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THE DETERMINATION OF THE ELASTIC CHARACTERISTICS OF UNIDIRECTIONAL PREPREG CARBON FIBER-REINFORCED EPOXY RESIN COMPOSITES

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Abstract:*The unidirectional prepreg carbon fiber-reinforced epoxy resin composites are used on a wide scale in various applications: automobile industry, recreation boat industry, chemical industry (pipes and tanks) etc. Depending on the stresses at which the composite parts are exposed to, they have different reinforcement structures (woven fabric, mats, unidirectional fibers). The axial loading of the structures having complex geometry implies unidirectional fibers reinforcement of the composite, therefore, it is of utmost importance to know the elasticity modulus, the fracture strength and the deformations induced. In the absence of these properties, the design and production of the structures would not be possible. This paper's objective is to determine the characteristic curve of the unidirectional prepreg carbon fiber-reinforced epoxy resin composites, as a result of the investigation upon two types of materials, belonging to different producers. The results suggested that between the two types of materials there are differences of approximately 9% among the values of the longitudinal elasticity modulus and of approximately 22% for the fracture strength.*
Keywords :*unidirectional prepreg carbon fiber-reinforced composite, longitudinal elasticity modulus, tensile test*

1. INTRODUCTION

The uniqueness and diversity of the characteristics by which composite materials may be described contributed to their growing importance at a global level. Starting from the lightest fly fishing rods, carbon fiber composite materials are used more often given their high value of the ratio strength – weight, as well as the easy methods of production. The goal of the composite materials is to obtain rigid and resistant components, yet having a low density. There materials contain reinforced fibers and polymer resins. Fibers are considered the basic component of composites, being the one which transmits forces. The polymer matrix transfers forces among fibers and offers resistance to corrosion, shock tolerance, thermal and environment stability [1, 2]. Some types of fibers may have identical chemical composition and similar mechanical properties, but they are different in structure, depending on the producer. Carbon fiber reinforced polymers (CFRP) are highly resistant and light. Carbon fibers are obtained by carbonization ofpolyacrylonitrile (PAN) fibers, pitch resins or the Rayon (through oxidation and thermal pyrolysis) at high temperatures. Then, by graphitization, the strength and elasticity of the fibers may be improved. Carbon fibers are obtained with diameters found between 9 and 17 *μm* and contain approximately 90% carbon. Research on unidirectional carbon fiber reinforced composites have emphasized values of the longitudinal modulus of elasticity E, varying between 136 GPa and 188 GPa depending on the type of the fibers, the volume ratio and the used matrix [3, 4]. This paper presents the experimental results determined on unidirectional, prepreg carbon fiber-reinforced epoxy resin composite specimens, and obtained by the void-pressure method.

2. TYPES OF SPECIMENS TESTED TO TRACTION

The studied composites were obtained from unidirectional carbon fibers having diameters between 0,008…0,1*mm*; 1,9 g/cm^3 density; the ultimate tensile strength$\sigma_{rt} = 10{,}0 \ldots 3{,}00\ GPa$, E=230…400 *GPa* and epoxy matrix. Two types of specimens were analyzed, encoded U and G, reinforced with unidirectional epoxy resin prepreg fibers (Fig.1). The shape and dimensions of the specimens tested to tensile are given in figure 2, a and b, having been obtained in conformity with the SR-EN ISO 527-2 specifications (Fig. 2, a and b).

