MECHANICAL ENERGY ABSORPTION OF WEIGHT-BALANCED COMPOSITE LAMINATES UNDER TENSILE LOADS

Cezar Afilipoaei[1], Dorin Rosu[2], Horațiu Teodorescu-Draghicescu[1]
[1] Transilvania University of Brasov, ROMANIA, cezar.afilipoaei@unitbv.ro, draghicescu.teodorescu@unitbv.ro
[2]S.C. COMPOZITE S.R.L., ROMANIA, compozitebv@yahoo.com

Abstract: *This original paper presents an evaluation of mechanical energy absorption of four weight-balanced composite laminates subjected to tensile loads until the ultimate tensile strength is reached. Glass fabric plies of 300 g/m^2, 500 g/m^2 and 800 g/m^2 specific weights have been used to reinforce a thermoset resin to form weight-balanced composite structures. Load-extension distributions have been carried out on a LS100Plus Lloyd Instruments material testing machine using the NEXYGEN PLUS software. A 5th grade polynomial function as well as the R^2-factor of these tensile tests have been computed using MATLAB software. This mathematical function presents R^2-factors close to 1 for all weight-balanced composite laminates used in tensile tests. The highest mechanical energy absorption has been computed for the 500 g/m^2 specific weight glass fabric reinforced polymer matrix composite laminate.*
Keywords: *weight-balanced composites, tensile loads, mechanical energy, numerical integration, R^2-factor*

1. INTRODUCTION

Composite materials are used since ancient times. For example, clay bricks were used in the constructions of ancient Egypt, in the production of which it was observed that they cracked under the action of the sun. By reinforcing the clay bricks with straw, the cracking of these building materials was eliminated. In modern times, the class of composite materials with the widest use is represented by composite materials based on the reinforced polymer resin. The length of the reinforcement fibers in a composite is very important by determining the subsequent mechanical properties of the composite. Thus, intensive researches have been carried out on composite materials such as Sheet Molding Compounds (SMCs) that encompass short fibers randomly oriented in their structure [1]. Switching from static loadings, composite structures have been subjected at cyclic loads also [2], [3]. The loadings of a stratified composite structure can also be accomplished outside its global coordinate axes, the mechanical properties of these structures may be determined using the finite element method [4], [5]. Researches on the behavior of a wide range of composite structures subjected to various loadings are presented in bibliographical references [6 – 10]. Both glass and carbon fibers have been predominantly used as a reinforcement material of the composite structures used in researches [11] and [12]. Scientific researches have also been carried out on structures based on thermoplastic resin as well as on natural composite materials [13 – 17].

2. MATERIAL SAMPLE DEFINITION

The materials tested in this paper are in the category of structural, laminate composites, having in structure a thermoset polymer reinforced with different number of glass fibers fabric plies. In order to have a better understanding of how composite laminates, in general, behave when they are subjected to tensile loads, four different material combinations have been used. These composite laminates have been manufactured in the hand lay-up process at Compozite Ltd., Brasov and have been chosen to present a weight-balanced structure (Table 1).

Table 1: Samples material definition

Material	No. of layers	Specific weight (g/m^2)
RT800	3	800
RT500	5	500
RT300	8	300
MAT300	8	300

The specimens have been cut from composite laminate plates using a diamond powder mill cooled with water, avoiding any possible material damage which can be induced by thermal or mechanical action. The size and shape of specimens respect the SR EN ISO 527-4 standard. For instance, Fig. 1 presents the MAT300 specimens.

Figure 1: Size and shape of MAT300 specimens (courtesy of Compozite Ltd., Brasov)

3. TESTING METHOD AND RESULTS

For a high accuracy of results a number of ten samples have been tested from each material, the measurements of load – extension distributions being realized in approximately 3000 points. Tests have been accomplished respecting the SR EN ISO 527-1 standard, using as equipment the LS100Plus materials testing machine manufactured by Lloyds Instruments. Measuring data given by the equipment software have been collected, organized, filtered and put it in graphically representation, as curves shown in Figs. 2 to 5. As could be observed, the highest values of load and extension have been registered by material who has in composition five plies of RT500 glass fibers fabric, most of the samples overpassing the 8 kN load at an extension between 1.2 and 1.3 mm. It is important to mention that the ultimate tensile strength in this case corresponds to the maximum value of load, the effective load at break being lower than this value. In all cases the shape of curve after the maximum load has a descendent tendency till the material completely separates.

