Experimental Research Concerning Mechanical Properties of Materials for Biomedical Use

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***Abstract*— The present paper deals with the study of the mechanical properties of some polymeric composite materials that may be used in manufacturing orthopaedic implants. The first part of the paper concerns theoretical aspects related to the studied composite materials. The second part of the paper deals with the experimental setup used for the materials tests, continuing with the obtained experimental results. The paper ends with the conclusions based on the performed studies and researches.**

***Index Terms*— composite materials, implants, compression, bending, mechanical properties.**

I. Introduction

A very important socio-economic issue of this century is the increasing occurrence of osteoporosis. The most severe complication of this disease is represented by the proximal femoral fracture that considerably contributes to the elder people mortality due to already existing diseases and complications after prolonged bed confinement.

The diagnosis and treatment expenses have been growing constantly as a result of new investigation techniques and new implants and instruments used for the internal fixation and joint replacement. One of the most promising possibilities of decreasing these costs is to identify and study new materials that may be used for implants and decide if they correspond both from mechanical and biomechanical point of view.

Our attention is focused on some types of polymeric composite materials whose processing and manufacturing involve reasonable costs, in order to determine the suitability of their mechanical properties.

II. Theoretical Aspects

The polymeric materials are the most representative class of materials used in the current manufacturing of various technical components and consumer goods. A special place is taken by the composite polymeric materials as a distinct and spectacular proposal for new and effective solutions.

Manuscript received March 17, 2010. This work was supported by Grant PNII-IDEI 722 and 744 with CNCSIS Romania.

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Regarding the mechanical tests meant for the study of polymeric composite materials behaviour we may consider a principle similarity with the tests applied on metals. The differences concern only the shape and size of the test specimens or the magnitude of the applied forces.

Most of the conception procedures either simple or sophisticated will be based on data concerning the stiffness and will be connected to the assessment of the deformation or bending limit. As a consequence, the values of Young's modulus are usually required for the principal directions on both planes using perpendicular axes. Young's modulus controls the displacement/ deformation within the material.

For an isotropic material, the connection between the stiffness parameters, Young's modulus (E) and transverse elastic modulus (G) is given by (1).

$$G = E/2(1+ v) \quad (1)$$

the equivalent equation for the elastic modulus on both planes G_{12} being

$$\frac{G_{12}}{G_m} = \frac{(1+\xi\eta V_f)}{(1-\eta V_f)} \quad (2)$$

where

$$\eta = \frac{(G_{12f}/G_m)-1}{(G_{12f}/G_m)+\xi'} \quad (3)$$

and the reinforcement constant ξ' is 1.

This determines different absolute values and also different ratios of the transverse elasticity and tension on both planes.

The bending stiffness denoted R for a sandwich type element consisting of thin layers with identical thickness is the result of the addition of the external layers bending stiffness and the core stiffness about the cross-section axes:

$$R = E_s \cdot \frac{b \cdot t^3}{6} + E_s \cdot \frac{b \cdot t \cdot d^2}{2} + E_c \cdot \frac{b \cdot c^3}{12}, \quad (4)$$

where E_s and E_c represent the Young's modulus of the layers and respectively of the composite core.

If the layers are made of different materials, with different thickness, as the analyzed structure, and assuming that the bending stiffness between the layers can not be neglected, it means that

$$\frac{d}{t} > 5.77 \quad (5)$$

The bending stiffness of the structure can be written as follows:

$$R = \frac{b \cdot d^2 \cdot E_{s1} \cdot E_{s2} \cdot t_1 \cdot t_2}{(E_{s1} \cdot t_1 + E_{s2} \cdot t_2)} + \frac{b}{12} \cdot \left(E_{s1} \cdot t_1^3 + E_{s2} \cdot t_2^3\right) \quad (6)$$

III. EXPERIMENTAL SETUP

The following materials have been used for the analyzed structure:

- MAT 600 - fibreglass composite (short wires) in the matrix of epoxy resin with specific weight 2x600g / m2, 2-2, 6 mm thick;
- RT 800 - fibreglass composite (fabric) in the matrix of epoxy resin with specific weight of 4x 800g / m2, thickness 3,2-3,6 mm;
- MAT 450 - fibreglass composite (short wires) in the matrix of epoxy resin with specific weight 2x450g / m2, 1.6-2mm thick.