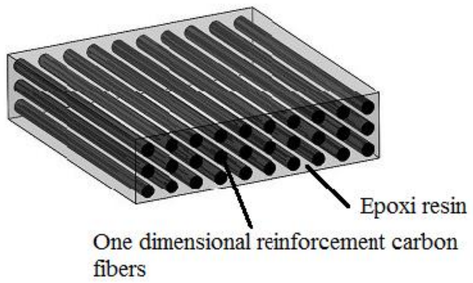
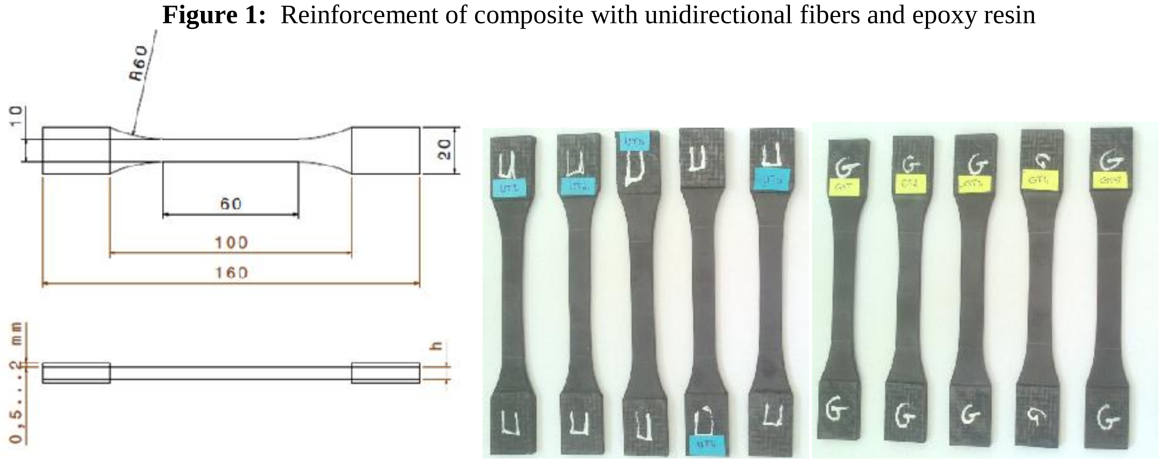


Figure 1: Reinforcement of composite with unidirectional fibers and epoxy resin



a) b)

Figure 2: a) Geometry and dimensions of the specimens tested to tensile; b) Types of tested specimens

Before starting the experimental part, the dimensions of each specimen have been precisely measured: the thickness and the length of the cross section. These dimensions of the specimens, alongside specifications regarding the advancing speed of the machine, presented in Table 1, have been introduced as input data into the computer connected to the testing machine, which had a NEXYGEN soft to receive the experimental data from the machine and to process them statistically.

Table 1: Data regarding the dimensions of the tensile tested specimens

Samples	Thickness *h mm*	Width *b mm*	Area of cross section *A* mm^2	The speed of loading, *mm/min*	Referencel engths, *mm*
GT1	1,86	11,74	21,8364	1	50
GT2	1,91	11,81	22,5571	1	50
GT3	2,02	12,08	24,4016	1	50
GT4	1,94	11,47	22,2518	1	50
GT5	1,95	11,86	23,1270	1	50
UT1	1,89	10,53	19,9017	1	50
UT2	1,85	10,32	19,0920	1	50
UT3	1,88	10,79	20,2852	1	50
UT4	1,83	10,59	19,3797	1	50
UT5	1,76	10,93	19,2368	1	50

3. EQUIPMENT USED AND THE EXPRIMENTAL METHOD

The experiment has been accomplished by aid of the testing machine with constant tensile speed, in conformity with ISO 527, including: fixed part, with lower grip for fixing the specimen and a mobile part also having gripto fix the specimen and a loading cell [5,6]. The testing machine, an LS100 Lloyd's Instrument type, presented in figure 3, belonging to the Mechanical Engineering Department of Transylvania University of Brasov, is characterized by the following: maximum loading domain: 100*kN*; maximum track: 840 *mm*; loading resolution:

<0,01% of the loading cell used; extension resolution: <0,1 *microns*; loading cell: XLC-100K-A1; analysis software: NEXYGEN MT. The tensile testing machine allows the electronic recording of the experimental result, through the NEXYGEN Plus soft (Fig. 3, a). The extensometer, by SR EN ISO 527, has the capacity to determine the relative variation of the reference length of the specimen in every moment of the test (Fig 3, b).

