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THE EFFECT OF CONSTRUCTIVE PARAMETERS ON TRACTION BEHAVIOR OF LAMINATED HYBRID EPOXI BIOCOMPOSITE REINFORCED WITH GLASS AND CARBON FIBERS USED IN BONE FIXATION IMPLANTS

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Abstract: *In the paper, the notion of biocomposite material or in short biocomposite designates the biomedical composite material that is implantable in living tissue. This family also includes interply hybrid polymeric biocomposite material reinforced with glass and carbon fibers that is used in the bone fracture repair process. Compared to metallic biomaterials, hybrid epoxy biocomposites can have, through the hybridization effect, a number of mechanical properties with acceptable performance of fractured bone prosthesis systems. The paper is aimed at the experimental investigation of the tensile properties of laminated hybrid epoxy biocomposite material reinforced with glass and carbon fibers used in the manufacture of bone plate and external fixation.*

Key words: *laminated hybrid epoxi biocomposites, carbon fibers, glass fibers, bone plate fixation, external fixation, liquid resin infusion (LRI).*

1. INTRODUCTION

Ramakrishna and Huang [1], Ambrosio [2] defines the term biocomposite materials, or biocomposites for short, "all implantable biomedical composites, made of biomaterials, synthetic or natural." In essence, Ambrosio [2] considers biocomposites as biomedical composites intended for use as biomaterials in the construction of implantable medical devices [3], artificial tissues and organs, functional support [4]. Interply hybrid polymeric biocomposite material reinforced with glass and carbon fibers can be included in the family of biocomposites being used in the bone fracture repair process [5], [6], [7].

The tensile strength of interply hybrid epoxy biocomposite reinforced with glass and carbon fibers is influenced by a significant number of factors [9], [10], [8]: the mechanical properties of the glass and carbon foil; sheet / laminate thickness; the architecture or succession of stacking the glass and carbon foil in the laminate; laminar orientation of glass fibers and carbon fibers; the relative volume fractions of the carbon fiber and fiberglass reinforcement systems, respectively; hybrid laminate manufacturing method etc. The mechanism of influence of these factors is complex and, especially in the 1970s and 1980s, [11], [10] a series of studies have been undertaken in this regard, mainly on unidirectional hybrid composites (UD).

Zhang et al. [12] tested on uniaxial tensile strength (ASTM D 3039-76 [13]) five types of composite laminates manufactured by hand lay-up technique and hardened at ambient temperature for 24 hours: a composite laminate with only fiber reinforcement carbon [C] 8; a composite laminate with only fiberglass reinforcement [G] 8; three types of hybrid composite laminates with carbon fiber and fiberglass reinforcement, manufactured in the stacking sequences [CG3] s, [C2G2] s, [CGCG] s. The laminates were made of the following materials: West system epoxy 105 cured with slow hardener 206; Sigmatex™ carbon 2/2 twill weave fabric T300, 3 K Tow, 199 GSM;

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Colan™ E-glass plain weave fabric. Following the uniaxial tensile tests [18] of the laminate test specimens, the authors found the following: composite laminate [C] 8 had the highest tensile strength; composite laminate [G] 8 had the lowest tensile strength; composite laminates with stacking sequences [C2G2] and [CGCG] found similar values to tensile strength (MPa) and Young's modulus for tension (GPa); composite laminates with stacking sequences [CG3] s and [CGCG] s. had similar values to the ultimate tensile strain (%).

Salman et al [14] investigated the influence of the stacking sequence of fiberglass layers (glass mat with a 0 /90 angle) and carbon fiber (carbon mat at -45/45 angle) of epoxy hybrid composite laminate (epoxy resin CIBA-GEIGYY, CY233) on its tensile behavior.

Five types of hybrid laminates were manufactured with the following stacking sequences: Type A (carbon/glass/carbon/glass) – 4 layers of fibers; Type B (carbon/glass/carbon) - 3 layers of fibers; Type C (glass/carbon/glass) – 3 layers of fibers; Type D (carbon/glass/carbon/glass/carbon) – 5 layers of fibers; Type E (glass/carbon/glass/carbon/glass) – 5 layers of fibers. Following specimens on the uniaxial tensile test [15], the authors reported that type D laminates, made of three sheets of carbon fiber and two sheets of fiberglass, provided the best tensile properties.