The equipment we used is a testing machine with constant compression speed, consisting of a fixed part provided with specimen fixing clamps and a moving part also with fixing clamps, a driving mechanism.

The testing machine type LS100 is manufactured by Lloyd's Instruments, Great Britain and is presented in fig.1.

It presents the following characteristics: Force field: 100kN; speed testing accuracy <0.2%; Force cell: XLC-100K-A1; Analysis software: NEXYGEN MT.

The equipment allows the acquiring of experimental results in electronic form by help of the NEXYGEN Plus software.

Fig. 1 Tensile testing machine

For the three points bending test we used another equipment coming from the same company as the tensile testing machine, that is a LR5K Plus machine (fig. 2) providing a maximum force of F_{max}= 5 kN.

Fig. 2 Three points testing machine

The three points are materialized by two supports and a hemispheric punch. Their alignment should be achieved according to a 0,02 mm accuracy. The radius R_1 of the hemispheric punch and the radii R_2 of the supports should be as follows: R_1= 5,0 mm ± 0,1 mm; R_2 = 2,0 mm ± 0,2 mm for specimen thickness smaller or equal to 3 mm and R_2= 5,0 mm± 0,2 mm for specimen thickness higher than 3 mm.

IV. EXPERIMENTAL RESULTS

Compression testing results

Before specimens testing we measured exactly the dimensions of the cross-section and width; these dimensions are introduced as input data in the testing machine computer, which works with a corresponding software designed to gather the experimental data from the machine and to process them.

The specimens were taken from a plate of 8 mm thickness, with a white gel coat layer. The specimens were polymerized for 24 hours at a 20^0C and are presented in fig.3.

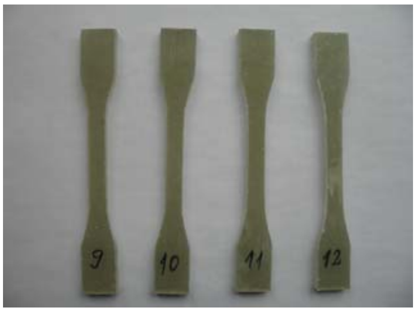

Fig. 3 Specimen examples (9-12) before testing

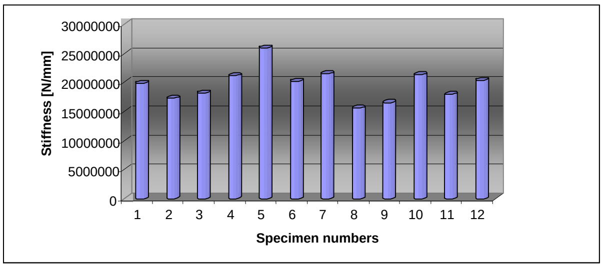

Fig. 4 Stiffness distribution for compression testing

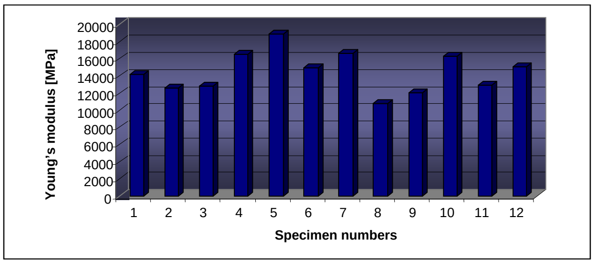

Fig. 5 Young's modulus diagram

The results for Young's modulus presented in fig.5 are the following: minimum value is 10820 [MPa] and maximum values goes up to 18932 [MPa].

The compression testing is considered to be a significant source of data concerning the polymeric materials mechanical properties and behaviour. This can be shown also by help of the force-displacement diagrams (fig.6) providing information about the material behaviour during gradually bending.

ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

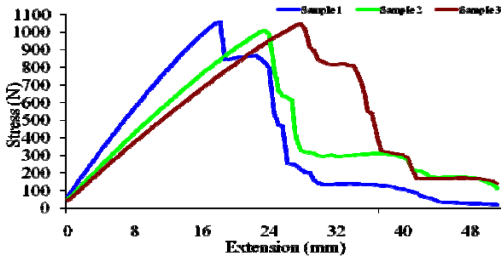

Fig. 6 Force-displacement diagram for specimens 1,2,3

Bending test results

In order to perform bending tests we used specimens manufactured according to the standard requirements.

The specimens (see fig.7) were taken from a 7 mm thickness plate, whose surface was protected with a white gel coat layer. The specimens were polymerized for 24 hours at 20^0C.

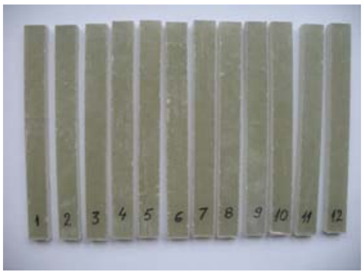

Fig. 7 Specimens prepared for bending tests

In fig.8 we presented the stiffness values for the 12 tested specimens. We notice that the minimum value of the stiffness is 60330 N/m for the specimen no.10, while the maximum value 79870 N/m is met for specimen 7.

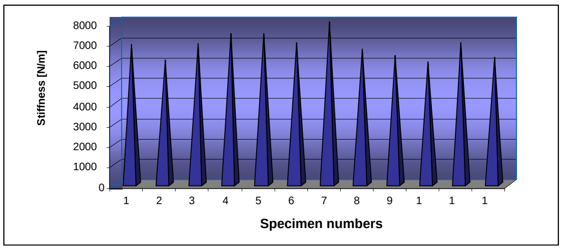

Fig. 8 Stiffness diagram for bending tests

In fig.9, the Young's modulus values for the 12 specimens are shown. We notice that the minimum value is 3440 MPa and the maximum one 4122 MPa.

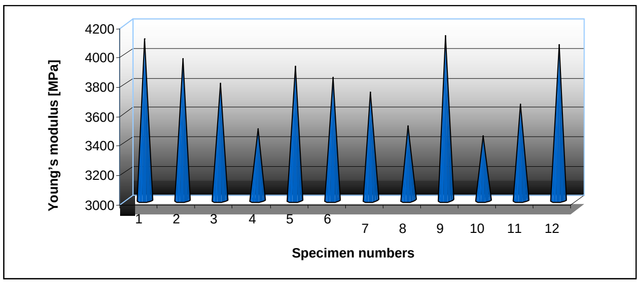

Fig. 9 Young's modulus diagram for bending

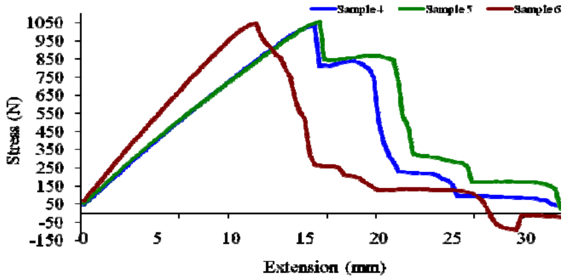

Fig. 10 Force-displacement diagram for specimens 4,5,6 subjected to bending

V. CONCLUSIONS

The purpose of the present paper is to enhance the knowledge concerning the mechanical properties of some polymeric composite materials that might be used in the manufacturing of orthopaedic implants.

Based on the performed experiments meant to determine the behaviour during compression and bending, and especially by analyzing the force-displacement diagrams we find there are differences between the values determined for each specimen, thus:

- for compression, along the axis X the displacement has shown values between 0 – 1,17 [mm], while along the axis Y the force changed between 0 – 15000 [N], the differences being due to the geometric variations of the specimens;
- for bending, along the axis X the displacement was between 0 - 0,65 [mm], while along the axis Y the force presented values like 0 – 1500 [N] due to the geometric differences of the specimens and also due to some structure variations.

As a follow we can say that the tested materials, even for the worst specimens structure, meet by far the mechanical conditions required by an orthopaedic implant but future researches need to establish the biomechanical compatibility in order to be able to accept them as a viable alternative for the more expensive materials.

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ISBN: 978-988-18210-7-2
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)