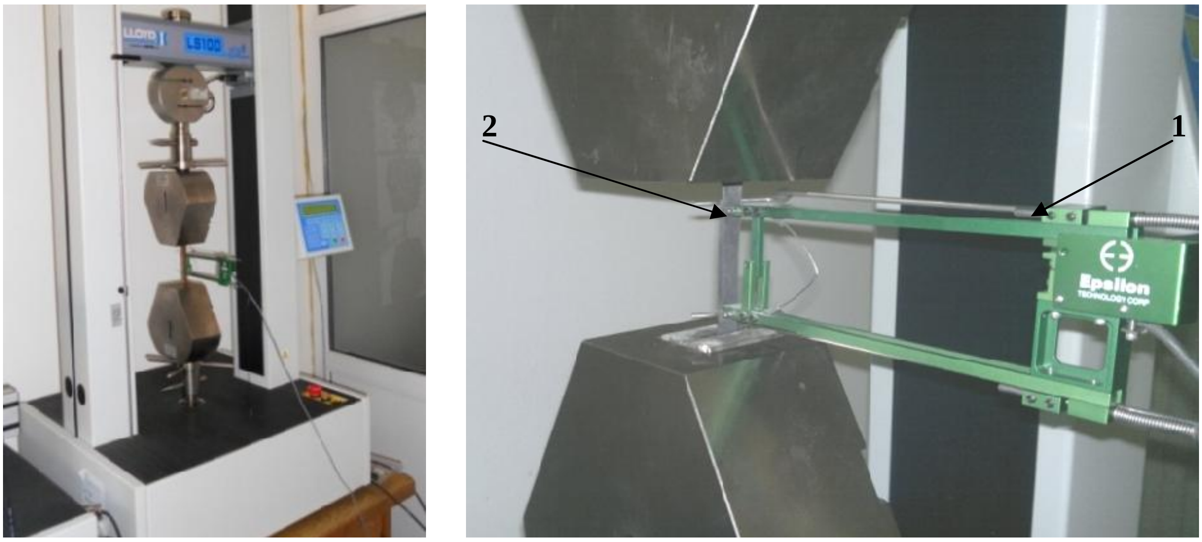


Figure3: The equipment used at tensile stress:
a – tensile testing machine LS100 Lloyd's Instruments; b – Axial extensometer 1, specimen 2 (3542 Epsilon Technology Corp), belonging to the Mechanical Testing laboratory of Transylvania University of Brasov, Mechanical Engineerin Department

The specimens were fixed between the grips of the tensile testing machine, such that the axis of the specimen to coincide with the direction of the central tensile line of the assembly in the tightening system. The extensometer has been attached so as to prevent the slipping between the extensometer and the specimen.

4. RESULTS AND DISCUSSION

After testing, it has been observed that the obtained values differ from a type of specimens to another (U and G), as well as among the specimens of the same category (Table 2). The forces recorded at failure for the composite G are with 21,12*%* lower than those of the material U (Fig.4). The mean value of the force at failure for specimens U is 18,48*kN*, while for composite G is 22,41 *kN*.

Table 2: Values of elastic characteristics obtained through experimental test

Samples	Stiffness *kN/m*	Longitudinal modulus of elasticity *MPa*	The maximum stress at the maximum loading *N*	Ultimate tensile strength *MPa*
GT1	42376,93	106465,60	21436,03	1077,095
GT2	47165,31	123521,10	22469,83	1176,924
GT3	36330,79	89550,00	24814,55	1223,283
GT4	32732,51	84450,50	21162,11	1091,973
GT5	53416,97	138840,60	22192,74	1153,661
UT1	50544,28	115734,00	29695,68	1359,917
UT2	40241,78	89199,82	33022,59	1463,956
UT3	43718,09	89580,38	31746,28	1300,992
UT4	46691,63	104916,50	30918,57	1389,486
UT5	46056,84	99573,74	33987,68	1469,610

The specific strain ε encountered in the case of type G specimens are 4,59% higher than those of U composite (fig.5). The ultimate tensile strength σ_r for the type G material is higher with approximately 22,20% than that of

U material (Fig 6). The unidirectional carbon fiber composite of type G is more elastic than the U type, the ratio between their longitudinal moduli of elasticity being E_G/E_U=0,9192 (Fig. 7).

