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Identification of mechanical properties from tensile and compression tests of unidirectional carbon composite

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Abstract: Selected stiffness and strength parameters of unidirectional composite, which consists of high strength fibers HTS and epoxy resin, are identified in this work. Load-displacement dependencies are measured for tensile and compression tests. The identification is performed with the use of numerical simulation of tests in finite element system MSC. Marc and optimization algorithms included in optiSlang software. The whole process of the identification is managed by scripts written in Matlab software.

Keywords: Experiment, Unidirectional composite, Identification, Compression test, Tensile test

1. Introduction

More material parameters than in standard metal materials are needed for definition of composite material behaviour. These all materials parameters of composite material often are not known from producer. Consequently, the material parameters have to be identified. For investigation of these parameters, several experimental tests must be carried out and then identification must be performed.

The most widely used in composite materials are long fiber reinforced composite material. Therefore, this material with high strength carbon fibers Tenax HTS 5631 and epoxy resin was used in this work. The identification of selected stiffness and strength parameters of this unidirectional composite was performed. Specimens were tested in tension and compression. Two types of compression tests and specimens with different geometry were used.

2. Experiments

All of the specimens were tested using Zwick/Roell Z050 testing machine in laboratory at Department of Mechanics, University of West Bohemia in Pilsen.

2.1. Tensile test

Tensile tests for specimens with different fiber angles were carried out. The specimens were cut with water jet from unidirectional composite plates, which were

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made from prepreg. The shapes of the tensile specimens are shown in Fig. 1. All plates were bonded on the specimens by Araldit AV 138M + HV 998 adhesive.

Measured properties were elastic modulus in the longitudinal direction (the fiber direction) E_L, elastic modulus in the transverse direction (perpendicular direction to the fiber) E_T, Poisson's ratio ν_{LT}, tensile strength in the longitudinal direction X^T and tensile strength in the transverse direction Y^T. Strain gauges (HBM, 350Ω) were used for measurement of Poisson's ratio ν_{LT} in test with $\theta = 0°$. The loading speed (crosshead speed) was $v = 1$ mm/min in all tensile tests.

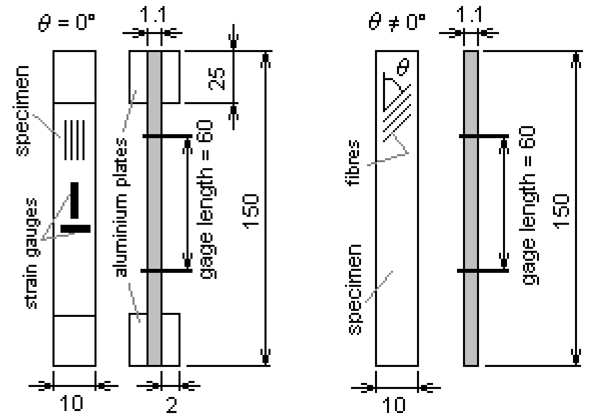

Fig. 1. Tensile specimens (a) $\theta = 0°$, (b) $\theta = 15°, 30°, 45°, 60°, 75°$ and $90°$.

The load-displacement dependencies for all investigated angles θ are shown in Fig. 2. The fracture of specimen for all fiber angles is displayed in Fig. 3.

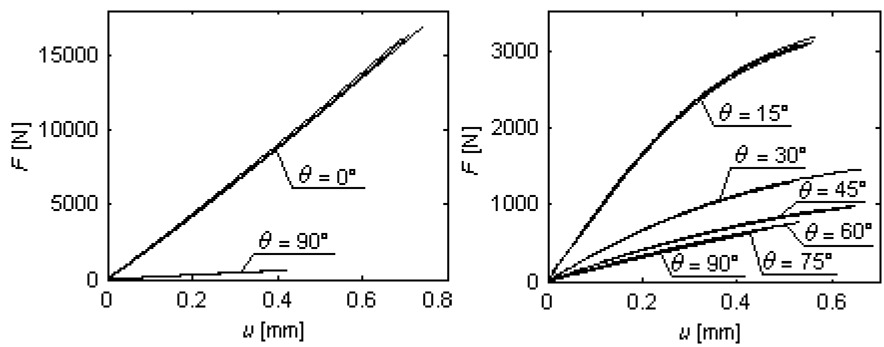

Fig. 2. Force and extension dependencies (a) $\theta = 0°$ and $90°$, (b) $\theta = 15°, 30°, 45°, 60°$ and $75°$.