Pandya et al. [16] analyzed the mechanical behavior at uniaxial tensile [18] of two types of hybrid composite laminates with epoxy resin matrix (Epoxy LY556 with hardener HY951) with carbon fiber (8H satin weave T300 carbon fabrics) and glass fiber (plain weave E-glass fabrics) fabricated by matched die molding. The laminates had two stacking sequences: a. glass sheets on the outside and carbon sheets on the inside respectively – $[G_3C_2]$ s; b. glass sheets on the inside and carbon sheets on the outside respectively $[C_2G_3]$ s. The results of the uniaxial tensile tests [13] showed that in the stacking sequence with the glass sheets on the outside and the carbon sheets on the inside, higher values appear at the final tensile deformation (ultimate tensile strain) and at tensile stress (tensile strength) than the stacking sequence with carbon sheets on the outside and glass sheets on the inside.

Jesthi et al. [17] analyzed the mechanical tensile properties of two groups of hybrid epoxy resin laminates (Diglycidyl ether of Bisphenol A) formed by stacking glass sheets (plain woven E-glass of 360 gsm) and carbon sheets (2 × 2 twill woven roving of bidirectional carbon fiber of 200 gsm) in two types of sequences: $[G_2C_2G]$ s and respectively $[CG_3C]$ s. The two types of hybrid laminates were manufactured by hand lay-up technique. After testing the two groups of uniaxial tensile hybrid laminates [13], at room temperature, the authors found that the hybrid laminate [G2C2G]s has a higher tensile strength (tensile stress) than the hybrid laminate [CG3C] s, a phenomenon explained by the high rigidity of the carbon fibers present in the middle of the hybrid laminate as well as values significantly close to the tensile modulus at both hybrid laminates [G2C2G] s and [CG3C] s respectively.

In this paper, we want to experimentally investigate the tensile properties of carbon / glass reinforced epoxy hybrid composites. Two groups of composite laminates were investigated, consisting of four sheets of carbon fiber fibers and carbon fibers with two stacking sequences, respectively.

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2 MATERIALS AND METHODS

2.1 Materials

The materials used for the manufacture of composite laminates were 200 gsm chopped strand mat fiberglass, 3K of 160 g / m2 plain weave carbon fiber [18] and 1050 / 1059s epoxy resin / hardener resoltech, Castro composites [19], [20]. The 1050 system resin is a liquid opalescent liquid with a viscosity of 429 [mPa·s], density 1.05, at room temperature (23ºC), and can be applied by brushwet, roller, infused or injected. It turns into a solid state after adding the hardener in mixing ratio by weight 100/35 (1 + 0.35) kg. The process of mixing the epoxy resin with the hardener was performed well, obtaining a full homogeneity with mixed density 1.12 [20].

2.2 Fabrication of hybrid composite laminates and test specimens

During the research, two groups of epoxy hybrid composite laminates reinforced with carbon fibers / glass, A and B were prepared with the stacking sequences (Fig. 1): A: [CF; GF; CF; GF; CF] and B:
[CF; CF; GF; CF; CF].

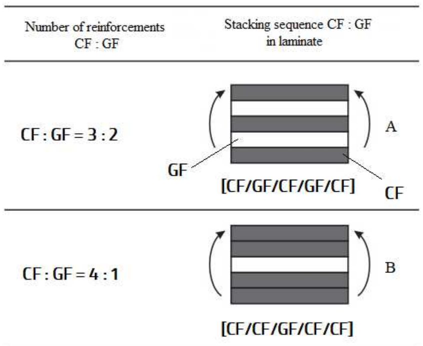
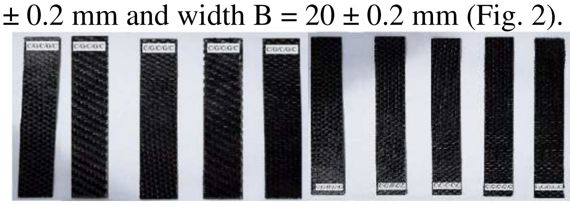


Fig. 1. Stacking sequences for carbon and glass sheets.

The hybrid composite laminates were manufactured in the form of two plates with dimensions 300mm x 250 mm and thicknesses 1.3 ± 0.1 mm (Fig. 3) by the Liquid Resin Infusion technique (LRI) [21].