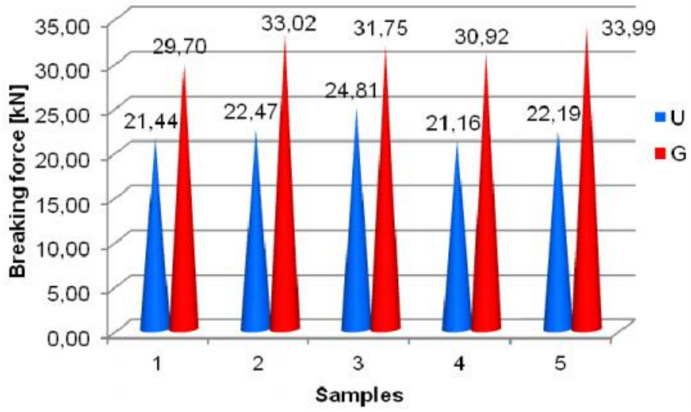


Figure 4: Variation of breaking force

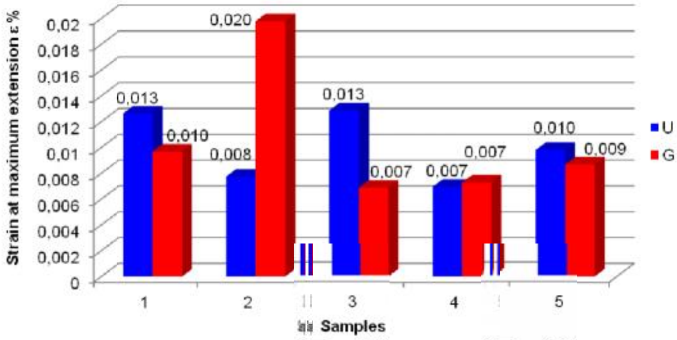


Figure 5: Specific strain ($\bar{\varepsilon}_G = 0,010469$; $\bar{\varepsilon}_U = 0,010009$)

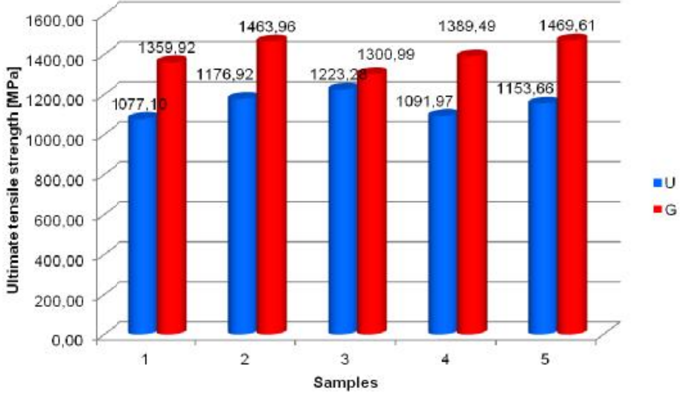


Figure 6: Variation of ultimate tensile strength

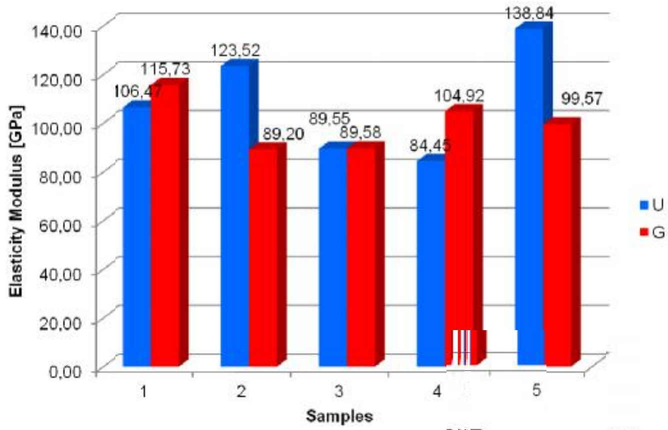
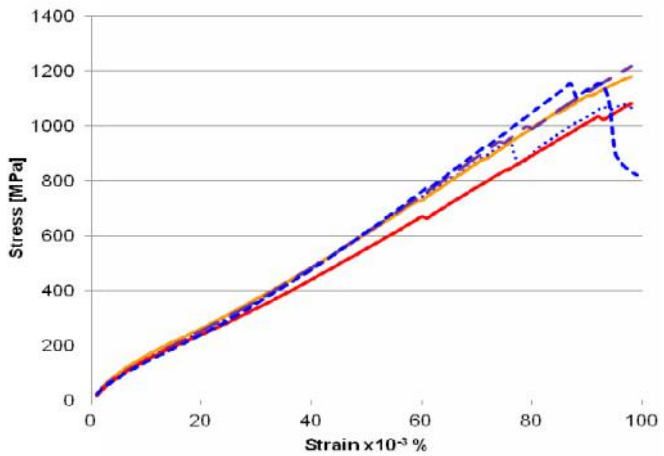
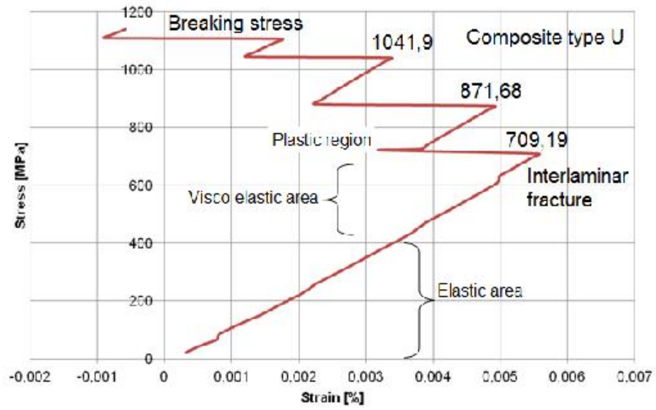


