5th International Conference
″Advanced Composite Materials Engineering ″
COMAT 2014
16-17 October 2014, Braşov, Romania

ASPECTS CONCERNING TO THE MECHANICAL PROPERTIES OF THE GLASS / FLAX / EPOXY COMPOSITE MATERIAL

Camelia Cerbu
Transilvania University of Brasov, Brasov, ROMANIA, cerbu@unitbv.ro

Abstract: *The first of all, the paper focus on the aspects concerning to the structure of the hybrid composite tested, the stacking sequence of the layers reinforced either with glass fabric or with flax fabric. The mechanical behaviour of the glass / flax / epoxy composite material was analyzed by using tensile test and flexural test (bending). The work describes the mechanical tests and the equipment used. After the statistical processing of the experimental data recorded on both weft and warp directions in case of all specimens tested, the average values of the following properties are computed: Young's modulus E in tensile test, tensile normal stress at failure, tensile normal strain at failure, Young's modulus in bending, flexural normal stress at failure, strain energy both tensile test, and bending. Finally, the results are compared with the ones corresponding to a similar composite material that contains the same number of layers reinforced only with flax fabric.*
Keywords: *composite, flax fibres, tensile test, flexural test*

1. INTRODUCTION

Nowadays there is an increasing interest for using of the natural fibers (flax, hemp, jute) to reinforce the composite materials. Natural fibers represents a renewable source, they provide lower weight to the new composites and usually are used to reinforce the insulation panels. Composite panels reinforced with natural fibers (flax, hemp, jute) are often used as sound insulation panels.
Therefore, statistics show that the using of plant fibres (non-wood and non-cotton) inreinforced plastics has tripled over the last decade.
The applications natural fiber-reinforced composite materials include: non-structural automotive interior components(such as door and instrumental panels); roof panels, insulation wall panels, beams in construction; boat hulls, tennis rackets, canoes (sports and leisure); packaging boxes, chairs, tables, helmets (furniture and consumer goods).
The major disadvantages of the natural fibers are concerning to the hydrophobic. In addition, fire behavior is not good because of large counterbore smoke.
Many applications of the composite materials reinforced with flax fibers refer to the randomly reinforcing with random discontinuous fibers. But recent published works [3] focused on the composite materials reinforced with flax continuous yarn forming biaxial weft-knitted structure.
The recently published results [3] revealed that although the NaOH treatment of the flax reinforcement improves the mechanical properties of the composites reinforced with such a fibers.
Another work [4] also showed that the matrix modification led to the better mechanical properties than fibre surface modification. Matrix modification refers to the chemical treatments with maleic anhydride, vinyltrimethoxy silane, maleic anhydride-polypropylene copolymer in order to improve the interfacial bonding between fibre and polymeric matrix.
A recent paper [5] has tried to answer to the following question: can flax replace E-glass in structural composites? In this purpose, the authors had investigated two variants of the 3.5m composite rotor blades (suitable for an 11 kW turbine): one made of flax/polyester and the other one built of E-glass/polyester. It could be remarked that: the flax/polyester blade is 10% lighter than the E-glass/polyester blade; the both versions satisfy the design and structural integrity requirements for an 11 kW turbine, under normal operation, according to the certification standards; larger tip deflection of the flax/polyester blade than in case of E-glass/polyester blade for the blade design involved; the two variants failed in different manners.

In the present work it proposes a hybrid solution of composite material with both flax and glass fabric. This hybride composite should combine the advantages of the both flax fibers and glass fibers.

2. MATERIALS AND TEST METHOD

2.1. **Materials**

In this investigation, two kinds of woven fabrics are used to reinforce a hybrid polymer composite material: flax woven fabric whose density is equal to $\rho = 280\, g/m^2$: glass woven fabric whose density is equal to $\rho = 200\, g/m^2$. The hybrid composite material contained four plies reinforced with flax woven fabric and four plies reinforced with glass woven fabric. The epoxy resin was used as matrix of the composite material. The weight of the fiber content was equal to 40%. It is known that different kinds of flax yarns were used on weft and warp directions to manufacture the flax woven fabric. Contrary, glass yarns are not different on both weft and warp directions in case of the glass woven fabric.

a) b)

Figure 1: Specimens cut on the weft direction of the flax woven fabric:
a) tensile specimen; b) specimens for flexural test

The first, it was made a laminated composite board by using hand lay-up technology. The conditioning time for the plate was two weeks at room temperature. The thickness of the composite board was equal to 5 mm.
Then, the plates made were cut to obtain: specimens for tensile test (Figure 1, a) according to [7]; rectangular specimens for bending (Figure 1, b) whose dimensions were 15x100 mm^2 according to [8].
The number of the specimens prepared for each test is shown in the Table 2. It may be remarked that two sets of specimens were manufactured in case of each mechanical test: a set of specimens whose length is parallel to the weft direction of the flax fabric while the other one set contains specimens whose length is parallel with the warp direction. This consideration was made taking into account that the flax yarns used for weft and warp directions are different according with the technical sheet of the flax woven fabric.