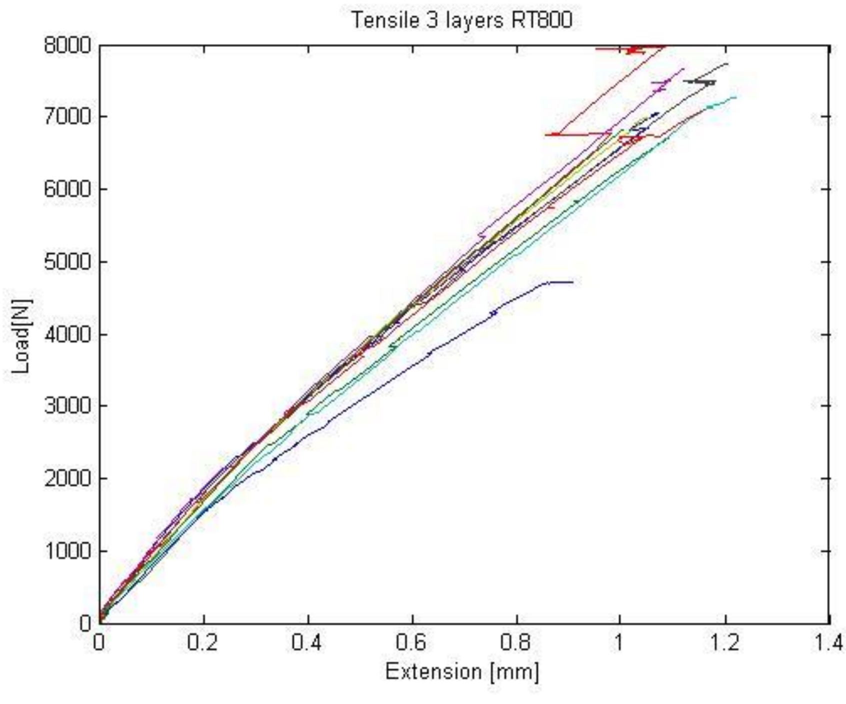

Figure 2: Load-extension distribution of three layers RT800 composite laminate under tensile loads

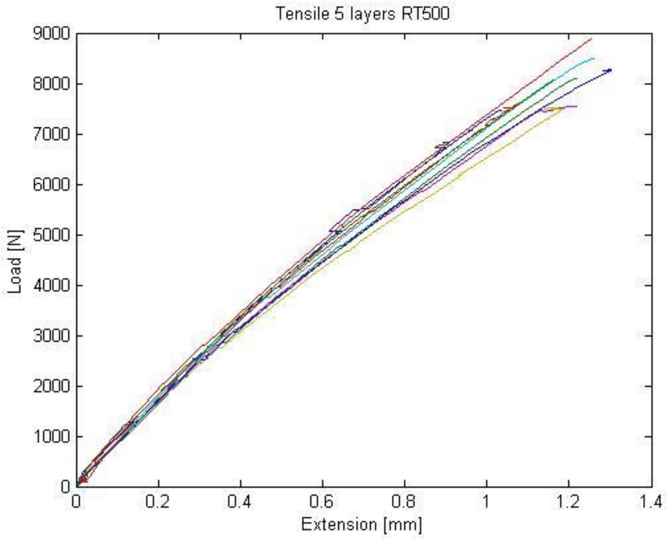

Figure 3: Load-extension distribution of five layers RT500 composite laminate under tensile loads

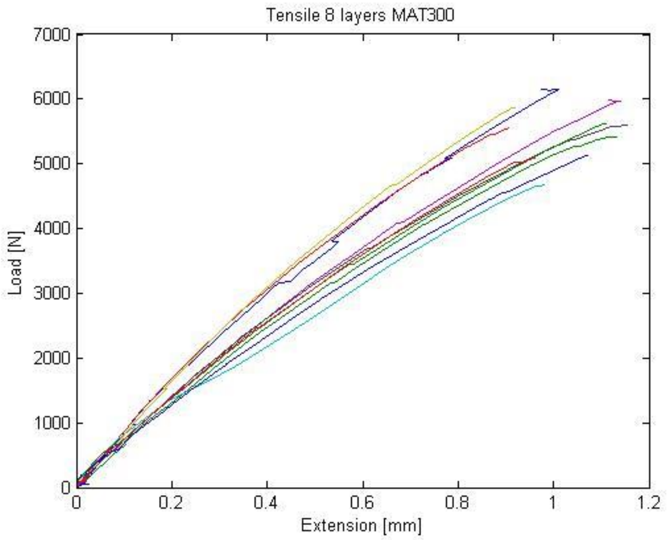

Figure 4: Load-extension distribution of eight layers MAT300 composite laminate under tensile loads

