Comparison between viscous elastic plastic behaviour of the composites reinforced with plain glass fabric and chopped strand mat

M D Stanciu[1], A Harapu[1], H Teodorescu Drăghicescu[1], I Curtu[1] and A Savin [2]

[1]Mechanical Engineering Department, Transylvania University of Brasov, Brasov, Romania
[2] National Institute of Resarch and Development for Technical Physics, Nondestructive Testing Department, 47 D.Mangeron Blvd, Iasi, 700050, Iasi, Romania

E-mail: mariana.stanciu@unitbv.ro

Abstract. Composite structures are used mainly two types of reinforcement materials: woven glass fabric and the chopped strand mat, each contributing either to increase the resistance of the composite whole or in isotropic distribution of stresses. This paper presents a comparison of the visco-elastic characteristics of composites reinforced with glass fabric and the chopped strand mat and the breaking mode of the two types of the composite. The first type of samples contain three layers of chopped strand mat known as MAT with density of $450g/m^2$ and $225g/m^2$) and the second type is composed of four layers of woven glass fabric type RT500 (density of $500g/m^2$). Both specimens were cut in accordance with EN ISO 527-2 SR. Characteristic curve of the two types of specimens highlights visco-elastic-plastic behavior which largely depends on the type of reinforcement used as the matrix resin is the same in both cases (orthophthalic polyester resin). Breaking mode of those types of specimens were observed and analyzed by electronic microscope.

1. Introduction
Reinforced fibreglass composites are commonly used in making sporting goods, household items, pipes, being appreciated for high strength, low weight and affordability. Mechanical behaviour of the composites reinforced with fibres depends on the size of the fibres (diameter and length), the distribution thereof in the composite structure, the strength and elasticity of the fibres, chemical stability and thermal resistance of the matrix and the nature of the interface between the fibres and matrix. There are many ways of reinforcing composites with fibres, the most common being the woven glass and mat form. The layers can be oriented differently so as to provide a multi-directional distribution of stresses during applications [1, 2].. If the composite is subjected to unidirectional loading, then is used unidirectional reinforcement. Numerous studies have shown that the method of reinforcement, the length and the nature of fibres influence the mechanical properties of the composite. Between the increase of the fibres content and increasing the elastic modulus of the composite is a linear relationship [3, 4]. The complexity of the composite behaviour consists of the differences between stiffness of components which lead to developing of shear stresses at the interface between matrix and fibers [5, 6, 7]. Even the tangential stresses are small, the debonding and the micro-cracks appear. The aim of this study is to compare the mechanical properties of the two types of polyester matrix composite: composites reinforced with four layers of glass fabric type RT500/500/500/500 and another type of composite containing three layers of mat type 450/225/450.

Samples were subjected to the tensile load and the bending load, being determined for each the elasticity modulus, characteristic curves stress-strain, stiffness and resistance for each type of analyzed composite.

2. Experimental set-up

2.1. Samples preparation

Tensile test specimens were made according to EN ISO 527-2-SR (figure 1, a and c) and for bending test, the samples were performed according to ISO 178: 2003 (figure 1, b and d). Comparative analysis of the viscoelastic behavior of the composites was conducted on two structures composite having the same array, but reinforcements different: the first, polyester composite reinforced by two layers of MAT450 and a layer of MAT225 applied between the two MAT450, and the second type of composite was made of four layers of fabric RT500 with the same orientation of the fibers direction. The geometrical characteristics of tested samples are shown in table 1.
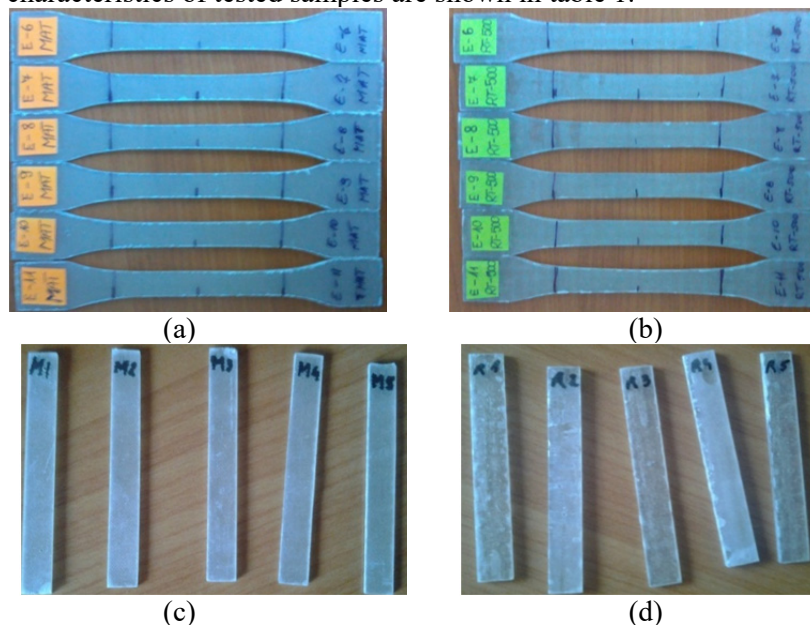

