1”. This indicates that the studied material is homogeneous and is different from the reference material, being in fact another material and not the reference material with defects. In the specific case of composite materials, a situation like this one may indicate that the studied material has different proportions of reinforce and resin, respectively, than those of the reference material.

3 Experiments

A first group, containing sets of hybrid resin test specimens having 75% natural Dammar resin and 25% epoxy resin and reinforced with hemp fabric having a specific mass of 350g/m², was realized. For the reference set, the specimens are made of 5 continuous

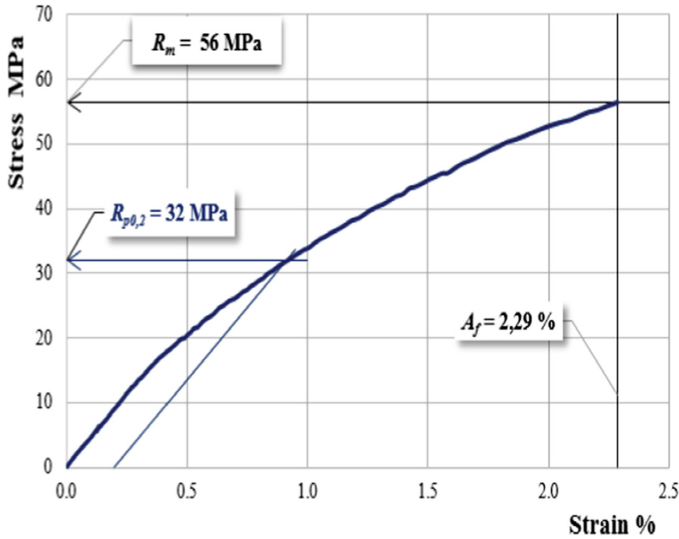


Fig. 1. The strain-stress curve for a hemp fabric reinforced specimen from the reference set 0-0

fabric layers. Concerning the other sets of specimens, one or two layers were interrupted, the lengths of the interruptions being zero, two and four centimeters, respectively. The reference set was marked 0-0, and the other sets were graded 1-0, 1-2, 1-4, 2-0, 2-2, 2-4, the first digit indicating the number of interrupted layers relative to the reference set, and the second digit indicates the length in centimeters of the interruptions.

The mechanical properties of hemp fiber are [9, 10]:

- density 1.4–1.5 g/cm³
- elasticity modulus 30–60 Gpa
- breaking stress 310–750 MPa
- elongation at break 2–4%.

The test pieces (specimens) were subjected to a tensile test. The LLOYD Instruments Lrx PLU mechanical test machine with a maximum force of 2.5 kN and a maximum cross member stroke of 1400 mm was used [11]. The tensile test was performed according to the provisions of SR EN ISO 6892-1: 2010. In order to compare the quality factors for the previously mentioned composite materials, in all tensile tests, the test pieces (specimens) were loaded on a length of 12 cm.

Figure 1 shows the strain-stress (characteristic) curve for a representative specimen from reference set 0-0 of hemp-reinforced specimens.

Figure 2 shows the strain-stress (characteristic) curve for a specimen from set 2-4 of the hemp fabric reinforced specimens.

The experimental results and quality factors for these composites are given in Table 1.

The second group contains sets of specimens made of hybrid resin with 75% Dammar and 25% epoxy resin, reinforced with linen fabric having a specific mass of 160 g/m². The

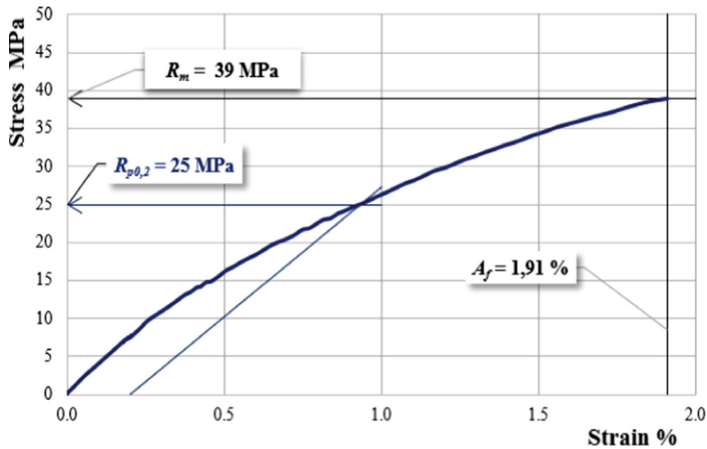


Fig. 2. The strain-stress curve for a hemp fabric reinforced specimen from the set 2-4

Table 1. Experimental results and quality factors for composite materials made of 75% Dammar and 25% epoxy resin and hemp fabric reinforced.

Specimen mark	Elasticity modulus (MPa)	Breaking stress (MPa)	Breaking strain (%)	Elasticity factor	Strength factor	Uniformity factor
0-0	4569	56	2.4	1	1	1
1-0	4497	47	1.9	0.984	0.839	0.852
1-2	4284	48	2,0	0.937	0.857	0.914
1-4	4090	47	2.2	0.895	0.839	0.937
2-0	4488	40	1.4	0.982	0.714	0.727
2-2	3973	39	1.7	0.869	0.696	0.801
2-4	3410	39	1.8	0.746	0.696	0.932

reference specimens are reinforced with 10 layers of fabric. In the other sets, two or four layers were interrupted, the interruption lengths being zero, two and four centimeters, respectively. The specimen marking method follows the rules mentioned above.

