Experimental and numerical analysis of impact test of carbon prepreg composite

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Abstract: Composite structures are now increasingly used for their properties in all areas of industrial production. They gradually replace metal parts and components not only because they are lighter, but above all for their comparable and in many ways even better mechanical properties. This paper presents the experimental and numerical analysis of composite a flat samples of prepreg. The individual layers are non-crimp or interconnected plain weave. Comparison of the numerical modeling and real output of samples produced from CF prepreg, which was specially designed for absorbing the energy during impact.

Keywords: prepreg, carbon fiber, impact test, experimental analysis, numerical analysis

1 Introduction

Research and development of composite materials has wide application in many industries. The composite material is usually defined as two or more component material; the resulting properties exceed the properties of the individual parts. The continuous phase (matrix) is to bind the reinforcement to maintain its orientation and to transfer strain. Reinforcement is a carrier of strength and stiffness of the composite. Changes the composition and the orientation of the reinforcement provides a better balance between mechanical properties and weight than traditional technical materials. The advantage of fibrous composites is based on high strength of fibers in the longitudinal direction and their very small cross-section. The fibers can be used as unidirectional oriented layers without mutual interconnection (UD layer; multiaxial knitted fabric), or as interconnected system with the specified direction of orientation (fabrics, braided structure). Energy absorption is interesting and important area in terms of research and prediction of the behavior of composite materials.

2 Experimental and numerical analysis of crash test of carbon composite

Article builds on the previous experiment. Originally it was prepared four series of samples from the unidirectional carbon prepreg with epoxy matrix (nominal matrix content 38%). Table 1 contains a list of series - L, D, C, W1 including parameters). The intention was to examine the different variations of double-layer composite arrangement [3]. Impact test was conducted on a high-speed hydraulic motor. Impactor with a diameter of 20 mm was awarded the speed of 10 ms^{-1}. The samples were mounted in the axis of movement of the impactor. Impact broke the samples in the middle. The maximum force at breakdown and elongation of sample were measured; the experiments were shot with high-speed camera. Fig.1 shows the device. A new series of samples was prepared from the same unidirectional prepreg; series T and W2; parameters are listed in Table 1. Fiber layers in multilayer samples are oriented at a given angle; precise positioning enables semisolid consistency of the matrix under normal temperature of 21° C. The focus of the experiment is the examination of biaxial layer samples - the group D, C and W1. Samples designed D and C are composed of two layers of unidirectional oriented fibers, the layers mutually enclose an angle of 90°. Samples designed W1 are formed by two layers of interlaced fibers, imitate the weave fabric of plain structure. For comparison, samples were prepared: single layer L, three-layer T and the sample of aluminum sheet. The dimensions of the samples are the same. Equipment used for crash test: hydraulic motor for high speed uniaxial loading Fig.1. On the piston rod of the hydraulic motor was placed the strength tester, on the tester was mounted hemispherical impactor. The speed of the impactor for the duration of the sample penetration was constant 10 ms^{-1}. Recording was made during the test period, the position of the impactor and the maximum value of achieved strength. During the experiment was recorded with high-speed camera. The numerical model that was created in the FEM program PAM CRASH, had given the same initial and boundary conditions as an experiment. Material models for carbon composites were selected from 130 - 132 - Multi-Layered Shell Element. Initial physical properties, which were used in the model, are presented in Table 2. Sample holder was modified to remove the influence of directional orientation of the layers when clamping the sample. Impact test was conducted with the same equipment and under the same conditions. The value of energy is determined by the equation 1:

$$U = \int_{x1}^{x2} F(x)dx \tag{1}$$

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

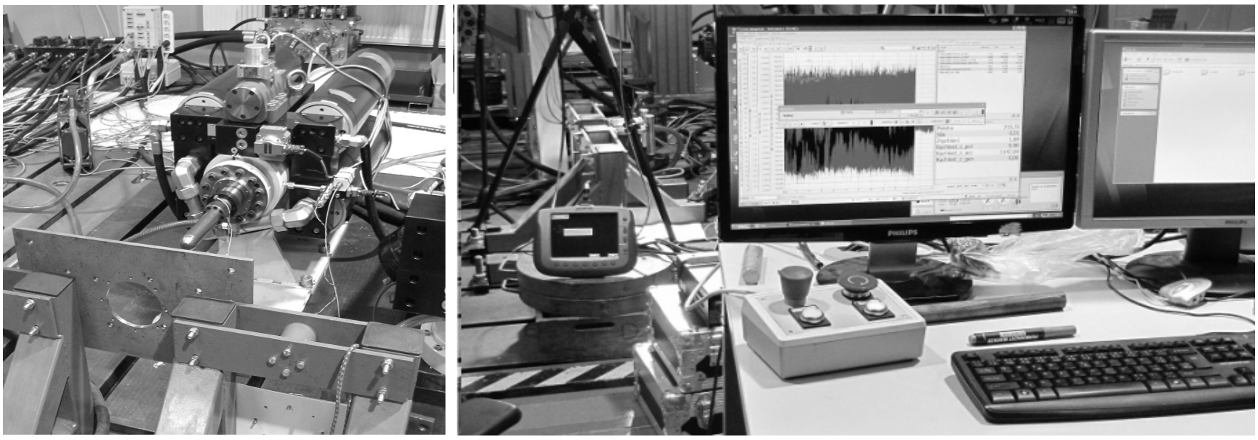

Fig. 1: Experimental device and measurement

Table 1: Parameters of experimental samples

sample	composition	thickness [mm]	areal weight [gm^{-2}]
L	1 pl;	0,16	250
D	2 pl; 0°/90°; non crimp	0,26	435
C	2 pl; ±45°; non crimp	0,30	435
W1	2 pl, plain weave	0,29	420
T	3 pl; 0°/90°/45°; non crimp	0,38	600
W2	2 pl, plain weave	0,29	425

Table 2: Physical parameters of numerical model

Material	Density [kg.m^{-3}]	Elastic modulus [GPa]		Shear modulus [GPa]		Poisson ratio [-]		Tensile strength [GPa]	Elongation [%]
		$E_{11}^{f,m}$	$E_{22}^{f,m}$	$G_{12}^{f,m}$	$G_{23}^{f,m}$	$\nu_{12}^{f,m}$	$\nu_{23}^{f,m}$		
Carbon fiber	1750±150	230	15	24	5.4	0,279	0,49	2,3±1,2	1,9±0,6
Epoxy matrix	1150±370	3.573	3.573	1,31	1,31	0,345	0,345	0,067±0,033	3,6

Numerical models were created for study of the mechanical properties of the samples of carbon composites. Models are based on analytical models, ie. Voight model, Reuss model, Chamis model and Halpin -Tsai model [2, 3]. From these simulations can be obtained elastic constants E_{22}, G_{12}, G_{23} (2-6), which can be compared with a numerical model [3]. Chamis model to calculate other elastic constants introduced into the solution to the square root of volumetric fibers $\sqrt{V^f}$; fibers are incompressibility in equations (3, 5-6), which is in accordance with the law of conservation of mass.

$$\frac{d\sigma_{11}}{d\varepsilon_{11}} = V^f \frac{d\sigma^f}{d\varepsilon^f} + V^m \frac{d\sigma^m}{d\varepsilon^m} \quad \Rightarrow \quad E_{11} = V^f E_{11}^f + V^m E^m \tag{2}$$