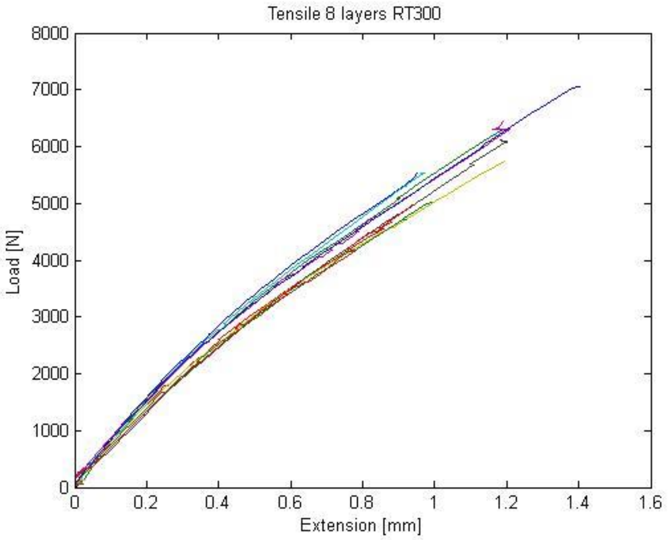

Figure 5: Load-extension distribution of eight layers RT300 composite laminate under tensile loads

It was noticed that before reaching the breaking point of material, a filamentary appears in the area of maximum stress, which is specific to laminate composites. By taking the samples with highest ultimate tensile strength values from each material, a new comparative graph has been accomplished (Fig. 6). The goal was to find a mathematical function which can be superposed over the actual results, having a R^2-factor close to 1, meaning to find the right curve as a best fit through the actual points. This mathematical expression is a 5th grade polynomial function:

$$f(x) = p_1x^4 + p_2x^3 + p_3x^2 + p_4x + p_5, \quad (1)$$

where the coefficients p_1 to p_5 for each material are presented in Table 2.

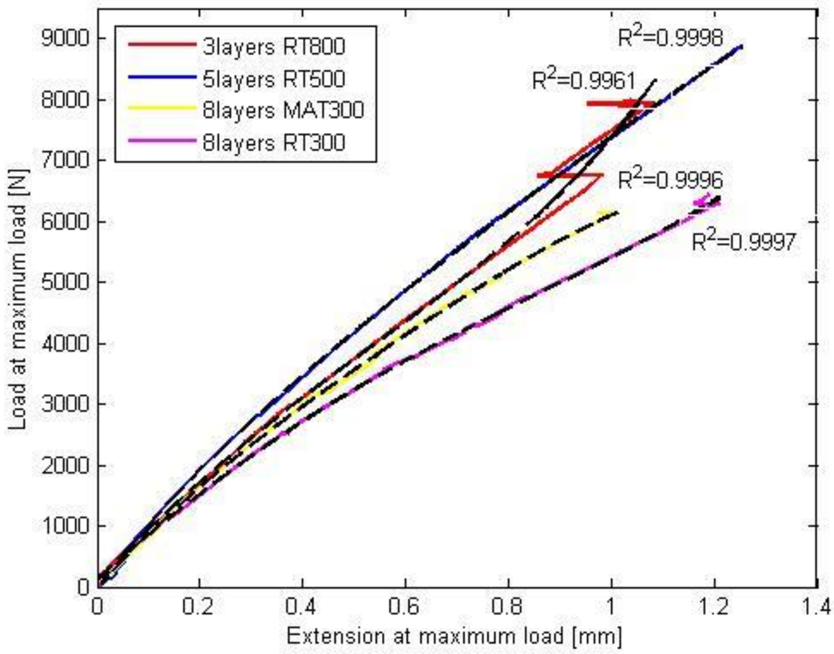

Figure 6: R^2-factor of four weight-balanced composite laminates (load at maximum load - 5th grade polynomial function)

Table 2: 5th grade polynomial coefficients

Polynomial coefficient	RT800	RT500	MAT300	RT300
p_1	2717	-1423	-3658	1120
p_2	-1135	4915	8534	-1127
p_3	-3049	-6923	-8513	-2115
p_4	8740	10850	9784	7396
p_5	101.9	-31.65	-42.81	136.3

