The effect of stacking sequence on flexural behavior of laminated hybrid epoxi biocomposite reinforced with glass and carbon fibers used in the bone plate and external fixation

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Abstract. In the field of orthopedic medicine, hybrid biocomposites with epoxy matrix reinforced with carbon fibers and glass fibers are being used. Through the hybridization phenomenon, appropriate properties can be obtained for the use of these biocomposites in the bone plate and external fixation. The paper presents the manufacture of hybrid laminate with epoxy matrix reinforced with carbon fiber and glass fiber, three-point bending test method and the influence of the laminate layering sequence on the bending behavior of composite biomaterial.

1. Introduction

In the biomedical literature, the term biocomposite materials, or biocomposites in short, defines "all implantable biomedical composite materials, made of biomaterials, synthetic or natural" [1], [2]. In this sense, biocomposite materials, found in different types are found in the construction of implantable medical devices [3], [4]. This is especially the case for polymeric biocomposite materials (Fig. 1).

The laminated hybrid epoxy biocomposites reinforced with glass and carbon fibers are non-resorbable composites [1] being composed of biocompatible materials: CF carbon fibers, GF glass fibers and epoxy resins (Fig.1).

The term "hybrid composite" refers to a composite material with a single type of matrix, mainly polymer, in which are mixed, at several structural levels, at least two different types of reinforcement which can be particles, short fibers, continuous or fabrics [5], [6], [7]. Mainly, they are found in the form of interlayer (interply) or laminated hybrid composites; intralayer (intraply) or woven hybrid composites; intrayarn or intermingled hybrid composites [5], [8], [9].

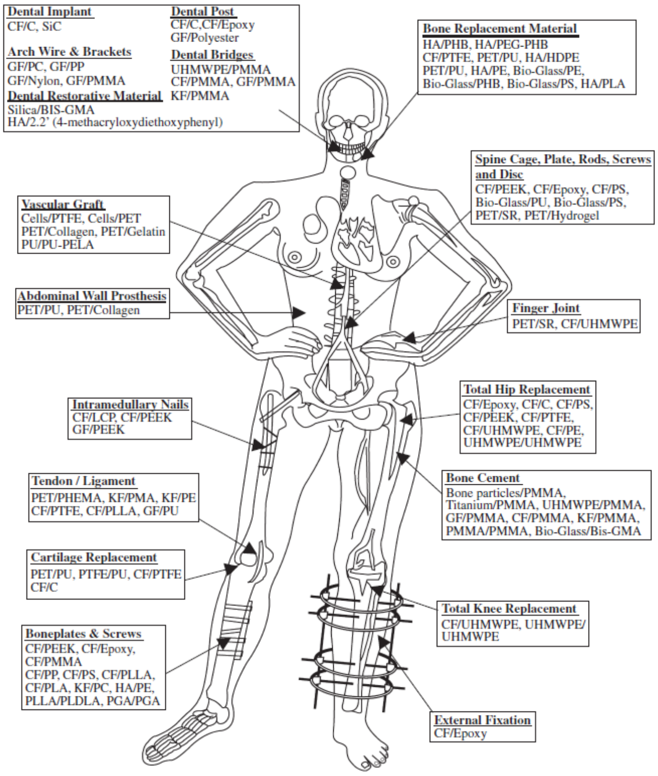
The carbon / glass hybrid epoxy laminated biocomposites can be used in the manufacture of light orthopedic components [7], [8]: orthotics, bone fixation plate and external fixation [12], [10], [11], [1].

The physical and mechanical properties of carbon / glass hybrid epoxy laminated composite bending is influenced by several factors, presented in the literature [9], [13], including the sequence of stacking layers in laminate.

2 Related work

Various authors have researched hybrid epoxy composite materials reinforced with carbon / glass fibers, with different combinations of the layering sequence, regarding the bending behavior.

Saravanan and Vetrivel [14] analyzed the bending behavior, in three points, ASTM D790 [15], of the hybrid composite laminate with epoxy resin (epoxy resin - araldit LY 556; hardener - araldit HY 951) reinforced with carbon fibers (uni -directional carbon fiber 330 GSM) / glass (bi-directional glass fiber 600 GSM) with the following three stacking sequences: 1. [CF90/GF0;90/GF0;90/GF0;90/GF0;90/CF90]; 2. [GF0;90/CF90/CF0/CF0/CF90/GF0;90]; 3. [CF90/GFO;90/CF90/GF0;90/CF 90/GFO;90/CF 90].



