Researches upon composite materials for prosthetic and orthetic devices

A. STANCIU, D. COTOROS, M. BARITZ*
University Transylvania of Brasov, Romania

The paper presents the researches upon some composite materials created for orthopaedic use in order to meet the requirements related to cost and mechanical properties. Several experimental approaches are presented for the new created material made of a combination of MAT and Roving, in order to determine the mechanical properties. The tests were performed for different orientations of the Roving fabric (warp and warp).

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1. Introduction

Composite materials represent a combination of materials that are joined in order to obtain materials with new, enhanced properties required by a certain type of application.

The benefits of using composite materials are not only connected to their superior properties in comparison to the component materials but also to the manufacturing technology, as they work with high efficiency and minimum production costs.

Fig. 1. Examples of prostheses.

The research priorities in the field of materials refer to diminishing energy consumption in the manufacturing processes, minimizing the impact upon the environment, creating the necessary materials for an increasingly developed population. In this context, designing materials with low cost and simple technologies, with minimum toxic wastes represents a priority.

Prosthetic devices and orthosis are meant to replace defficient parts of the human organism or to support their function (fig.1). Usually they are made of polymers (polyesters, silicons, polymetilacrylates, polyethylene) and composite materials (carbon-carbon, polymers reinforced by carbon or glass fibers). Fibers based upon carbon-carbon, epoxy-carbon, biodegradable polymers are playing an important part in designing prostheses for tendons and ligaments.

Medicine uses more and more composite materials, both in the intervention medical kit and in prosthetics. Orthopaedics uses mostly polysulphuric graphite, polypropylene, epoxidic glass, all with a good biologic adaptability.

The goal of our research was to create a material that fulfils both the conditions related to cost and the ones concerning the mechanical properties required for a prosthetic device.

2. Theoretical and experimental approach

The researches for different structures of layered composite materials reinforced with glass fibers were directed upon the study of the fibers orientation effect and the position of lamina on the mechanical characteristics of these materials, for various types of loading combinations. Also, studies were performed upon their behaviour during bending, traction, etc., determination of stiffness, elastic modulus and other mechanical properties.

The designed material consists of various numbers of layers made of two types of materials, conventionally named MAT and Roving, with complementary properties.

MAT with short fibers is the most used reinfrorcing material and consists of a layer made of fibers having the length somewhere between 3,2 and 50 mm random oriented and connected by means of a light binder. The quality of such material is expressed by the ratio between weight and surface unit, the values of this ratio being between 300 and 750 g/m^2. (see Fig. 2)

Continuous roving is a collection of parallel fibers or filaments joined together without an intended weaving action (see Fig. 3). It is used for reinforcing structures where we require high resistance along the fibers direction and especially in the filament wraping process that can be used for long structures (prosthesis for arm, leg).

In order to be able to perform the tests for identifying mechanical properties of the new created material we manufactured samples made of several layers of MAT and Roving in various combinations and subjected them to different loads. Then comparisons were made between the theoretical results obtained by finite element method and the experimental results

The combination consists of layers made of MAT and Roving type materials and is shown in Fig. 4.

Fig. 2. MAT sample.

Fig. 3. Roving sample.

Fig. 4. MAT-Roving sample.

The test sample was made of 8 layers of MAT and Roving (warp fabric) and provided the following maximum specific deformation: theoretically determined by FEM between *-0.020* and *0.021*, while the experimental determination gave values between *-0.02* and *0.02.*

We performed a study concerning the material behaviour on each layer applying both the theoretical method based on FEM using MSC Nastran and experimental by help of Spider 8 equipment (as shown in Fig. 5) that determins the material displacements. The test sample was subjected to pure bending, using the equipment in fig.6, for the MAT-Roving material made of 8 layers, the test force was 1000N. The representation of the test sample is shown in Fig. 7, while the specific deformation distribution is presented in Fig. 8.

Fig. 5. Spider 8 equipment.

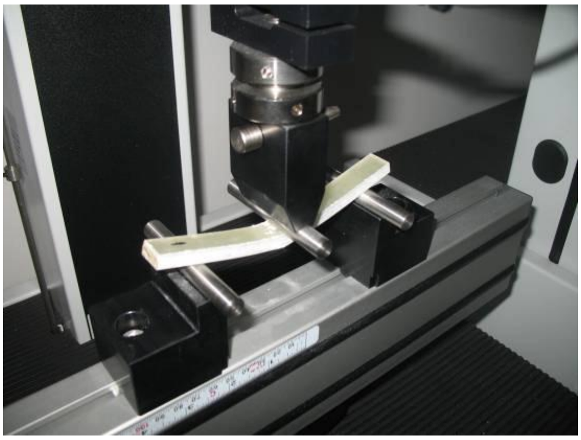

Fig. 6. Bending machine at work.