Figure 6 contains some similarities in terms of extension at maximum load, being able to group the weight-balanced composites laminates two by two, RT300 with RT500 and MAT300 with RT800, comprising values over 1.2 mm in first case and around 1 mm in the second one. However, over all, it has been remarked that material who has in composition five plies of RT500 glass fibers fabric describes the most accurate mathematical curve with a R^2-factor of 0.9998. Starting with the same curves from Fig. 6, has been made a new comparative graph between tested materials showing the mechanical energy areas absorbed during loading conditions. Each curve has been closed by a vertical line which touch the X - axis. Using numerical integration by trapezoidal method *trapz(x,y)* as function in MATLAB software, it has been computed the integral of *y* with respect of *x*, graphical represented in Fig. 7. Having the corresponding function, this rule connects all trapezoids contained by the graph of function and then calculates the sum of all trapezoids' areas. The number of used intervals has a major impact in the accuracy of areas determination. An increased number of intervals determines a high number of trapezoids thus a good result accuracy. In this calculation we have been used the default increment of 1. It can be easily observed that the material with the highest load, RT500 in five plies, had absorbed the biggest deformation energy among all materials.

Figure 6 demonstrates the importance of the composite laminate's structure, using the same number of plies, eight, RT300 shows an increased level of energy absorption, approximately 22% higher compared with MAT300.

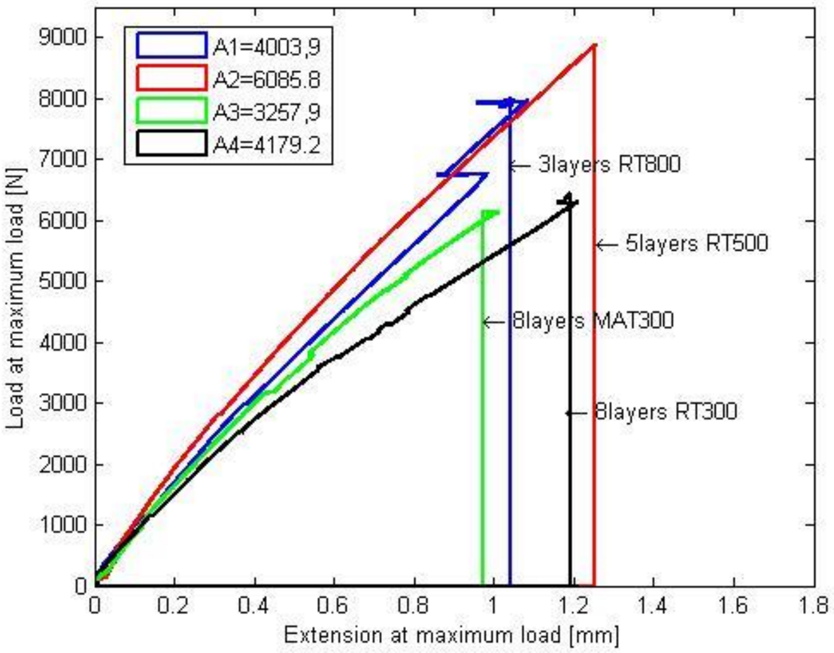

Figure 7: Mechanical energy area absorbed by four weight-balanced composite laminates

4. CONCLUSION

The capacity of mechanical energy absorption is directly correlated with the properties of materials contained by the composite laminates, not being necessary to use many layers of glass fibers fabrics in order to obtain high values of energy, therefore high mechanical properties. In this paper work it was shown that the specific weight of reinforcement element plays an import role in the performance of composites and in many cases the orientation and distribution of fibers within material is crucial. By comparing the energy absorption, under tensile loads, of a laminated composite which are using as reinforcement glass fibers in mat structure (MAT300) is with 47% lower than composites which are using fabrics (fibers orientated at 90°, e.g. RT500).

REFERENCES

[1] Teodorescu-Draghicescu, H., Vlase, S., Homogenization and Averaging Methods to Predict Elastic Properties of Pre-Impregnated Composite Materials, Comp. Mater. Sci., 2011, 50, 4, 1310-1314.

[2] Teodorescu-Draghicescu, H., Vlase, S., Scutaru, L., Serbina, L., Calin, M.R., Hysteresis Effect in a Three-Phase Polymer Matrix Composite Subjected to Static Cyclic Loadings, Optoelectron. Adv. Mat., 2011, 5, 3, 273-277.

