AN EXPERIMENTAL STUDY ON MECHANICAL OF A COMPOSITE MATERIAL FOR ORTHOPEDIC USE

M. Boulkra,1,2* K. Bey,3 S. Boudif,4 S. Boukhezar, L. Alimi, M. Hassani, N. Sassane, A. Azzi, Y. Yakelef, N. Hamzaoui, N. Boughdir, N. Bouadila, N. Touati, H. Griza, M. Hassani, N. Sassane, A. Azzzi, Y. Yakelef, N. Hamzaoui, N. Boughdir, N. Bouadila, N. Touati, H. Griza

1 Research Center in Industrial Technologies CRTI, P.O Box 64 16014 Cheraga, Algiers, Algeria.
2 Advanced Systems and Materials Laboratory (LASMA); physics department; BADJI Mokhtar-Annaba University, B.P. 12, El-Hadjar, Annaba 23000 - Algeria.
3 Laboratory of Industrial Mechanics (LMI), Faculty of Engineering Sciences BADJI Mokhtar-Annaba University, B.P. 12, El-Hadjar, Annaba 23000 - Algeria.
4 Department of Production, National Office of Apparatus and Accessories for the Disabled (ONAAPH), Annaba Unit, Algeria.

m.boulkra@crti.dz, boulkramohamed@hotmail.fr

ABSTRACT

This study consists in the mechanical characterization of a composite material used in the fabrication of orthopedic prostheses by ONAAPH (Annaba - Algeria). The studied composite is the result of a combination of a polymethyl methacrylate (PMMA) resin, fiberglass reinforcements and an absorbent of the resin, namely Perlon.

The method adopted for obtaining specimens is the same as that used in the manufacture of prostheses, except that the shape of the mold used in our study is rectangular, allowing to obtain composite plates. The three-point bending tests were carried out on a MTS43 universal machine in the Advanced Materials Research Unit (URMA / CRTI, Annaba / Algeria). The identification of the damage mechanisms according to the mechanical loading conditions as well as the degradation of the constitutive elements, will be discussed.

Keywords: Composite, mechanical tests, mechanical behavior, finite elements.

INTRODUCTION

The development of composite materials is born from the desire to combine the technical qualities with the need for relief in the same material, which must then adapt to the technological solutions of the problems to be solved.

A composite material results from the combination of two different materials by their shape as well as by their mechanical or chemical properties in an attempt to increase their performance. The two constituents of the composite are the matrix and the reinforcement, which, in combination, give a heterogeneous material often anisotropic, that is to say whose properties differ in the directions [1, 2].

The materials constituting the composite are generally chosen according to the application that one wishes to make thereafter. The selection criteria may be, for example, composite materials formed of several layers of fibers bound by a matrix, which is often a polymeric resin.

PMMA / fiberglass composite materials are widely used in the manufacture of orthopedic prostheses because of their lightness, moderate cost and easy implementation. This prompted researchers to study their mechanical behavior in service to better understand their mechanisms of rupture. The composite material used as a human tibial prosthesis generally consists of fiberglass / Perlon reinforcements impregnated in a methyl methacrylate resin. In order to obtain good performances of this composite, granules of date cores have been incorporated into the resin of the reference material. The materials in this study were prepared in the laboratory by vacuum molding under normal conditions.

This work includes an experimental work in static fiberglass laminate/polymethyl methacrylate PMMA solicited in static 3-point bending. Thus, an observation of the fracture facies of the studied material are carried out.

However, laminates are particularly sensitive to loadings, such as low speed impacts, which can create internal damage that is invisible to the naked eye (delamination, matrix and fiber breakage). Much research has been dedicated to improving the properties of composites.
EXPERIMENTAL

Materials Used and Their Implementation

The composite material studied is intended for the manufacture of orthopedic prostheses of ONAAPH. It is composed of fiberglass; PMMA resin. The most common reinforcements for common applications are fiberglass. They are made from the fusion and extrusion of silica associated with various oxide (alumina, alkaline, alkaline earth).

Table 1. Fiberglass properties

<table>
<thead>
<tr>
<th>Elementary filament diameter (µm)</th>
<th>Density (Kg/m³)</th>
<th>Tensile breaking load (MPa)</th>
<th>Elasticity module (MPa)</th>
<th>Charge of Compression failure (MPa)</th>
<th>Elongation at break (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.54</td>
<td>400</td>
<td>3000</td>
<td>200</td>
<td>0.8</td>
</tr>
</tbody>
</table>

For the purpose of making dumbbells for tensile tests, to complete the tensile mechanical properties of PMMA/glass fiber composite used in the fabrication of housings within ONAAPH. The composite architecture of the plate is the same as that of the socket, namely twice 2 perlon/2 fiberglass/2 perlon.