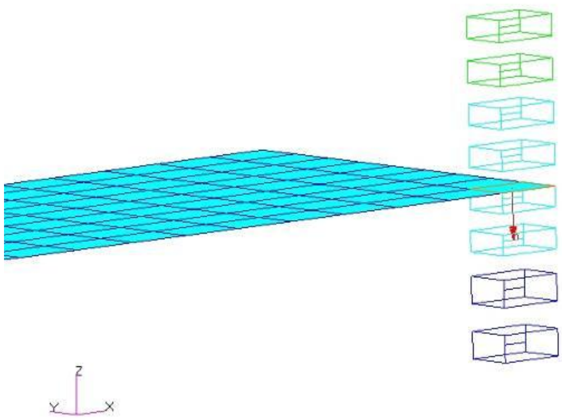

Fig. 7. Test sample MAT450-RT800 (warp)- MAT600.

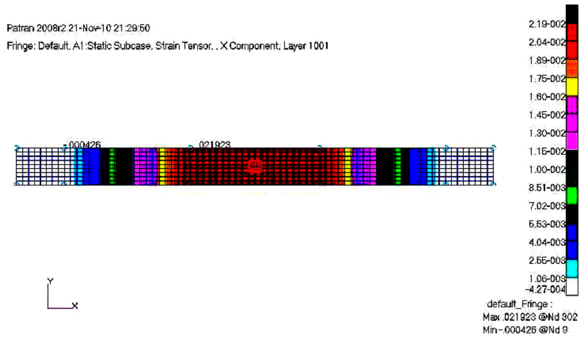

Fig. 8. Specific deformation distribution of the test sample MAT450-RT800 warp - MAT600.

Table 1. Values of specific deformations for test sample MAT450-RT800 warp- MAT600, theoretical and experimental approach.

Tetsing area	Test sample thickness mm	Distance to the test sample neutral axis mm	Specific deformation by strain gauges (TER) (ε)	Distance to the neutral axis by FEM, mm	Specific deformation by FEM (ε)
f1	6.88	6.88	0.022	5.90	0.023
TER 1	4.92	4.92	0.017	3.84	0.021
TER 2	2.86	2.86	0.009	2.01	0.014
TER 3	1.26	1.26	0.004	1.19	0.008
TER 4	-0.34	-0.34	-0.001	0.41	0.003
TER 5	-1.94	-1.94	-0.005	-1.19	-0.002
TER 6	-3.54	-3.54	-0.010	-2.79	-0.007
TER 7	-5.21	-5.21	-0.015	-4.43	-0.014
f2	-6.88	-6.88	-0.022	-6.10	-0.020

We notice that for the test samples made of MAT – Roving combinations the values of the deformations are smaller than for the ones made of only one type of material, both due to the material thickness and to the combined properties of the two materials.

In Fig. 9 we presented the diagram of the values obtained for the specific deformation using the theoretical approach by FEM and the experimental results given by the strain gauges (TER). The results are very close, the small differences (those determined theoretical are a little higher) appear due to the differences between the layers' deformation. Anyway, there is a high correlation between theoretical and experimental approach, fact that may encourage the use of a simulation programme.

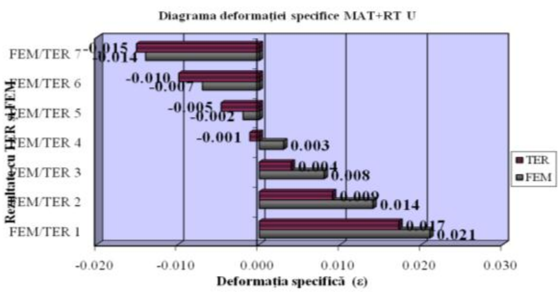

Fig. 9. Representation of specific deformations according to the fiber position at a given time for the test sample MAT450-RT800 warp- MAT600.

In Fig. 10 we represented the force variation with respect to time during our experiment on the bending equipment shown in Fig. 6. We used 12 test samples made of 8 layers of MAT-Roving type of material, polymerized for 24 hours, at 20^{0}C before the experiment.

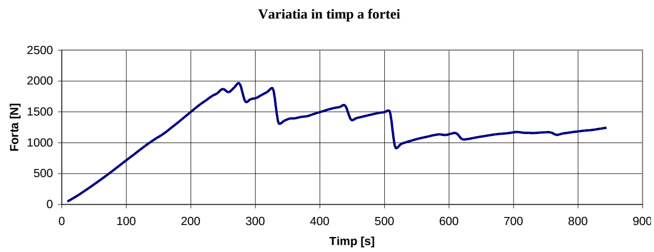

Fig. 10. Force variation with respect to time for test sample made of MAT450-RT800 warp- MAT600.

As mentioned before, the orientation of fibers is playing an important role in ensuring the resistance, elasticity and other mechanical properties of the material. This is why the tests were also performed upon a different orientation of the Roving fibers, this time like weft fabric. The values obtained for the deformations are presented in Table 2, again by comparison to the theoretical method, FEM.