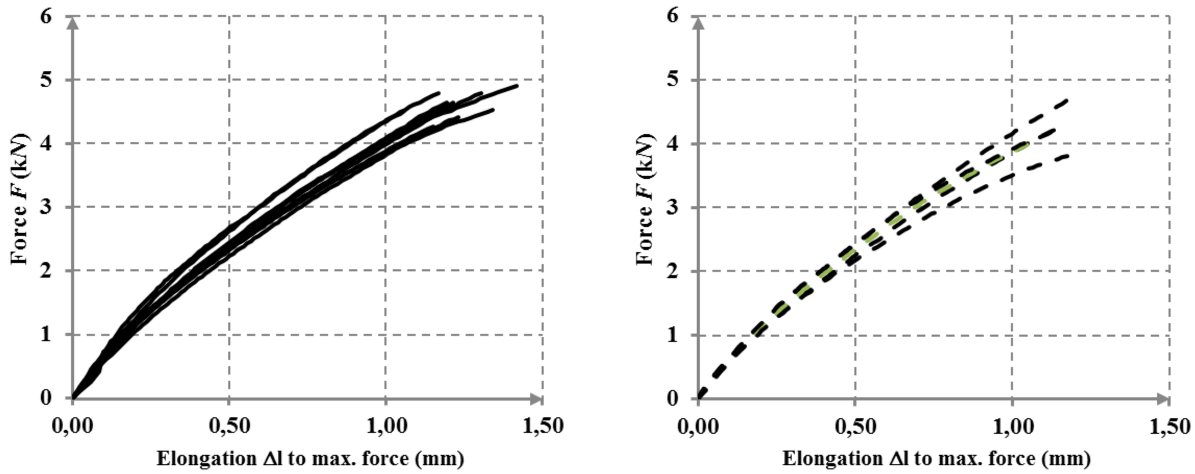
2.2. Test method

The testing equipment used for both tensile test and flexural test consists of hydraulic power supply. The maximum force capacity is ±15 kN. The speed of loading was equal to 1 mm/min or 1.5 mm/min during the tensile test or during the flexural, respectively. The method of the three points was used for testing in bending (flexural test).
Before each mechanical test of a specimen, the dimensions of the cross-section were accurately measured and then, they were considered as input data in the software program of the machine.
The testing equipment allowed us to record pairs of values in form of text files having 200-300 lines: tensile force F and extension of the specimen; bending force F and deflection v at midpoint of the flexural specimen. The experimental data were statistically processed in order to determine the mechanical properties. The modulus of elasticity E in tensile test and bending test was determinate on the linear portion of the loading curve. Therefore, the average values of the following quantities could be accuracy computed for tensile test: Young's modulus E in tensile test; maximum tensile stress $\sigma_{\max}$; elongation Δl to the maximum force $F_{\max}$; normal strain ε to the maximum force $F_{\max}$; mechanical work W done until the maximum force $F_{\max}$.

The average values determinate in bending test are the following: Young's modulus E in flexural test; flexural rigidity EI_z ; maximum bending stress $\sigma_{\max}$ at maximum load; mechanical work W done until the maximum force $F_{\max}$.

3. RESULTS

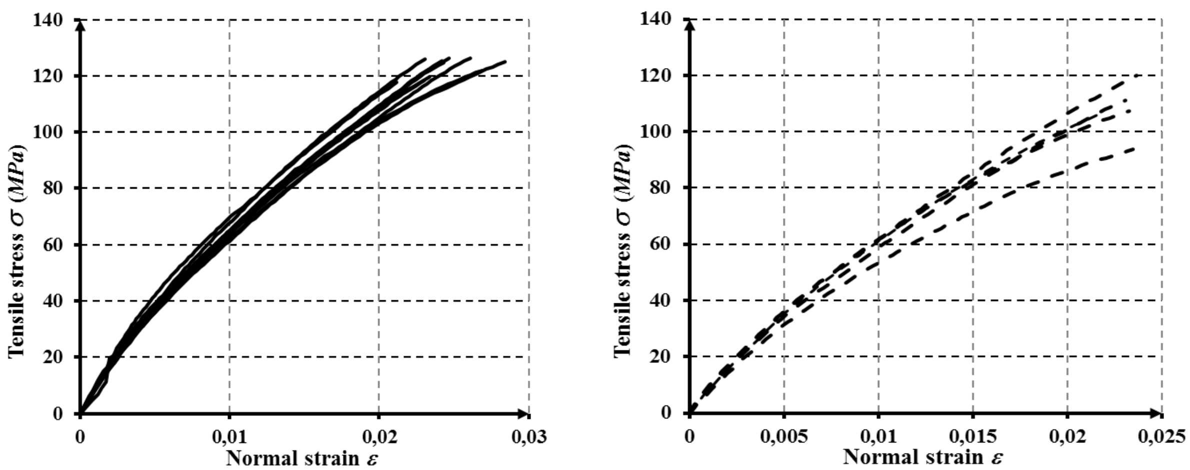
The force – elongation $(F - \Delta l)$ curves recorded in tensile test are shown in case of the both cases: the axial force is parallel to the weft direction of the flax fabric (Figure 2, a); the axial force is parallel to the warp direction of the flax fabric (Figure 2, b). Analyzing these figures we may observe that the maximum values of the tensile force are a little greater when the applied force is parallel to the weft direction of the flax fabric that the other one case of tensile loading.