(a)	(b)
(c)	(d)

Figure 1. The geometry of the two types of composites: for tensile (a) MAT450/225/450, (b) tensile samples RT500; for bending in three points: (c) MAT450/225/450, (d) RT500.

Table 1. Geometrical characteristics of samples.

Tensile									
Samples code	RT1	RT2	RT3	RT4	RT5	MAT1	MAT2	MAT3	MAT4	MAT5
Length [mm]	150	150	150	150	150	150	150	150	150	150
Width [mm]	10	9.8	10	9,9	10	10	9,6	10	9,7	10
Thickness [mm]	2,5	2,6	2,7	2,5	2,4	2,1	2,2	2,3	2	2,5
Area [mm^2]	25	25,48	27	24,75	24	21	21,12	23	19,4	25
Three points bending									
Length [mm]	80,26	80,10	80,14	80,36	80,62	80,07	80,60	80,12	79,84	79,70
Width [mm]	10,44	10,52	10,70	10,84	10,84	10,64	10,60	10,85	10,73	10,72
Thickness [mm]	2,70	2,18	2,50	2,44	2,40	2,15	2,40	2,12	2,52	2,12
Area [mm^2]	28,18	22,93	26,75	26,44	26,01	22,87	25,44	23,00	27,03	22,72

2.2. The tested method

The first test was the tensile test. The specimens were loading with a constant tensile speed of 5 mm/min until breaking, being used the equipment by LS100 Lloyd's Instrument belonging to the Mechanical Engineering Department of Transylvania University of Brasov (figure 2, a). In the second assay, the samples were tested at bending in three-point (figure 2, b).
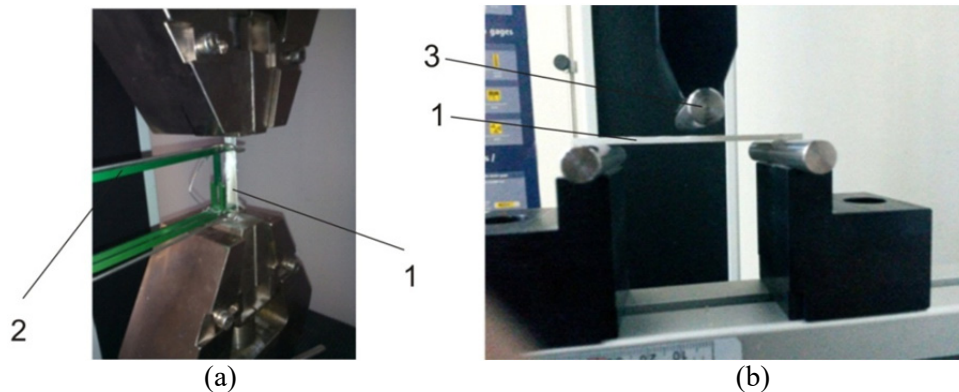

(a)   (b)

Figure 2. Tested equipment: (a) at tensile; (b) at bending; 1 – sample; 2 – axial extensometer; 3 – force device for the three-point bending.