$$E_{22} = \frac{E^m}{1 - \sqrt{V^f}\left(1 - E^m / E_{22}^f\right)} \tag{3}$$

$$\nu_{12} = V^f \nu_{12}^f + V^m \nu^m \tag{4}$$

$$G_{12} = \frac{G^m}{1 - \sqrt{V^f}\left(1 - G^m / G_{12}^f\right)} \tag{5}$$

$$G_{23} = \frac{G^m}{1 - \sqrt{V^f}\left(1 - G^m / G_{23}^f\right)} \tag{6}$$

3 Results and conclusion

In the experiment were measured the following values: the maximum force and elongation before a crack of the sample. The results of experimental measurement were compared with FEM models that have worked with an error about of 9%. Models showed stress on samples distribution and failure of structure (Fig.2). Approximate value of the energy needed to crack the sample was calculated. Values are given in Table 3. Samples after the test are seen in Fig.3. New clamping device has helped to reduce error of measurement. All samples from the series T, W2 were broken in the middle from the impactor. Graph for describe of force versus elongation of the samples for a series of W2 is see Fig.3, where are a curves of force and the elongation of three samples for same series is similar. The measurements produced the following results as for examples: The quantity and orientation of non-crimp layers have a direct influence on the strength of the sample. Strength increases with the number of layers (D, C, T). Higher quantity of non-crimp layers reduces the flexibility of the sample and the elongation at impact (D, C, T). The highest values of strength and elongation achieved samples of plain weave (W2).

Table 3: Results of measurement

Variable/sample series	L	D	C	T	W1	W2	Al
Average of strength [kN]	0,63	3,83	4,74	4,48	2,69	4,83	1,51
Average of displacement [mm]	7,41	14,84	19,67	10,55	17,36	19,96	11,3
Average of energy [J]	-	-	-	21,30	-	38,38	-

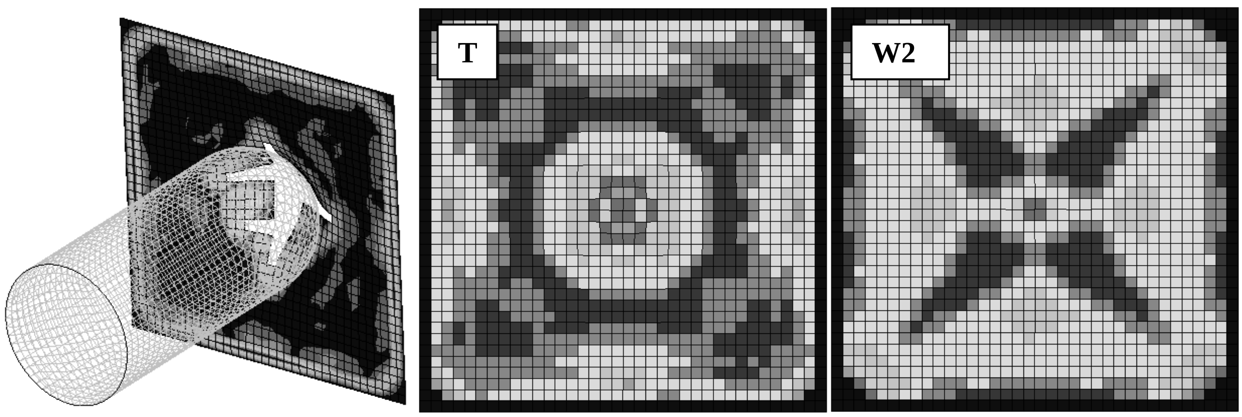

Fig.2: Numerical analysis: results major stress for sample T and W2 before a crack