Figure 7: Variation of the longitudinal modulus of elasticity($\bar{E}_U = 108570\ MPa$; $\bar{E}_G = 99801 MPa$)

In figure 8, a, the characteristic curves of the U type of specimens are presented, where it can be observed that up until the value of 600 *MPa* in tensile strength the material has an elastic region. Around 650 *MPa*, the interlaminar stress is recorded, as the composite includes 4 layers of unidirectional fabric (Fig. 8, b). Between 650 and 1100 *MPa*, plastic deformations appear simultaneously with the failure of the layerswhich induces a rise in stress with approximately 24% for each layer in particular. A similar behaviour is observed in the case of the G type of composite, where the ultimate tensile strength of the layers is higher than that of the U composite, although the first interlaminar ultimate tensile strength appears around a 640 *MPa* value.
In figure 9 the elastic-visco-plastic model of the multilayered unidirectional carbon fiber, epoxy resin composite is presented.Elastic elements*k*determinethe linear correlationstress(σ) -specific deformation(ε);plastic elements«representshorizontal correlationsσ-ε where the fracture of each lamina is recorded; the elements viscous¦characterizedslowly increaseoftensile stress valuewith a low strain ratewhich is produced due to the interlaminar bonding and between fiber and matrix [8, 9].



a)



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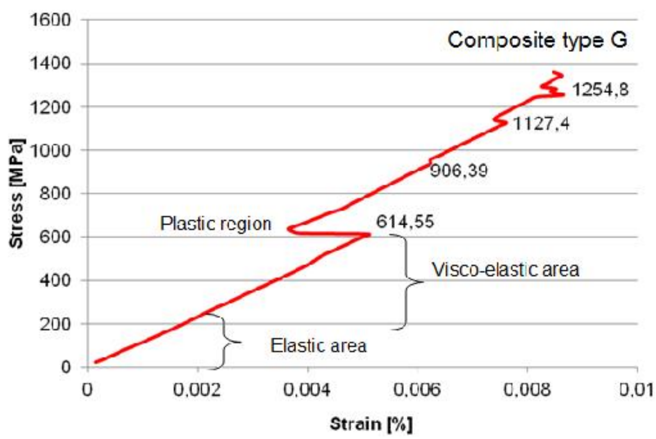

c)

Figure 8: a) Characteristic curves of unidirectional composite; b)variation of interlaminarfracturestresses in case ofU composite; c) variation of interlaminarfracturestresses in case ofG composite;

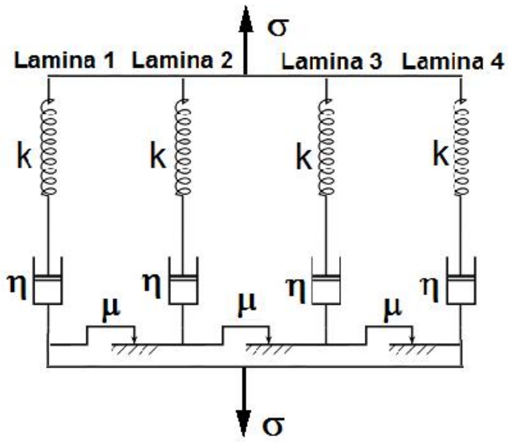

Figure 8: Elasto-visco-plastic model of composite (k -the elastic element type Hooke; η-characteristics ofviscous element type Newton;μ-characteristics of plastic element type Saint Venant) [9]

5. CONCLUSION

In conclusion, the unidirectional carbon fiber reinforced composites present elastic characteristics which are different depending on three factors: the carbon fiber fabric producer, the imperfections developed when cutting the specimens, such that the loading axis does not coincide with the orientation of the fibers, the prepreg resin content and even production flaws. Yet, the advantages of the multilayered unidirectional carbon fabric composite are influenced by its capacity to store strain energy, its elastic-visco-plasticbehaviour and its high tensile strength even in the case when cracks and interlaminar failures are developed.

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