a) b)

Figure 2: Force – elongation $(F - \Delta l)$ curves: a) weft direction; b) warp direction.

The stress-strain $(\sigma - \varepsilon)$ curves determinate in tensile test are also shown in the Figure 3, where normal stress σ is the ratio between the axial force F and the area of the cross-section while the normal strain is the ratio between the elongation Δl and the initial length of the specimen.
It may be remarked that the specimens are stronger on the weft direction of the flax fabric.



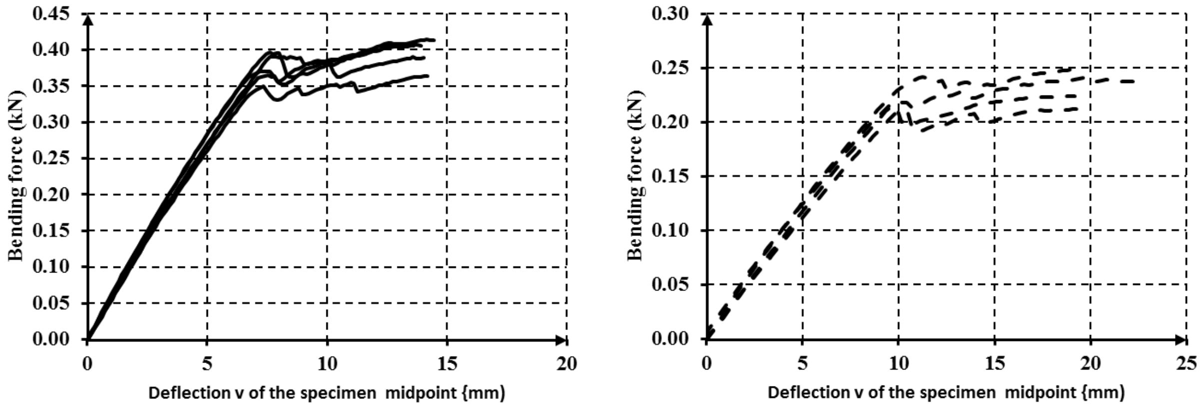
a) b)

Figure 3: Stress - strain $(\sigma - \varepsilon)$ curves: a) weft direction; b) warp direction

The $\sigma - \varepsilon$ curve recorded in case of each tensile specimen was used in order to determine the modulus of elasticity E. Approximation of the experimental data was made by linear regression which means approximation by a linear function. So that the approximation to be considered "the best", sum of squares of the distances from each point to the curve that approximates the data, must be minimal. This is known as squares regression method. In fact, the slope of the line that approximates the linear portion of the $\sigma - \varepsilon$ curve is the *Young*'s modulus E corresponding of the tested specimen. This procedure is repeated for each tensile specimen. After statistically processing of the experimental data recorded in tensile test, the average values of the mechanical properties are summarized in the Table 1.

Table 1: The average values of the mechanical characteristics measured in the tensile test

Direction of the axial force with respect to the flax fabric	F_{max} **(kN)**	**Elongation** Δl **la** F_{max} **(mm)**	**Strain** ε **to** F_{max}	**Max. tensile stress** σ_{max} **(MPa)**	**Young's modulus *E* in tensile test (MPa)**	**Work to maximum load (N.mm)**
Warp direction	4.104	1.141	0.0229	104.69	7261.58	2727.88
Weft direction	4.607	1.221	0.0244	122.83	7936.45	2894.77



a) b)

Figure 4: Force - deflection $(F - \mathrm{v})$ curves: (a) weft direction; (b) warp direction

Figure 5 shows the force – deflection $(F - \mathrm{v})$ curves recorded in bending test. The quantity v represents the vertical deflection of the cross-section located at the midpoint between the two simple supports in case of the bending test by using the method of the three points. It may be remarked again that the maximum bending force F recorded is greater in case of the specimens whose length is parallel to the weft direction. The modulus of elasticity E in bending was determinate taking into account the experimental data located on the linear portion of $F - \mathrm{v}$ curve. In this case, the linear portion was considered up to $v = 4\,mm$.

