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Crash Test of Carbon Composite

RYVOLOVÁ Martina[1,a] and VOSÁHLO Josef[1,b]

[1]**Institute for Nanomaterials, Advanced Technology and Innovation,** Technical University of Liberec, Studentská 1402/2, Czech Republic

[a]martina.ryvolova@tul.cz, [b]josef.vosahlo@tul.cz

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Abstract. The article summarizes the work of authors about a carbon unidirectional prepreg. The current results are based on the previous measurement of force and deformation obtained during crash tests. The amount of impact force was determined for different variants of carbon plates. The dependence of the value of the energy absorbed by the impact on the composition of the composite was monitored and all cases were modelled under the same conditions. Results of measurement and mathematical model were compared.

Introduction

Generally, components made of fibre reinforced plastics have a higher energy absorption than similar components made of metals. High strength and low weight are typical properties of structural laminates. The behaviour of the laminates depends on the type of fibre, the type of resin, the thickness of the laminate - the number of layers and their orientation, and production technology of fibre reinforcement. A number of works show that the appropriate choice of material and construction can affect the rate of impact destruction - the amount of energy absorbed by the impact. There are many methods and approaches to determine the resistance of composite material to impact. Using numerical methods, these processes can be modelled. Thin CFRPs have a higher energy absorption efficiency (EAE) at a higher speed impact. It is deduced from the results of experiments and mathematical simulations [1]. CFRP laminates with higher thickness have a higher EAE at a lower speed impact. There are differences in CFRP response depending on the type of reinforcement used. [2] described the difference energy absorption for laminates from woven fabrics (plain and satin weave were compared) and from woven reinforcement consolidated with kevlar sewing at high impact velocity. Different test method is used for composite energy absorbers. Composite materials absorb energy through controlled gradual material failure. Total absorbed energy (AE) and specific absorbed energy (SAE) are determined. The total absorbed energy is the area under the force-displacement curve. Series of tests on shape-defined absorbers was realized, which had a different composition and were made of different materials. The SAE value was dependent on the orientation of the reinforcement. Specimens with reinforcement oriented in the load direction have achieved the best results [3]. Comparison of absorbers produced by different technologies was made. Specimens were made from pressed composite boards absorb more energy than specimens were made from filament wound composite tubes [4].

Material and methods

The experiment was performed on specimens made from unidirectional carbon prepreg [5]. It is semi finished product formed high strength carbon fibres that are pre-impregnated epoxy matrix (matrix constitutes 38% by weight of prepreg). The fibres are oriented in one direction only. Three groups of specimens was prepared for experiment, groups was designated by composition L, T, W. Specimens were made with different composition, orientation of the reinforcement and with different number of plies. Table 1 contains composition and properties of specimens.

Tab. 1 Properties of specimens

specimens	composition	thickness [mm]	areal weight [gm^{-2}]
L	1 pl;	0.16	250
T	3 pl; 0°/90°/45°; non crimp	0.38	600
W2	2 pl, plain weave	0.29	425

For crash test was used hydraulic motor for high speed uniaxial loading with hemispherical impactor with a radius of 20 mm. The speed of the impactor for the duration of the sample penetration was constant 10 ms^{-1}. The course of the test is shown in Fig. 1. A graph for each composite specimen was created from measured force and displacement values. An example of a force dependence on displacement for a W marked specimen is shown in Fig. 2.

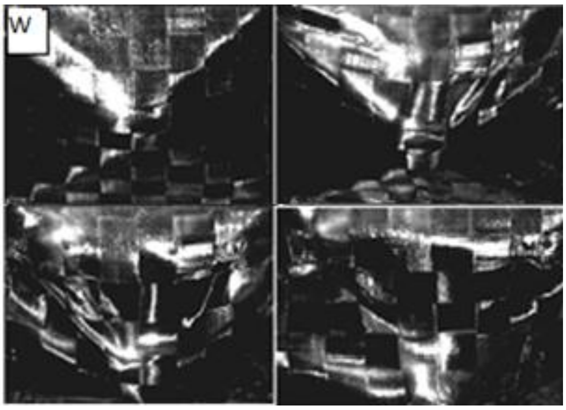

Fig. 1 The course of crash test

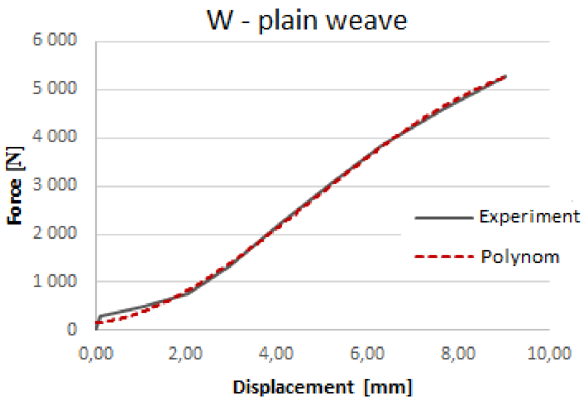

Fig. 2 Graph of W specimen

The curve of the graph was spaced by a 4th degree polynomial that approaches the experimental curve (Fig. 2). The polynomial data was used to calculate value of impact energy – total absorbed energy (Equation 1).

$$U = \int_{X1}^{X2} F(x)dx \tag{1}$$

In the preceding formula represents: U - mechanical energy [J], F(x) - function of the force-deformation of the test piece [N], x - deformation of test [m].

Verification of the correctness of the calculation was performed by combining the start and end points of the curve (minimum and maximum force) with the tangential. Results of measurements shows Table 2.