With a diamond disk, with a diameter of D = 200 mm, a width of B = 3 mm and a speed of n = 2000 rpm, a set of five test specimens was tested from plates A and B for uniaxial tensile testing. According to the ASTM D3039 / D3039M-17 standard [13], the specimens had a rectangular shape and dimensions: Length=150 ± 0.2 mm and width B = 20 ± 0.2 mm (Fig. 2).



a. b.

Fig. 2. *Sets of five composite hybrid laminated test specimens:* a. [CF/GF/CF/GF/CF]; b. [CF/CF/GF/CF/CF].

The cutting operation was performed very carefully and the specimens were prepared for tensile testing.

Tensile testing of the specimens was performed on the universal electromechanical testing machine type ELIB 50 from Ibertest (S.A.E. Ibertest, Madrid, Spain) (Fig. 3).

Prior to the tensile test operation, a series of preparatory activities were performed: a. the test specimen was positioned and aligned accordingly in the two jaws of the test machines bench (Fig.4); b. the test has been equipped and adjusted to the concrete conditions of the application, with a constant working speed of the mobile jaw of 5 mm / min [13]; the temperature of the test chamber at 23ºC was ensured, (Fig. 5). The traction load took place until each test tube broke.

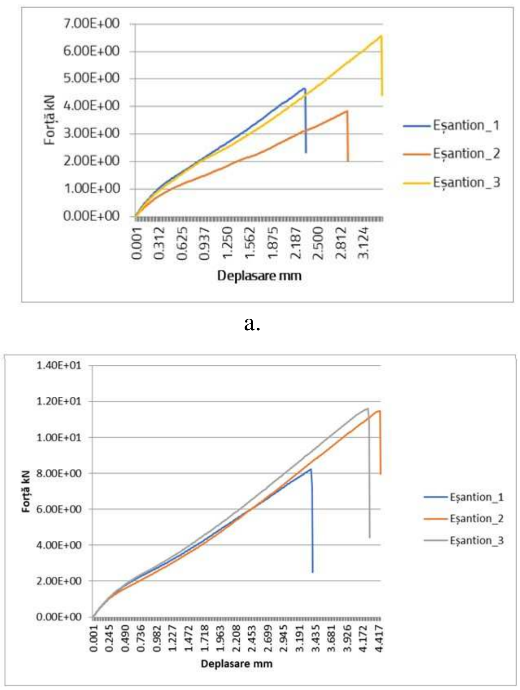
Fig. 3. Universal electromechanical testing machine type ELIB 50.

Fig. 4. Fixing mode of the test piece on the universal electromechanical testing machine type ELIB 50.

Fig. 5. Sample set of specimens [CF / GF / CF / GF / CF] broken after tensile stress.

3 MECHANICAL PROPERTIES EVALUATION

The mechanical properties of interply hybrid polymeric biocomposite material reinforced with glass and carbon fibers, are the result of uniaxial tensile tests, are exemplified (only for the first three specimens) by the cumulative force-displacement diagrams and the parameter values: modulus of elasticity (E), tensile strength (Rm), maximum strength, yield strength (Rp) and elongation at break% (A) (Fig. 6).



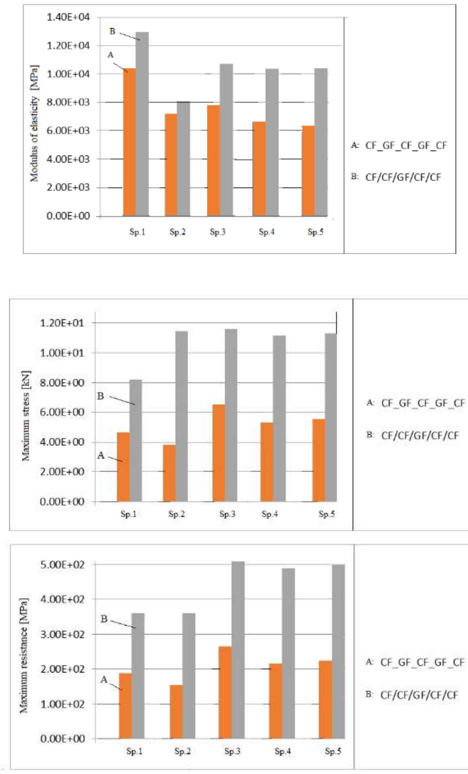
a.

b.

Fig. 6. Tensile diagram for biocomposite epoxy laminates CF:GF (only three samples): a. laminated [CF/GF/CF/GF/CF]: b. laminated [CF; CF; GF; CF; CF].