CF: Carbon fibers, C: Carbon, GF: Glass fibers, KF: Kevlar fibers, PMMA: Polymethymethacrylate,
PS: Polysulfone, PP: Polypropylene, UHMWPE: Ultra-high-molecular weight polyethylene,
PLDLA: Poly(L-DL-lactide), PLLA: Poly (L-lactic acid), PGA: Polyglycolic acid, PC: Polycarbonate,
PEEK: Polyetheretheketone; HA: Hydroxyapatite, PMA: Polymethylacrylate,
BIS-GMA: bis-phenol A glycidyl methacrylate, PU: Polyurethane, PTFE: polytetrafluoroethylene,
PET: polyethyleneterephthalate, PEA: poltethylacrylate, SR: silicone rubber,
PELA: Block co-polymer of lactic acid and polyethylene glycol, LCP: liquid crystalline polymer,
PHB: Polyhydroxybutyrate, PEG: polyethyleneglycol,
PHEMA: poly(20hydroxyethyl methacrylate)

Fig.1 Various applications of different polymer biocomposite materials, [1]

Following the results of the bending test [15] of the three categories of laminates, the authors found an increase in bending strength with the increase in the ratio of carbon fiber reinforcement in laminate. Dong et al. [16] tested in three points [17] two hybrid laminates A and B with epoxy matrix (Kinetix R240 high performance epoxy resin with H160 hardener at a ratio of 4: 1 by weight), reinforced with fiberglass (S -2 unidirectional glass Unitex plain wave UT-S500 matte fibers) and carbon fibers (Toray T700S 12 K carbon fibers) with stacking sequences: A: [GF / CF / CF / CF / CF] and B: [GF / GF / CF / CF / CF]. They found an increase in the bending modulus with the increase in the percentage of glass fibers in the laminate.

3. Experimental details

3.1 Materials

The materials used for the manufacture of the carbon-glass fiber reinforced epoxy hybrid biocomposite laminate were:

- fibreglass chopped strand mat 200 gsm;
- carbon fibre plain weave 3K of 160 g/m^2 [18];
- epoxy resin/hardener resoltech 1050/1059s, Castro composites [19]. The 1050/1059 system resin has the following properties: a. liquid neutral opalescent with viscosity 429 [MPa.s]; density 1,05, at room temperature (23^{0}C); the mixing ratio by weight 100/35 (1 + 0.35) kg; can be applied by brushwet, roller, infused or injected; optimal homogeneity of the density of the resin / hardener mixture 1.12; mechanical characteristics of the system 1050/1059S la 23^0 C: a. Modulus (GPa) 3,56; maximum strength [MPa] 81,6; Elongation at max. strength (%) 2,4.

3.2 Composite and hybrid specimens preparation

Two groups of laminates I and II of hybrid epoxy biocomposites reinforced with CF carbon fibers / GF glass were prepared in the form of plates with dimensions 300mm x 250 mm and thicknesses h = 1.2 ± 0.1 mm, with the following sequences stacking (Fig.2): laminate I: [CF / GF / CF / GF / CF]; laminate II: [CF / CF / GF / CF / CF].

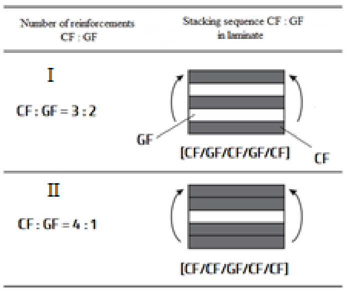


Fig.2. *Laminate I (CF: GF 3: 2) and II (CF: GF = 4: 1) stacking sequences*

The two plates were made (Fig.3) By the Liquid Resin Infusion (LRI) technique [20].

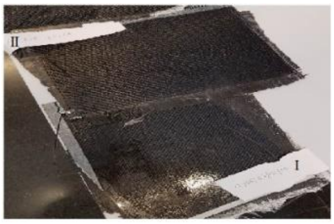


Fig. 3. Interlay hybrid type biocomposite plates I and II

Five specimens were cut from the plates with a diamond disk, according to ASTM D 7264/D 7264M – 07 [17]: L = 80 mm and width b = 10 ± 0,5mm (Fig.4).

a. b. c.

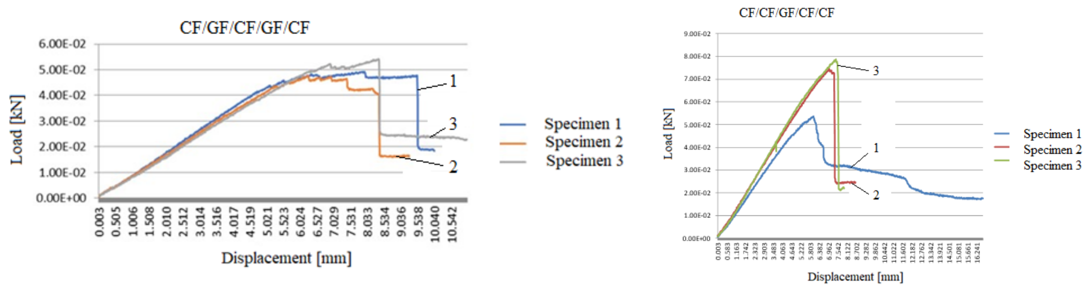
Fig.4. ASTM Standard Specimen I and II prepared for flexural studies: a. and b. before the bending test; c. after the bending test

3. Experimental results

Experimental bending tests met the ASTM D7264 / D7264M standard, A-Three-Point Configuration Procedure [17] (Fig.5). Machine used in experimental tests: ELIB 50S.A.E. Ibertest, Madrid, Spain with a test load cell of 5 [kN].

