11th International Research/Expert Conference
”Trends in the Development of Machinery and Associated Technology”
TMT 2007, Hammamet, Tunisia, 05-09 September, 2007.

NOVEL FIBER REINFORCED COMPOSITE MATERIALS AS CANDIDATES FOR MEDICAL PROSTHESIS

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ABSTRACT

The paper aims to present different combinations of fiber reinforced composite materials embedded in polymeric materials (e.g. epoxy, polyester, etc.) as potential candidates for medical prothesis. The combinations were choosen after extensive survey on biocompatible composite material class with the aim to fulfill few requirements such as: medium/low stiffness, stability in case of environmental parameters changes and external applied loads, etc.

Keywords: fiber, biocomposite, polymer, prosthesis.

1. INTRODUCTION

The development of modern biomaterials is related to the development of modern medicine and new materials. Today, various biomaterials have been developed (polymers, ceramics, composites and metals with improved properties) in order to address applications such as: orthopedics, vascular and heart surgery, etc.

The selection of suitable fibers is determined by the required value of the stiffness and the tensile strength of the composite, as well as their thermal stability, dynamic and long time behavior, and nonetheless their price and processing costs. Biocompatibility criteria must be addressed in case the composite material is being designed to be used in medical applications.

The paper herein is a part of extensive studies and subject of a project with the aim of developing intelligent medical prosthesis. The materials implied in this study were chosen to replace the existing ones used to manufacture external prosthesis mostly because of mechanical properties revealed during the preliminary tests.

In these circumstances were chosen glass fibers with various sizes (fiber distribution and size weren’t a first concern, only its volume fraction) randomly distributed in several polymeric materials, such as epoxy resin, epoxy vinyl ester resin, polyester resin respectively.

The theoretical model developed herein was the first step in the overall design criteria developed to characterize these biomaterials and will be used as references for comparison with their counterpart retrieved on finite element basis modeling.

2. THEORETICAL MODEL. NUMERICAL SIMULATIONS

The elastic properties of a material are a measure of its stiffness. Computation of effective elastic moduli is a very difficult problem in elasticity theory and only a few simple models allow an exact analysis. Among these theoretical models the composite cylinder assemblage (CCA) is one that allows precise elastic moduli evaluation for random distributed fibers of different sizes.

In case the fibers are considered isotropic the following applies:

- *Young modulus along the fibers’ direction*

$$E_L = E_m + \left(E_f - E_m\right)\cdot V_f + \frac{4\cdot\left(\nu_f - \nu_m\right)^2\cdot V_f\cdot\left(1-V_f\right)}{\frac{1-V_f}{K_f}+\frac{V_f}{K_m}+\frac{1}{G_m}} \cong E_m + \left(E_f - E_m\right)\cdot V_f \tag{1}$$

- *Young modulus transversal to the fibers*

$$E_T = \frac{E_m}{1-\left(1-\frac{E_m}{E_f}\right)\cdot\sqrt{V_f}} \tag{2}$$

- *Shear modulus along the fibers' direction*

$$G_L = G_m + \frac{V_f}{\frac{1}{G_f - G_m}+\frac{1-V_f}{2\cdot G_m}} \tag{3}$$

- *Bulk modulus*

$$K = K_m + \frac{V_f}{\frac{1}{K_f - K_m}+\frac{1-V_f}{K_m + G_m}} \tag{4}$$

- *Poisson ratio*

$$\nu = \nu_m + \left(\nu_f - \nu_m\right)\cdot V_f + \frac{\left(\nu_f - \nu_m\right)\cdot\left(\frac{1}{K_m}-\frac{1}{K_f}\right)\cdot\left(1-V_f\right)\cdot V_f}{\frac{1-V_f}{K_f}+\frac{V_f}{K_m}+\frac{1}{G_m}} \tag{5}$$

The shear modulus transverse to the fibers comply the following quadratic expression:

$$a\cdot\left(\frac{G_T}{G_m}\right)^2 + 2\cdot b\cdot\frac{G_T}{G_m} + c = 0 \tag{6}$$

where a, b and c are being expressed function of the fiber volume fraction:

$$\begin{aligned}
a &= 3\cdot V_f\cdot\left(1-V_f\right)^2\cdot(\gamma-1)\cdot\left(\gamma+\chi_f\right)+\\
&+\left[\gamma\cdot\chi_m+\chi_m\cdot\chi_f-\left(\gamma\cdot\chi_m-\chi_f\right)\cdot V_f^3\right]\cdot\left[V_f\cdot\chi_m\cdot(\gamma-1)-(\gamma\cdot\chi_m+1)\right]\\
b &= -3\cdot V_f\cdot\left(1-V_f\right)^2\cdot(\gamma-1)\cdot\left(\gamma+\chi_f\right)+\\
&+\frac{1}{2}\cdot\left[\gamma\cdot\chi_m+(\gamma-1)\cdot V_f+1\right]\cdot\left[(\chi_m-1)\cdot\left(\gamma+\chi_f\right)-2\cdot\left(\gamma\cdot\chi_m-\chi_f\right)\cdot V_f^3\right]+\\
&+\frac{V_f}{2}\cdot(\chi_m+1)\cdot(\gamma-1)\cdot\left[\gamma+\chi_f+\left(\gamma\cdot\chi_m-\chi_f\right)\cdot V_f^3\right],\\
c &= 3\cdot V_f\cdot\left(1-V_f\right)^2\cdot(\gamma-1)\cdot\left(\gamma+\chi_f\right)+\left[\gamma\cdot\chi_m+(\gamma-1)\cdot V_f+1\right]\cdot\left[\gamma+\chi_f+\left(\gamma\cdot\chi_m-\chi_f\right)\cdot V_f^3\right]
\end{aligned} \tag{7}$$

and

$$\begin{aligned}
\gamma &= \frac{G_f}{G_m},\\
\chi_m &= 3-4\cdot\nu_m,\\
\chi_f &= 3-4\cdot\nu_f.
\end{aligned} \tag{8}$$

In the previous the indices stand for: f – fiber, m – matrix, L – longitudinal, T – transversal, E – Young modulus, G - shear modulus, K – bulk modulus, ν – Poisson ratio, etc.

In figures 1 to 6 are being plotted the elastic coefficients vs. fibers volume fraction of the different polymeric composite materials chosen as candidates for external intelligent prosthesis, embedded with random dispersed isotropic glass fibers whereas in figures 7 and 8 are being plotted the Young modulus and shear modulus for comparison in opposite with carbon fibers embedded in same polymeric matrix materials.