The mechanical properties of linen fibers are [9, 10]:

- density 1.5 g/cm³
- Elasticity modulus 27–39 Gpa
- Breaking stress 345–800 MPa
- Elongation at break 2.7–3.2%

Figure 3 shows the strain-stress (characteristic) curve for a specimen from the 0-0 reference set of linen-reinforced specimens.

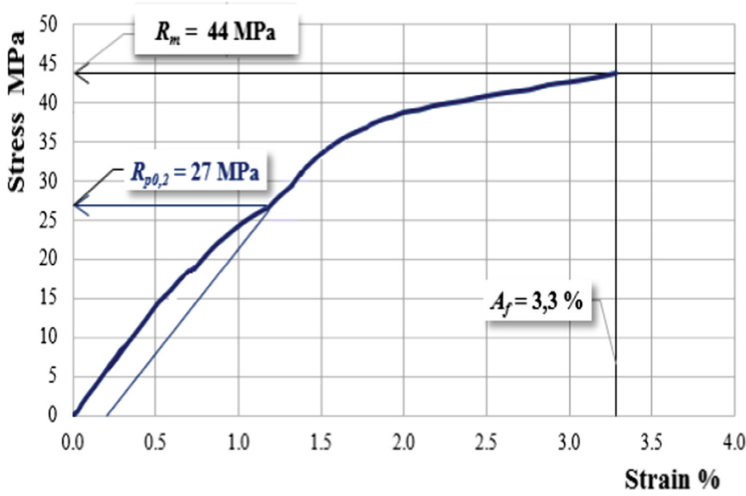


Fig. 3. The strain-stress curve for a linen fabric reinforced specimen from the reference set 0-0

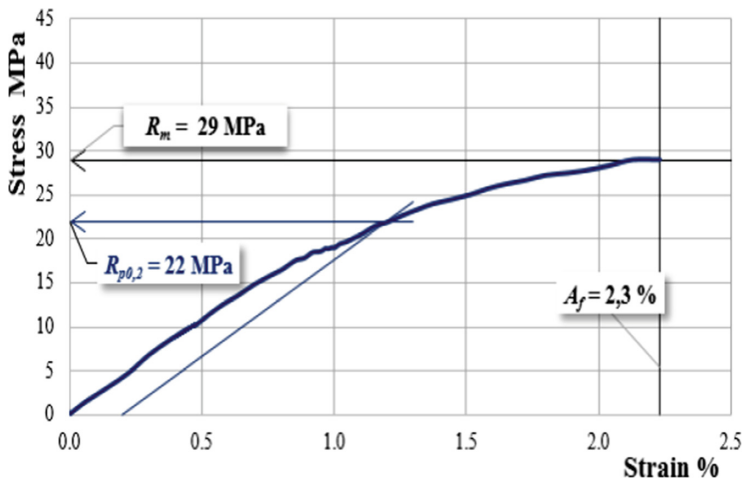


Fig. 4. The strain-stress curve for a linen fabric reinforced specimen from the set 4-4

Figure 4 shows the strain-stress (characteristic) curve for a specimen from set 4-4 of the linen fabric reinforced specimens.

The experimental results and quality factors for these composites are given in Table 2.

Table 2. Experimental results and quality factors for composite materials made of 75% Dammar and 25% epoxy resin and linen fabric reinforced.

Specimen mark	Elasticity modulus (MPa)	Breaking stress (MPa)	Breaking strain (%)	Elasticity factor	Strength factor	Uniformity factor
0-0	2875	44	3.3	1	1	1
2-0	2708	35	2.5	0.942	0.795	0.843
2-2	2624	35	3.0	0.912	0.795	0.871
2-4	2483	35	3.2	0.863	0.795	0.921
4-0	2670	31	2.1	0.928	0.704	0.758
4-2	2352	32	2.4	0.818	0.727	0.888
4-4	2197	30	2.4	0.764	0.681	0.891

4 Conclusions

For composite materials made of epoxy resin reinforced with hemp fabric or linen fabric, it comes out that the breaking strength and elasticity modulus decrease greatly as the number of interrupted layers and the length of the interruption increase. The experimentally obtained values are significantly lower than the theoretical ones. An explanation for this phenomenon may consists in the fact that in the interruption zones, where the amount of resin is higher and the amount of fiber is lower, the matrix hardening reaction, which also has a thermal manifestation, causes a deterioration of the fibers, with the decrease their resilience.

The following conclusions can be drawn from the analysis of Tables 1 and 2.

- the elasticity factor decreases as the number of interrupted layers increases;
- the elasticity factor decreases as the interruption length of the layers increases;
- the resistance factor decreases as the number of interrupted layers increases;
- the strength factor is not influenced by the interruption length of the layers;
- the uniformity factor decreases as the number of interrupted layers increases;
- the uniformity factor increases as the interruption length of the layers increases.

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