3. Results and discussion

3.1. The behavior of the tensile loading

Comparing the characteristic curves stress-strain at tensile of the two types of composite materials is observed that the reinforcement with fabric RT has a higher capacity to store the deformation energy than the composite reinforced with mat. Thus can be estimate that the composite with glass fabric has an elastic plastic behaviour compared with viscous elastic response of the composite reinforced with mat (figure 3, a). Analyzing the stress-strain curve of the composite reinforced with fabric, it can be noted that between the elastic limit and fracture point of the material, there are four areas indicating the interlaminar behaviour and of the laminas response during the loading (figure 3, b). Thus, the first area (I) indicates the first interlaminar micro-crack, the tensile stress being distributed to the rest of the composite. The following breakage occurs at a stress increment of 29 MPa (figure 3, c). Unlike composite reinforced fabric, the mat composite (figure 3) has a continuous characteristic curve, the first debonding of the matrix and dispersed fibres occurring nearly the breaking of the entire specimen.
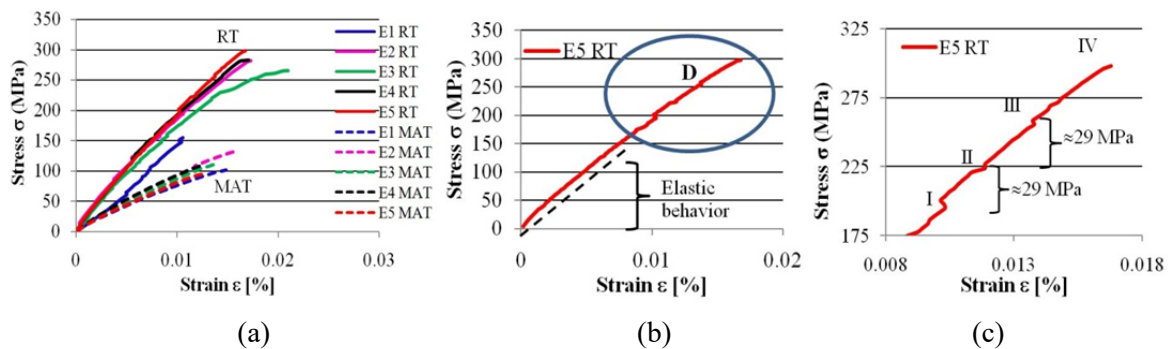

(a)   (b)   (c)

Figure 3. Characteristic curve stress-strain: (a)at tensile loading; (b) curve σ-ε for RT sample;

(c) the D detail for the stress range between 175 – 325 MPa.

In figure 4 are shown the ways of breaking of the two tested composites. Thus, it is seen that the breakage of the composite reinforced with the chopped fibres is produced through the simultaneous destruction of the matrix and the dispersed fibres in about 80% of the width of the sample. In the case of the glass fabric-reinforced composite, it has been observed that the matrix had broken first, the inner efforts being distributed to longitudinal fibres of the glass fabric which continuous the deformation until reaching the breakage at the maximum stress. It can be appreciated that the use of a composite fabric structure doubles the tensile strength comparing with mat reinforcement.
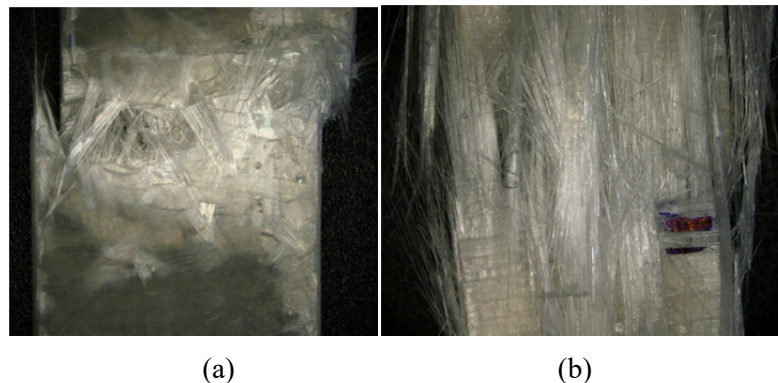

(a)   (b)

Figure 4. The fracture of the two composite subjected to tensile: (a) MAT; (b) RT.