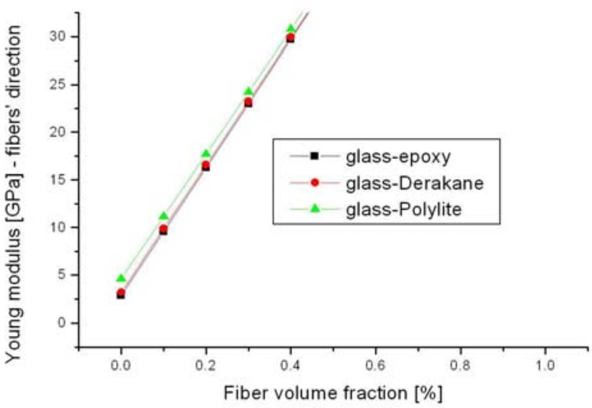

Figure 1. Young modulus – longitudinal direction

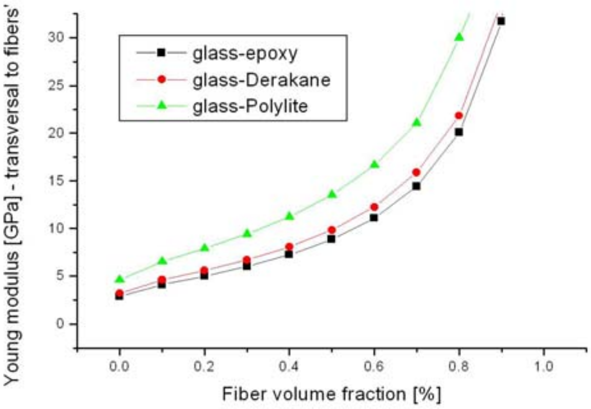

Figure 2. Young modulus – transversal direction

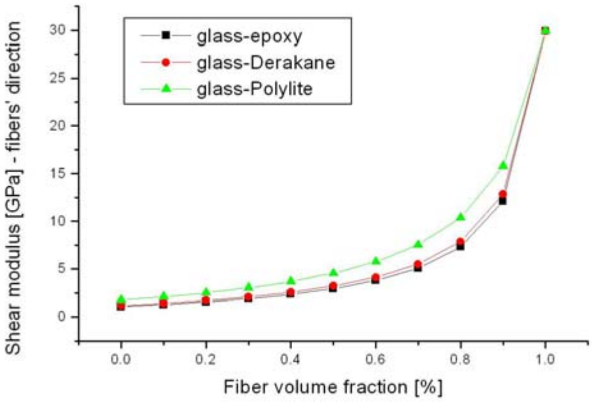

Figure 3. Shear modulus – longitudinal direction

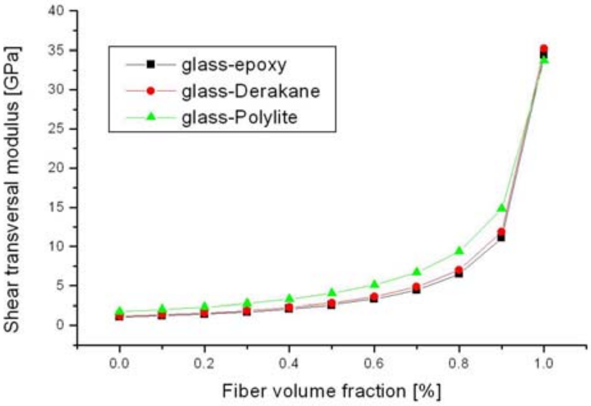

Figure 4. Shear modulus – transversal direction

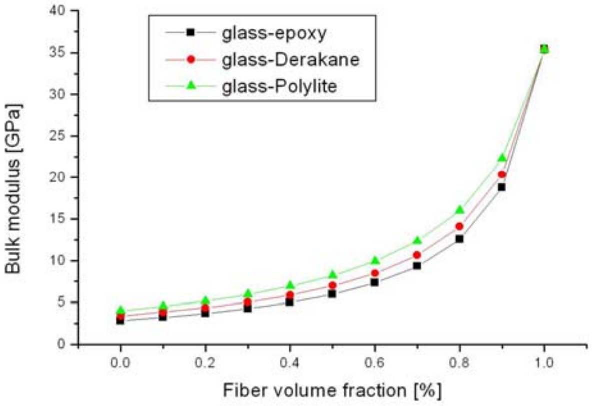

Figure 5. Bulk modulus vs. fiber volume fraction

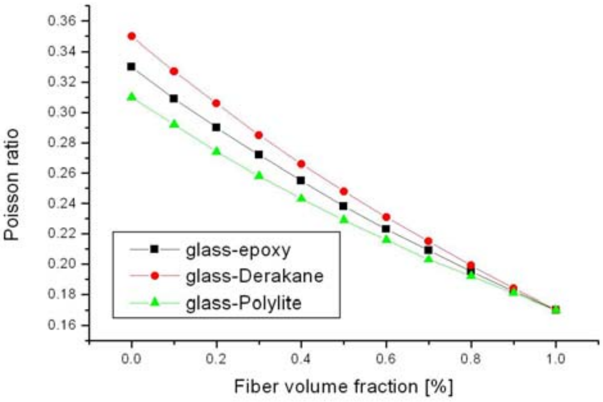

Figure 6. Poisson ratio vs. fiber volume fraction

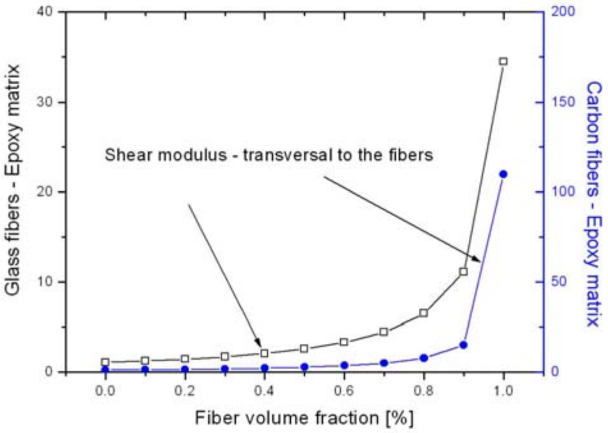

Figure 7. Shear modulus – comparison – different fiber materials

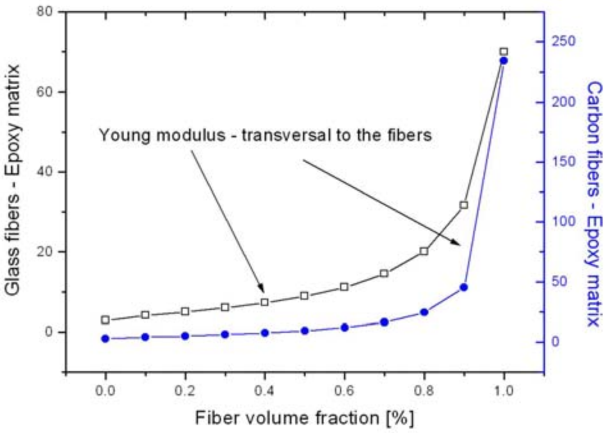

Figure 8. Young modulus – comparison – different fiber materials

3. DISCUSSION. CONCLUSIONS

As can be seen from the previous plots, the matrix material does not influence greatly the elastic moduli variation with respect to the fiber volume fraction. The polymeric materials used in this case helps fibers bonding and in what extent rise the overall flexibility of the composite can be proved only by further mechanical testing.

With respect of fiber materials to be used, there are differences on magnitude of elastic coefficients in proportion of 1:3 between the glass and carbon fibers, respectively. Glass fibers structures shown to be flexible than the carbon fibers ones, that make them the perfect candidate for external prosthesis and especially for protective/recovering aids in case of chest injuries, for example, not mentioning their costs that are lower than those for the carbon fibers.

4. REFERENCES

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