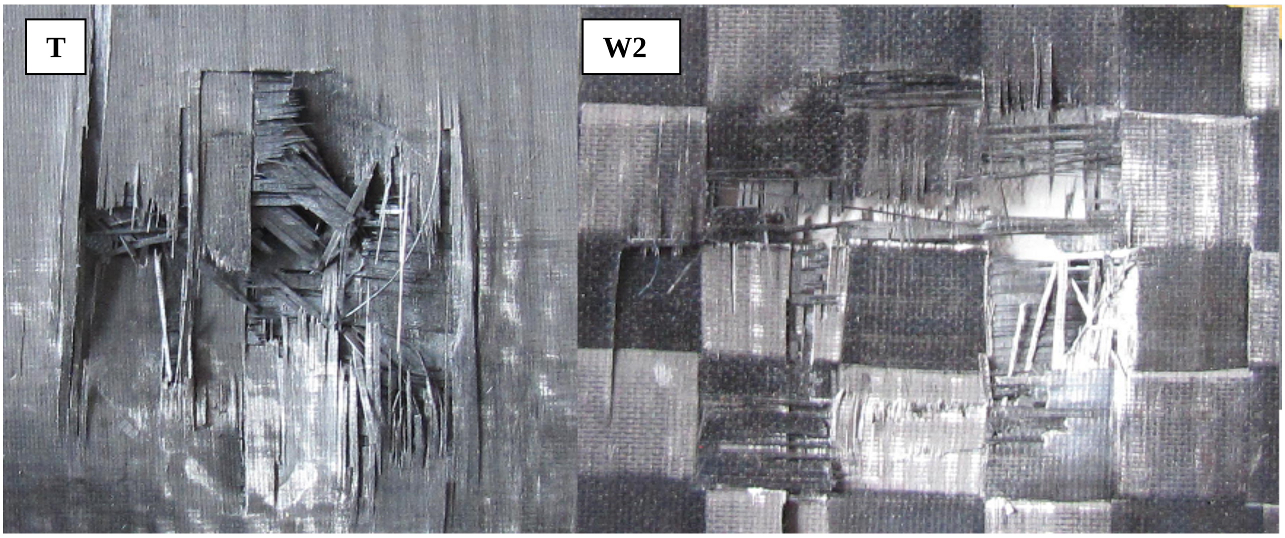

Fig. 3: Samples after test

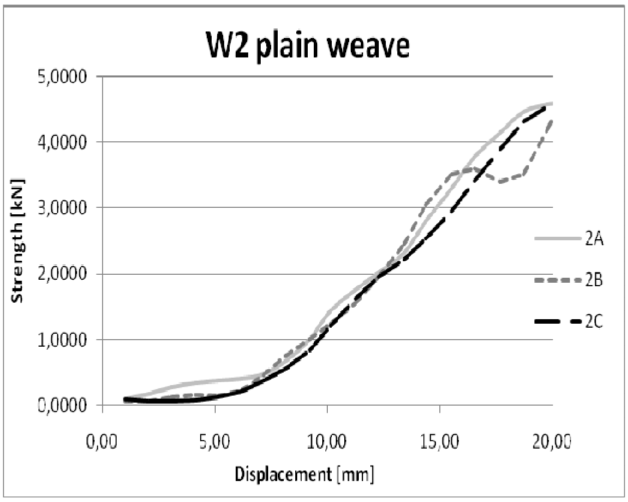

Fig.4: Graph of results of strength

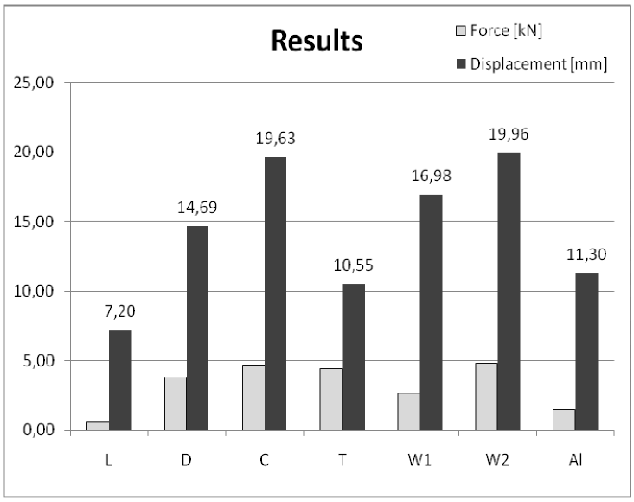

Fig.5: Graph of results: force and displacement

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