The diagrams in figure 7 illustrate, in graphical form the values of the parameters: modulus of elasticity (E) (a), maximum stress (b) maximum strength (c) tensile strength (Rm), yield strength (Rp) and elongation at break% (A). The existence of a normal dispersion at each measured parameter is mentioned.

Table 1 shows the average values of the experimentally analyzed parameters.



a.

b.

c.

Fig.7. Values of experimentally analyzed parameters: a. modulus of elasticity; b. maximum stress; c. maximum resistance.

Table 1

Experimentally determined average values.

Experimentally evaluated parameters		**CF / GF hybrid epoxy laminate group (Arithmetic mean of the five tests)**	
		A [CF/GF/CF/GF/CF]	B [CF/CF/GF/CF/ CF]
Parameter name	U.M	Values	
Elongation at break	%	37.716	48.4082
Young`s modulus (E)	MPa	7692.74	10518.48
Maximum resistance	MPa	208.94	444.2
Tensile strength (Rm)	MPa	209.94	472,8
Elasticity limit (Rp)	MPa	39.9	105.78
Maximum stress	kN	5.1864	10.7554

4. CONCLUSION

Following the experimental research on the tensile stress tests of laminated hybrid epoxy biocomposites reinforced with glass and carbon fibers, the following conclusions can be drawn.:

- the manufacture of hybrid composite slats complied with the requirements of the Liquid Resin Infusion technique (LRI). In this sense, the following was performed: proper pickling and drying of the work table surface; rigorous compliance with the dosage of epoxy resin and hardener at the ratio of the resin / epoxy mixture, according to the instructions for use recommended by the manufacturer; proper stacking of carbon fiber and fiberglass fabrics in compliance with flatness; continuous realization of the infusion process of the resin / hardener mixture at a temperature of 23^{o}C and without allowing the formation of gaps in the laminate during the infusion; maintaining the laminate boards manufactured in the recommended time for drying;
- the values of the parameters modulus of elasticity (E), tensile strength (Rm), maximum strength, yield strength (Rp) and elongation at break% (A) had a normal distribution;
- the value variations measured when testing the specimens are mainly due to the pretentious conditions of fixing each specimen in the working tanks of the testing machine;
- by stacking two sheets of carbon on the outside of the laminate and a single sheet of glass fibre on the inside of the hybrid laminate [CF/CF/GF/CF/CF] resulted, compared to stacking [CF/GF/CF/GF/CF] increased values of the parameters modulus of elasticity (E), tensile strength (Rm), maximum strength, yield strength (Rp) and elongation at break% (A). This aspect is determined by the strong adhesion between the carbon sheets as well as by the mechanical properties of the carbon fiber.
- the hybrid composite has high strength and low modulus, close to that of bone as opposed to metallic biomaterials (Tab.2), a particularly important aspect in eliminating stress shielding effect.

Table 2

Values of some mechanical properties of biomaterials [22], [6]

Material	**Modulus** *GPa*	**Tensile strength** *MPa*
Cortical bone (longitudinal direction)	17.7	133
Stainless steel	190	586
Ti-alloy	116	965
Hybrid [CF/GF/CF/GF/CF]	7,62	208,94
Hybrid [CF/CF/GF/CF/CF]	10,51	444,2

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Efectul parametrilor constructive asupra comportamentului la tracțiune a biocompozitului hibrid laminat epoxi armat cu fibre de sticlă și de carbon utilizate la implanturile de fixare osoasă

Rezumat: *In prezentul articol, noțiunea de material biocompozit sau, pe scurt, biocompozit desemnează materialele compozite biomedicale implantabile în țesuturile osoase vii. Această familie include și materialele biocompozite polimerice hibride ranforsate cu fibră de sticlă și carbon care se folosesc în procesul de vindecare a fracturilor osoase. Comparativ cu biomaterialele metalice, biocompozitele epoxidice hibride pot avea, prin efectul de hibridizare, o serie de proprietăți mecanice cu performanțe acceptabile pentru sistemele de protezare a fracturilor osoase. Lucrarea are ca scop investigarea experimentală a proprietăților de tracțiune ale materialului biocompozit epoxidic hibrid laminat, armat cu fibre de sticlă și carbon, utilizat la fabricarea plăcilor externe de fixare osoasă.*

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