[3] Vlase, S. Teodorescu-Draghicescu, H., Motoc, D.L., Scutaru, M.L., Serbina, L., Călin, M.R., Behavior of Multiphase Fiber-Reinforced Polymers Under Short Time Cyclic Loading, Optoelectron. Adv. Mat., 2011, 5, 4, 419-423.

[4] Vlase, S. Teodorescu-Draghicescu, H., Călin, M.R., Serbina, L., Simulation of the Elastic Properties of Some Fibre-Reinforced Composite Laminates Under Off-Axis Loading System, Optoelectron. Adv. Mat., 2011, 5, 4, 424-429.

[5] Teodorescu-Draghicescu, H., Stanciu, A., Vlase, S., Scutaru, L., Călin M.R., Serbina, L., Finite Element Method Analysis Of Some Fibre-Reinforced Composite Laminates, Optoelectron. Adv. Mat., 2011, 5, 7, 782-785.

[6] Stanciu, A., Teodorescu-Draghicescu, H., Vlase, S., Scutaru, M.L., Călin, M.R., Mechanical Behavior of CSM450 and RT800 Laminates Subjected to Four-Point Bend Tests, Optoelectron. Adv. Mat., 2012, 6, 3-4, 495-497.

[7] Vlase, S., Teodorescu-Draghicescu, H., Călin, M.R., Scutaru, M.L., Advanced Polylite composite laminate material behavior to tensile stress on weft direction, J. Optoelectron. Adv. M., 2012, 14, 7-8, 658-663.
[8] Teodorescu-Draghicescu, H., Scutaru, M.L., Rosu, D., Calin, M.R., Grigore, P., New Advanced Sandwich Composite with twill weave carbon and EPS, J. Optoelectron. Adv. M., 2013, 15, 3-4, 199-203.
[9] Modrea, A., Vlase, S., Teodorescu-Draghicescu, H., Mihalcica, M., Calin, M.R., Astalos, C., Properties of Advanced New Materials Used in Automotive Engineering, Optoelectron. Adv. Mat., 2013, 7, 5-6, 452-455.
[10] Vlase, S., Purcarea, R., Teodorescu-Draghicescu, H., Calin, M.R., Szava, I., Mihalcica, M., Behavior of a new Heliopol/Stratimat300 composite laminate, Optoelectron. Adv. Mat., 2013, 7, 7-8, 569-572.
[11] Heitz, T., Teodorescu-Draghicescu, H., Lache, S., Chiru, A., Calin, M.R., Advanced T700/XB3585 UD carbon fibers-reinforced composite, J. Optoelectron. Adv. M., 2014, 16, 5-6, 568-573.
[12] Teodorescu-Draghicescu, H., Vlase, S., Stanciu, M.D., Curtu, I., Mihalcica, M., Advanced Pultruded Glass Fibers-Reinforced Isophtalic Polyester Resin, Mater. Plast., 2015, 52, 1, 62-64.
[13] Scutaru, M.L., Teodorescu-Draghicescu, H., Vlase, S., Marin, M., Advanced HDPE with increased stiffness used for water supply networks, J. Optoelectron. Adv. M., 2015, 17, 3-4, 484-488.
[14] Modrea, A., Gheorghe, V., Sandu, V., Teodorescu-Draghicescu, H., Mihalcica, M., Scutaru, M.L., Study of a New Composite Material Rt800 Reinforced with Polyte 440-M888 in Endurance Conditions, Procedia Technology, 2016, 22, 182-186.
[15] Teodorescu-Draghicescu, H., Gheorghe, V., Munteanu, R., Szava, I., Modrea, A., Advanced RT300 Glass Fabric/Polylite Composite Laminate Simulation, Procedia Engineering, 2017, 181, 293-299.
[16] Teodorescu-Draghicescu, H., Scarlatescu, D., Vlase, S., Scutaru, M.L., Nastac, C., Advanced high-density polyethylene used in pipelines networks, Procedia Manufacturing, 2018, 22, 27-34.
[17] Stanciu, M.D., Ardeleanu, A.F., Teodorescu-Draghicescu, H., Reverse engineering in finite element analysis of the behaviour of lignocellulosic materials subjected to cyclic stresses, Procedia Manufacturing, 2018, 22, 65-72.