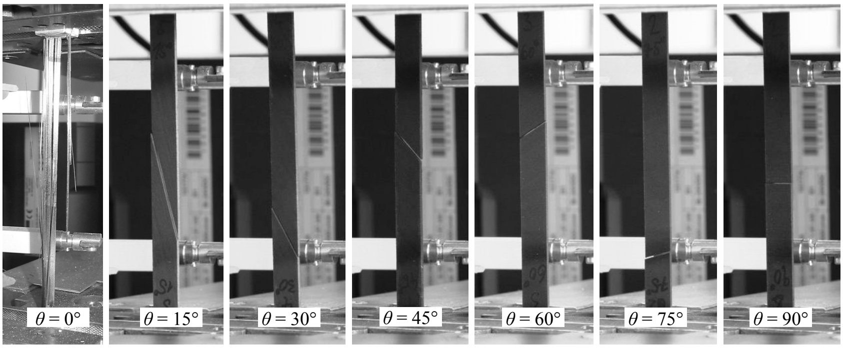

Fig. 3. Fracture of specimens.

2.2. Compression tests

Two types of compression tests (see Fig. 4) were performed. The shapes of the compressive specimens are illustrated in Fig. 4. The geometric properties of compressive specimens are presented in Table 1 in case of compression test type I and Table 2 in case of compression test type II.

Measured properties for type I compression test were compressive strength in the transverse direction Y^C and angle of the fracture plane in pure transverse compression α_0. Measured properties in type II of compression test were compressive strength in the longitudinal direction X^C and compressive strength in the transverse direction Y^C.

The loading speed was v = 1.3 mm/min in case of compression test type I and v = 0.2 mm/min in case of compression test type II.

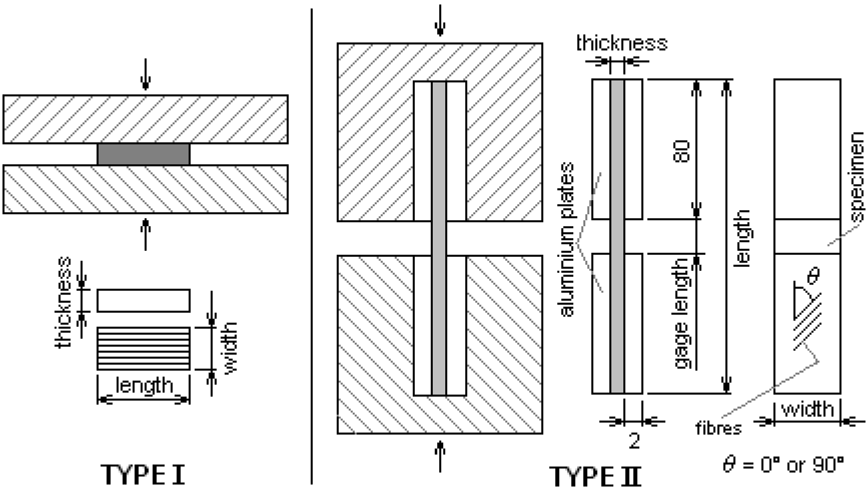

Fig. 4. Types of compression test.

In Table 1, compressive strengths in the transverse direction for the different geometric parameters of specimens in case of type I are presented. Fracture of specimen after the compression test is displayed in Fig. 5.

Table 1. Compressive strength – compression test I

Labelling	Length [mm]	Width [mm]	Thickness [mm]	Y^C [MPa]
C-I_a	4.9	9.9	2.2	210
C-I_b	9.9	4.9	2.2	220
C-I_c	9.9	10.0	2.2	220
C-I_d	17.8	4.9	2.2	203
C-I_e	4.9	17.8	2.2	245*
C-I_f	9.9	17.8	2.2	272*

* incorrect fracture

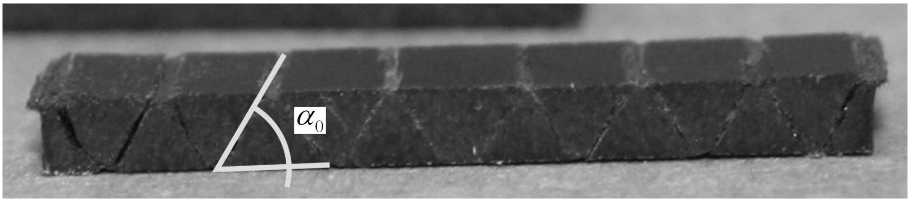

Fig. 5. Fracture of specimen C-I_a.