3.2. The bending behavior

At the bending loading, the behavior of the two types of composite materials is similarly: the material reinforced with the mat has a predominantly viscous deformation being much higher in relation to the increasing of stress (figure 5, a) . RT presents the elastic-plastic behavior (similar with the tensile behaviour), registering four steps of plasticity corresponding to the four laminae from composite structure. So, with increasing the load, delamination and debonding of the layers occur at a stress intensity which decrease with increases the failure of composite from 100 to 80 MPa, 50 MPa and 40 (figure 5, b). The MAT composite has a visco-elastic behavior characterized by the Kelvin-Voigt model (figure 5, c).
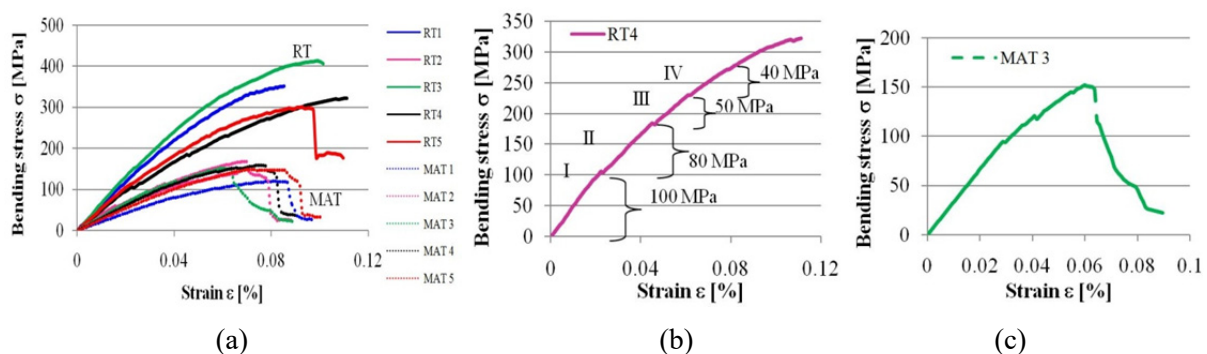

(a)   (b)   (c)

Figure 5. The characteristic curve at flexural: a) for all tested samples; b) the elastic plastic behavior of the composite RT; c) the visco-elastic behavior (type Kelvin-Voigt) behavior of composite reinforced with MAT.

During the bending, in addition to the normal stresses, appear tangential stresses between fiber and matrix due to different stiffness of each parts - matrix and fiber. These lead to debondig of the layers of the interface between the matrix and fibers, which decrease the strentgh of the composite structure. The variations of the normal stress and the tangential stress are presented in figure 6. The normal stress varies linear, but with local variation for each layer formed from matrix, fibers and interface between matrix and fibers (figure 6, b). The tangential stress vary parabolic, the highest values being

recorded in neutral surface which is represented by the resin layer in case of composite RT (figure 6, c).
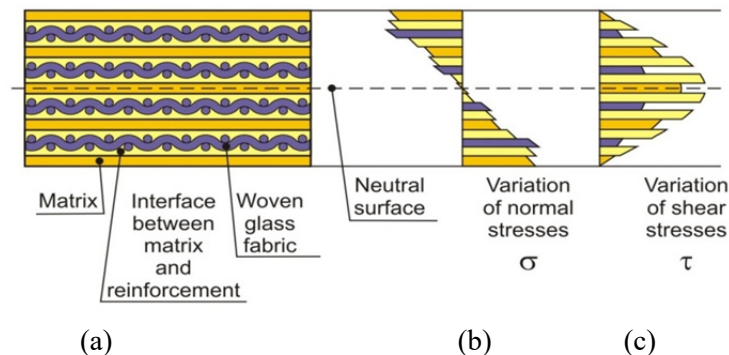

(a)   (b)   (c)

Figure 6. The variation of normal stresses σ and tangential stresses τ at bending: (a) the section of composite reinforced with glass fabric; (b) the normal stress variation; (c) the parabolic variation of tangential stress

The average values of the mechanical properties of the composites tested at the tensile and bending are presented in table 2. It can be seen that both tensile and flexural, the composite reinforced with glass fabric presents the elastic modulus two times greater than the composite reinforced with mat (figure 7).

Table 2. Average values of mechanical properties of tested samples.