Tab. 2 Results of experiment

Specimens	Avr. of force [kN]	Avr. of displacement [mm]	Average of energy [J]
L (L1-L3)	0.63	7.41	3.25
T (T1-T3)	4.48	10.55	25.19
W (W1-W3)	4.83	19.96	39.26

FEM model

The geometry of the three test specimens was created in the Solidworks CAD program. Sample parameters were based on real values, size 100x100mm and thickness 0.16, 0.38 and 0.29 mm. A 20 mm diameter ball end impactor was positioned perpendicular to the centre of the sample. Sample assemblies were saved in * .step format and imported into ANSYS software. The module for explicit dynamics was used to simulation. The new material model was created in the library. The measured mechanical properties were inserted into the model. The linear elastic orthotropic properties of the material were used to create the material modulus [6]. The elastic modulus, the Poisson number, and the shear modulus were also calculated from the measured values. Material properties of the steel were introduced into the model according to Table 3.

Tab. 3 Material properties of model

Material	Density [kg.m^{-3}]	Elastic modulus [GPa]		Shear modulus [GPa]		Poisson ratio [-]		Tensile strength [Gpa]
		$E_{11}^{f,m}$	$E_{22}^{f,m}$	$G_{12}^{f,m}$	$G_{23}^{f,m}$	$\nu_{12}^{f,m}$	$\nu_{23}^{f,m}$	
Carbon fiber	1318	12.33	77.80	5	3.08	0.27	0.42	1.332
Structural steel	7850	200		76.9		0.3		0.25

Describe of destruction

Fixation boundary conditions were inserted into the edges of each sample. Conditions prevent rotation and displacement in all directions. The motion boundary condition was inserted into the impactor model that moved perpendicularly to the model of composite plate. The displacement corresponded to the maximum measured values of the experiment. The result of each simulation was the value of the impact energy [7, 8].

Specimens L: single layer of prepreg, fibres with directional orientation 0 °. The matrix was broken during impact, the fibres were broken too (Fig.3). The direction of deformation in the model is in accordance with the orientation of the fibres, the maximum energy is concentrated at the point of impact (Fig. 3)

Specimens T: three layers of prepreg, 0 ° / 90 ° / 45 ° directionally oriented. The impact energy is concentrated at the point of contact, the fibres are damaged in this area (Fig. 4). The model shows instead of the maximum energy concentration and its propagation in the plate (Fig. 4)

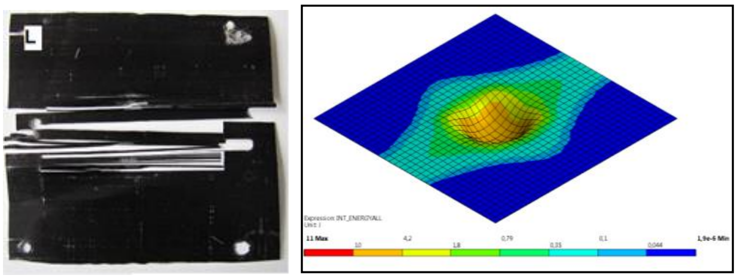

Fig 3. Specimen L after test and model

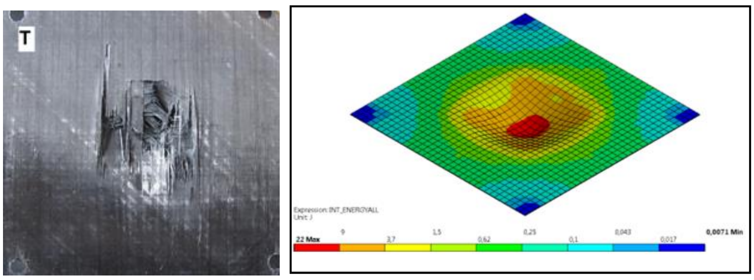

Fig 4. Specimen T after test and model

Specimens W: The square shows the binding point (warp or weft, change of fibre orientation 0°/90°and 90°/0°). The specimen area is composed of binding elements. In the event of an impact, the energy is concentrated to the point of impact and continues to be limited (Fig. 5). The model shows instead of the maximum concentration of energy. The binding elements absorb energy using alternation the directional orientation of the layers and limit crack propagation.

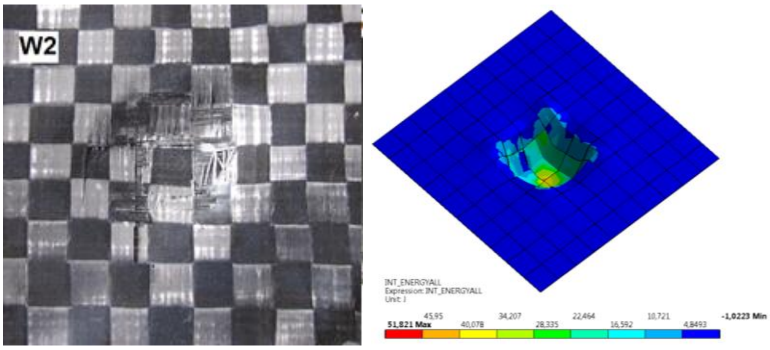

Fig 5. Specimen W after test and model

Conclusion

Crash tests were performed on three variants of carbon prepreg specimens. Measurement results (force and deformation) were used to calculate the energy required to break individual specimens. Calculated values were verified using a mathematical model. Results is showed Table 4.

Tab. 4 Comparison of energy

	L	T	W
Energy (calculation) [J]	3.25	25.20	39.26
Energy (simulation) [J]	6	22.1	51.8

The energy value for the L series specimens is 50% higher than the energy obtained from the measurement. Values are almost equivalent for T-series specimens. The mathematical model assumes a higher energy value for W series specimens by 32% than measured. Conclusions of the experiment are difficult to generalize due to the low number of specimens.

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