Table 2 summarizes the average values of the mechanical characteristics determinate in bending test.

Table 2: The average values of the mechanical characteristics measured in the flexural test

Direction of the length of specimen	**Max. Load** F_{max} **(kN)**	**Maximum bending stress** σ_{max} **(MPa)**	**Young's modulus *E* in bending (MPa)**	**Work to break (Nmm)**
Warp direction	231.65	144.18	5322.45	3489
Weft direction	454.86	194.08	5046.92	4354

4. CONCLUSION

Analyzing the results presented in the previous section it may observe that all mechanical properties corresponding to the weft direction of the flax fabric reinforcement are a little greater than the ones recorded on the warp direction. More exactly, for example, the average value of the *Young*'s modulus *E* recorded in tensile test is greater with 9.29% on the weft direction (7936.45 *MPa*) than the one recorded on the warp direction (7261.58 *MPa*). The maxim value σ_{max} of the normal tensile stress is greater with 17,32% on the weft direction (122.83 *MPa*) than the value corresponding to the warp direction (104.69 *MPa*).

In case of the bending test, the maximum value $\sigma_{max\,b}$ of the flexural stress is also greater with 34.61% in case of the weft direction (194.08 *MPa*) than in case of the warp direction (144.18 *MPa*).

On the contrary, the average value of the *Young*'s modulus is lower with 5.46% on the weft direction (5046.92*MPa*) than the value recorded on warp direction (5322.45 *MPa*). Flexural modulus values recorded in the two directions differ very little indeed. Explanation might be that the flax reinforcement layers are core layers.

The results were compared with the ones obtained in case of a composite material made of eight layers (the same number of layers) of flax woven fabric [6]. The flax woven fabric used as reinforcement was the same like in the hybrid composite material involved in this work. It has been noted an increasing of all mechanical properties corresponding to the both direction. For example, the mechanical properties corresponding to the weft direction of the woven fabric in case of the composite material reinforced only with flax fibers were: 5870.64 MPa for *Young*'s modulus *E* recorded in tensile test; 68.29 MPa for maxim value $\sigma_{\max}$ of the normal tensile stress; 101.57 MPa for maximum value $\sigma_{\max b}$ of the flexural stress.

Therefore, it could be remarked that the mechanical properties corresponding to the weft direction of the flax fabric increase: with 35.19% in case of the *Young*'s modulus *E* recorded in tensile test; with 79.86% in case of the maxim value $\sigma_{\max}$ of the normal tensile stress; with 91.08% in case of the maximum value $\sigma_{\max b}$ of the flexural stress.

Taking into account the applications of such a composite material, the results shown within the present paper are useful in the modeling of the mechanical behavior of such a hybrid composite material reinforced with both glass and flax woven fabric. The paper shows different values of the mechanical characteristics depending on the direction of flax fabric – weft direction or warp direction of the flax woven fabric.

Moreover, the behavior of the material is elastic-plastic. So, the stress-strain $(\sigma-\varepsilon)$ curves recorded on the both directions (weft and warp), in tensile test are required to define the material on the plastic domain.

REFERENCES

[1] Shahzad A., Hemp fiber and its composites – a review. J Compos Mater, 2012;46(8), p.973–986.

[2] Carus M. Bio-composites: technologies, applications and markets. In: 4th International conference on sustainable materials, polymers and composites. Birmingham, UK; 6–7 July 2011.

[3] Daoshun Xuea, Hong Hu, Mechanical properties of biaxial weft-knitted flax composites, Materials & Design, Volume 46, 2013, p. 264–269.

[4] Arbelaiz A., Fernández B., Cantero G., Llano-Ponte R., Valea A., Mondragon I., Mechanical properties of flax fibre/polypropylene composites. Influence of fibre/matrix modification and glass fibre hybridization, Composites Part A: Applied Science and Manufacturing, Volume 36, Issue 12, 2005, p. 1637–1644.

[5] Shah Darshil U., Schubel Peter J., Clifford Mike J., Can flax replace E-glass in structural composites? A small wind turbine blade case study, Composites: Part B, 52 2013, p.172–181.

[6] Camelia Cerbu, Mechanical characterization of the flax / epoxy composite material, in Proceeding of the 8th International Conference Interdisciplinarity in Engineering, INTER-ENG 2014, 9-10 October 2014, Tirgu-Mures, Romania.

[7] SR EN ISO 527-4 /2000. Plastics - Détermination of tensiie properties - Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites.

[8] SR EN ISO 14125 /2000. Fibre-reinforced plastic composites – Determination of flexural properties.