The development of the plate was carried out in the ONAAPH-Annaba workshop, by the technician responsible. The implementation of modified composite material is obtained from the reference orthopedic composite (Fiberglass + PMMA resin).

The implementation of the composites is carried out by the method of vacuum molding to the bag [3]. Laminates are stacked and impregnated at room temperature and molded between mold (PVC film) and counter mold Figure 1.

![Image 1](image1.png)

**Figure 1.** Plate Development

The parallelepiped test pieces were cut, using a wire saw, from a laminated plate. The dimensions of the specimens are identical to the AFNOR standard NF T 57-105: \( L = 50 \text{ mm} \), \( a = 40 \text{ mm} \), \( l = 15 \text{ mm} \) and \( e = 2.5 \text{ mm} \), where \( L \), \( a \), \( l \) and \( e \) are respectively the length total, the distance between supports, the width and the thickness of the specimen Figure 2.

The adaptation provided is limited to the geometric shape of the mold to allow the obtaining of plates that will be used to cut test pieces.
**Bending test**

The bending tests are performed on a computer-controlled universal MTS type A43 machine equipped with TestSuite software; and equipped with a force sensor of 50 KN at the test shop; characterization and measurement (AECM / URMA / CRTI) [4]; This is connected to an acquisition chain that allows the simultaneous recording of stresses and deformations during bending, force and displacement Figure 3.

![Figure 3. Device of the bending test [4]](image)

The principle of the test is as follows:
1. The cross-sectional dimensions and the length with an accuracy of ± 0.05 mm are measured at mid-length of the test piece.
2. The test piece is placed on the flexion bench so that the load is applied parallel to the rings.
3. The two cylindrical loading heads are brought into contact with the upper face, then the bending load is increased at constant loading speed: 10 mm / min until breaking is reached.

The four tests for each type of material are conducted at a temperature of 23 ° C at a speed equal to 10 mm / min.

**RESULT**

Figure 4 represents the evolution of the stress as a function of the deformation, they show a small fluctuation between the different test pieces, which shows the homogeneity of the elaborated material.
Figure 4. stress-strain in three-point bending of the four specimens.

The inclination of the slopes of the linear part of these curves denotes a slight variation of the modulus of elasticity at bending, this is due to the errors related to the cutting during the preparation of the specimens, and/or to the presence of porosities in the material.

The appearance of matrix cracks before the rupture is at the origin of the nonlinearity of the curves of flexion. The four load-displacement curves of the specimens which have the same appearance show a linear elastic behavior, followed by a nonlinear behavior to lead to a sudden rupture. The inclination of the slopes of the linear part of these curves denotes a slight variation of the modulus of elasticity to traction. This is due to the errors in cutting specimens from the plates and to the presence of porosities in the material. The appearance of matrix cracks before rupture is at the origin of the nonlinearity of the behavior curves.

Observation of facies

After bending tests, and to see the effect of the heterogeneity of the structure of the composite materials is at the origin of the multiplicity of types of degradation, which can be distinguished by their nature and their mode of development figure 5.

The importance of the study of composite damage lies in the identification of these types of degradation in the different levels: Breaks in adhesion between the fibers and the matrix or porosity, cross or longitudinal cracks and fractures of the fibers at the mesoscopic level, finally local separation between two layers that usually starts at the free edges of the structure.

For our study, observations will be made by optical microscope in different stages of the bending test.

Figure 4. Observation by optical microscope of the breaking points

CONCLUDING REMARKS

Composite materials therefore have a wide range of physical characteristics, so their preparation will depend on the desired objective. However, the results obtained from these tests cannot really be interpreted: it
would have been necessary to obtain materials free from defects and better reproducibility between the specimens. The heterogeneity of the structure of composite material due to the presence of defects of which are characterized by the size, the dimensions, the orientation within the volume is noted. These defects are introduced in various ways during the preparation or during the preparation of the specimens. All of these manipulations allowed us to familiarize ourselves with a method of manufacturing composite materials and tests of mechanical bending on specimens. The experimental mechanical behavior curves obtained are linear elastic with different slopes denoting a slight variation of flexural modulus of elasticity of the test pieces tested. A dispersion of the results was observed for the values of the tensile stresses and flexural modulus of elasticity. It is mainly related to the mode of implementation of the laminates, the fiber rate and their arrangement in the structure of materials. Examination of the fracture facies revealed delamination of the folds with rupture of the fibers cracking accompanied by rupture of the matrix.

REFERENCES