Table 2. Values of specific deformations for the test sample MAT450-RT800 (weft fabric)-MAT600, theoretical and experimental approach.

Testing area	Test sample thickness mm	Distance to the test sample neutral axis mm	Specific deformation by strain gauges (TER) (ε)	Distance to the neutral axis by FEM, mm	Specific deformation by FEM (ε)
f1	0	6.64	0.033	5.93	0.037
TER 1	1.83	4.81	0.020	3.80	0.030
TER 2	3.76	2.88	0.012	2.415	0.020
TER 3	5.39	1.25	0.006	1.615	0.011
TER 4	7.02	-0.38	-0.002	0.39	0.004
TER 5	8.65	-2.01	-0.011	-1.25	-0.006
TER 6	10.28	-3.64	-0.014	-2.88	-0.014
TER 7	11.78	-5.14	-0.018	-4.44	-0.024
f2	13.28	-6.64	-0.033	-5.94	-0.035

The maximum deformation for the test sample made of 8 layers of MAT and Roving (weft fabric) was experimentally determined somewhere between -0.02 and 0.02, while the theoretical approach provides values between -0.035 and 0.020. The values are very similar, the convergence towards the correct solution of the theoretical approach increases with the number of interpolation functions.

The following diagram is presenting the comparison between the specific deformations according to the fiber's position at a given time, determined both by FEM and by help of stran gauges (TER) (Fig. 11).

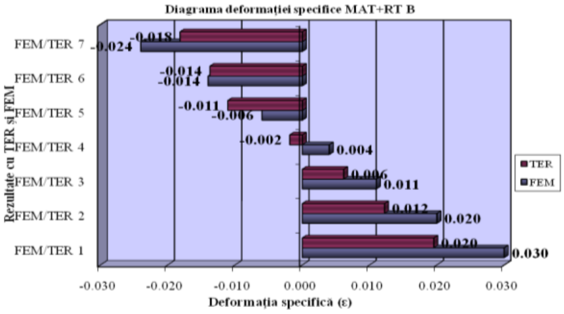

Fig. 11. Representation of specific deformations according to the fiber position at a given time for the test sample MAT450-RT800 weft fabric- MAT600.

The variation of the force during the test is presented in Fig. 12.

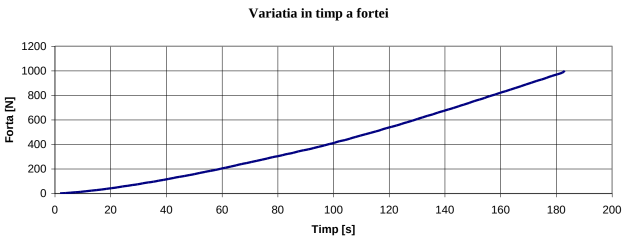

Fig. 12. Force variation with respect to time for test sample made of MAT450-RT800 (weft fabric)- MAT600.

3. Conclusions

Analyzing the experimental results we find that the specific deformation of the material reaches a maximum variation of 1,25 proving a better elasticity of the material than the one consisting of a single element, either MAT or Roving.

Experiments showed that the main properties of the studied composite reinforced materials are compatible to the requirements of orthopaedic prostheses, namely:

- High traction resistance combined with a very low elongation (average of 3,5%)
- Exceptional compression and impact resistance, both along the fibers and perpendicular to the fibers
- High elasticity modulus
- Good temperature resistance and low humidity absorption
- Good dimensional stability and resistance to bad weather conditions

The bidirectional fabrics contribute to the increase of the composite material, with higher values along the parallel direction. If the fibers distribution along the direction of warp or weft is equal, the lamina properties are comparable along these directions, not necessary equal.

In case of bending, the programme made statistical determinations, indicating average values for the main mechanical characteristics of the tested material. The results are presented in Table 3.

Table 3. Average values of the bending mechanical characteristics.

Mechanical properties for bending of MAT-Roving	Average values for MAT-Roving
Stiffness, *N/m*	69111
Elasticity modulus, *MPa*	3815,9
Bending rigidity, *Nm²*	1,9164
Tension at maximum load, *MPa*	211,10
Specific deformation at maximum load	0,066354
Specific deformation of the test sample from the initial values to the maximum one	40,620
Mechanical work performed from the initial value to the maximum one, *Nmm*	16646
Load at break, *kN*	0,10620
Tension at break, *MPa*	21,384
Specific deformation at break	0,12211
Tension at maximum deformation, *MPa*	2,91

The results strongly depend on the reinforcement materials quantity and also on their orientation; a high reinforcement materials ratio will increase the break resistance and also the elasticity module. This means that according to the required mechanical properties we may change this ratio and adjust the fibers' orientation.

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*Corresponding author: mbaritz@unitbv.ro