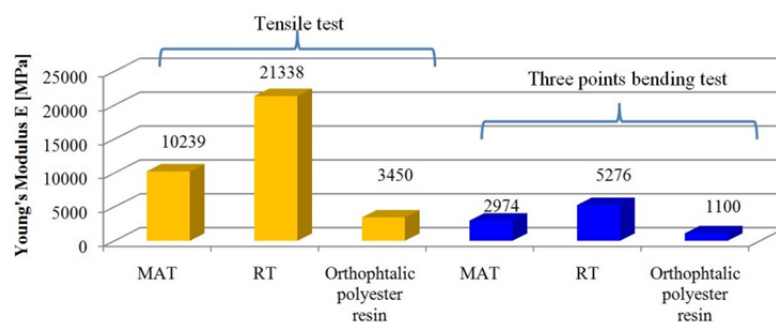|	Tensile test			Three points bending		
	MAT (70%)	RT (50%)	Orthophtalic polyester resin [6]	MAT	RT	Orthophtalic polyester resin [2]
Stiffness k [N/m]	3318196,0	7692261		- 7005,617	9826	-
Young's Modulus E [MPa]	10239,0	21337,5	3450,0	2973,838	5276	1100,0
Load at Break [kN]	2,4	5,7385		- 0,0201	0,1443	-
Stress at Break [MPa]	110,0	228,0	55,0	150,0	252,0	80,0
Strain at Break	0,0140	0,0205	0,021	0,0913	0,0917	-

Figure 7. Variation of the elasticity modulus with type of reinforcement and type of loading

The same differences between two composites are maintained for all determined mechanical properties: breaking load (figure 8, a), strain and ultimate stresses (figure 8, b). Comparing with the elasticity modulus of polyester resin, the Young modulus of the mat composites is 2.5 times greater and of the composite reinforced with fabric about six times higher than stiffness of pure matrix. Hence

the reinforced composites have the advantage to be characterized by superior mechanical properties than the single components.

It can be appreciated that the high tensile strength of the composite is due to reinforcement and type of fibres used, while flexural strength is due to the elastic characteristics close of the two components - matrix and reinforcement, which makes both components to work together enhancing the resistance to bending of the composite.
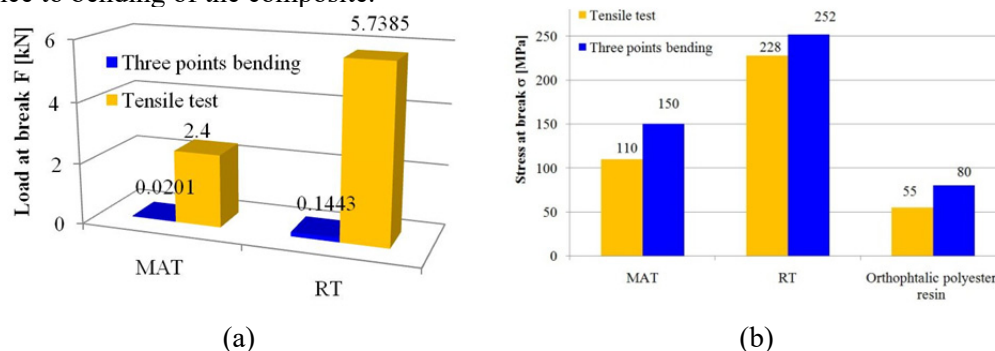

(a)   (b)

Figure 8. The variation of: (a) the breaking load and (b) the breaking stresses with type of reinforcement and type of loading.

4. Conclusion
The present study has aimed to analyze the two types of reinforcements - MAT and fabric RT, subjected to tensile and bending in three points, being determined the modulus of elasticity, deflection and breaking resistances. The values obtained are similar to those in the literature. Knowing these parameters are useful in designing layered composite structures and optimization of the composites in terms of growth of mechanical strength and decreasing the weight, with applications in wind turbine blades. It is obvious that the reinforcement with glass fabric shows superior mechanical properties than glass mat, but the alternating the mat reinforcement with glass fabrics in composites structure lead to diminishing of the anisotropy, the material becoming quasi-isotropic. Thus, regardless of the loading directions, the composite will response about the same in all direction.

5. References
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