Fig.5. Bending test in three-point configuration

Each laminate test piece was positioned on the two supports of the machine in rigorous conditions of horizontality and symmetry and was bent at a speed of 10 mm / min. Figure 6 shows the Load-Displacement bending tests diagrams for the first three specimens of laminates I and II. In figure 7 there are compared values of maximum resistance, maximum stress and flexural modulus of elasticity parameters in the bending tests of the group of five specimens of the two categories of hybrid laminates I: [CF / GF / CF / GF / CF] and II: [CF / CF / GF / CF / CF].



a. b.

Fig. 6. Diagram Load-Displacement bending tests for 3 first specimens made by laminate: I: [CF/ GF/ CF/ GF/ CF] and II: [CF/CF/GF/CF/CF]

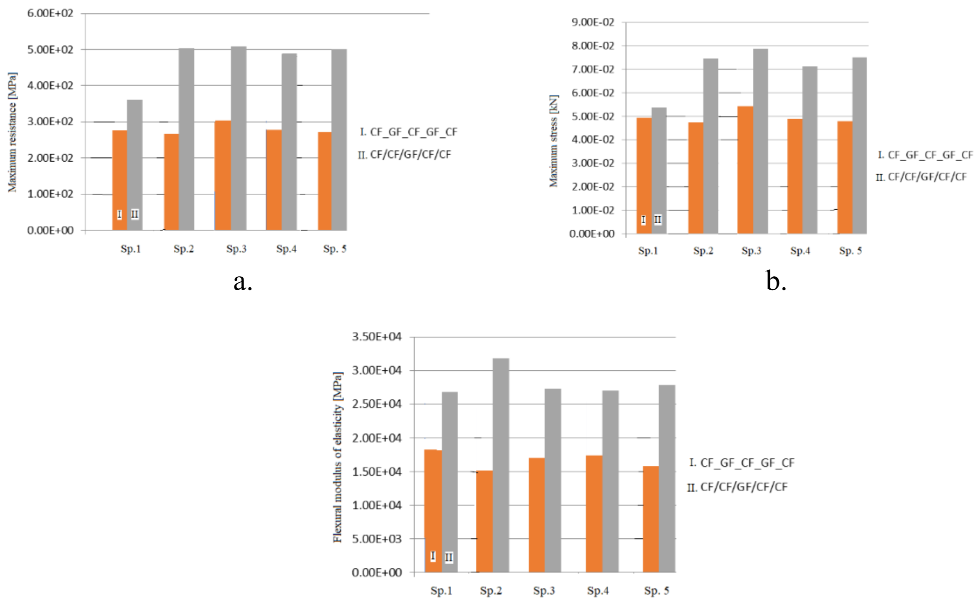
Using the following relations we can calculate the flexural strength, flexural modulus and the maximum displacement in the middle of the specimen f [mm] [17], [21]:

Flexural strength = $1,5 F_{max} L / b h^2$ (1)

Flexural modulus $E_F = m L^3 / 4 b h^3$ (2)

Maximum displacement $f = F_{max} L^3 / 48\, E_F I_z$ (3)

Where: F_{max} - maximum load at failure [N]; L - distance between centers of support [mm]; I_z - inertia moment in the transversal section vs the bending axis [mm^4]; b- width of the specimen [mm]; h- thickness of the specimen [mm]; m- initial slope of the load-deflection curve [N/mm].



a. b. c.

Fig.7. Numerical values determined experimentally in the bending test for hybrid laminates I and II: a. maximum resistance; b. maximum stress; c. flexural modulus of elasticity

4. Conclusion

The average values of the maximum resistance, maximum stress and flexural modulus of elasticity parameters obtained after bending testing are presented in table 1.

Tab.1 The average values of the parameters laminates I and II determined experimentally in the bending test

Experimentally evaluated parameters		CF / GF hybrid epoxy laminate group I and II (Arithmetic mean of the five tests)	
		I [CF/GF/CF/GF/CF]	II [CF/ CF/ GF/ CF/ CF]
Parameter name	U.M	Numeric values	
Maximum resistance	MPa	279,12	444,02
Maximum stress F_{max}	kN	0, 04962	0,07066
Flexural modulus of elasticity E_F	MPa	16707,6	28147

In the hybrid laminates I and II, subjected to bending testing, it was noticed the increase of the average values of the constructive parameters: maximum resistance, maximum stress and flexural modulus of elasticity due to the presence of carbon sheets on the upper faces (required for compression) and lower (required for stretching) of the hybrid laminate.

Research on bone bending testing [22] humerus, ulna and radius has shown the following values for average bending strength [23]: 128.43 ± 6.17 [MPa], 135.16 ± 30.43 [MPa] and 80.31 ± 14.55 [MPa]. The values obtained in the experimental research performed are close. However, by choosing the optimal stacking sequence in the analyzed hybrid biocomposite, optimal values of its bending behavior can be obtained under the conditions of the bone plate and outer fixation.

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