In case of compression test – type II, compressive strength in the transverse direction Y^C and compressive strength in the longitudinal direction X^C for the different geometric parameters of specimens are presented in Table 2. The fracture of specimens is displayed in Fig. 6.

Table 2. Compressive strengths – compression test II

Labelling	Length [mm]	Gage length [mm]	Width [mm]	Thickness [mm]	Fiber angle [°]	Y^C [MPa]	X^C [MPa]	*Failure identification code*
C-II_a	165	5.0	25.0	1.1	90	185	-	HAM
C-II_b	170	10.0	25.0	2.2	90	175	-	AAT
C-II_c	165	5.0	9.8	1.1	0	-	987	TAM
C-II_d	170	10.0	9.8	2.2	0	-	853	HAM

Variances of the values of compressive strength in the transverse direction Y^C for specimens C-II_a and C-II_b were much larger then in case of compression test I. Consequently, only value from compression test I were used for the identification.

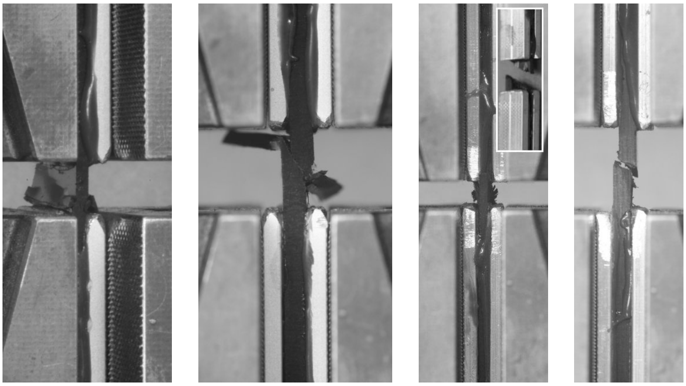

Fig. 6. Fracture of specimens (a) C-II_a, (b) C-II_b, (c) C-II_c (d) C-II_d

A failure identification code, which is presented in Table 2, consists of three characters [1]. The first one is the failure mode, the second one is the failure area and third one is the failure location. Used characters are described in Table 3.

Table 3. Failure identification codes [1]

First character		Second character		Third character	
Failure mode	Code	Failure area	Code	Failure location	Code
Angled	A	At grip/tab	A	Top	T
tHrough thickness	H			Middle	M
Transverse shear	T				

3. Identification of material parameters

It was possible to obtain material parameters X^T, Y^T, X^C, Y^C, α_0 from the experiments

$$X^T = \frac{F_{\max}^{T\_0}}{A},\ Y^T = \frac{F_{\max}^{T\_90}}{A},\ X^C = \frac{F_{\max}^{C\_0}}{A},\ Y^C = \frac{F_{\max}^{C}}{A}, \tag{1}$$

where A is area of cross-section, $F_{\max}^{T\_0}$ is maximal tensile force in test with $\theta = 0°$, $F_{\max}^{T\_90}$ is maximal tensile force in test with $\theta = 90°$, $F_{\max}^{C\_0}$ is maximal compressive force in compression test type II with $\theta = 0°$, $F_{\max}^{C}$ is maximal compressive force in test type I.

The values of these strength parameters are presented in Table 4. The linear dependence of tensile force on displacement (up to the fracture of specimen) is obvious from load-displacement curves (see Fig. 2.) for specimens with fibre angles 0° and 90°. Elastic modules (in the longitudinal and transverse direction) were determined directly from these dependencies. Values of these elastic modules are presented in Table 4.

In case of specimens with fibre angles between 15° and 75°, the nonlinear dependence of tensile force on displacement is obvious (see Fig. 2.). The linear relationship can be used with sufficient accuracy only in case of small displacement. The nonlinear function had to be used for description of material behaviour up to fracture. The nonlinear function with constant asymptote [3] was used for shear modulus G_{LT} in the process of identification

$$G_{LT}(\gamma_{LT}) = \frac{G_{LT}^0}{\left[1+\left(\frac{G_{LT}^0 \cdot \gamma_{LT}}{\tau_{LT}^0}\right)^{n_{LT}}\right]^{1+\frac{1}{n_{LT}}}}, \qquad (2)$$

where G_{LT}^0 is initial shear modulus, γ_{LT} is shear strain, τ_{LT}^0 is asymptote value of shear stress and n_{LT} is shape parameter. Parameters $G_{LT}^0, \tau_{LT}^0, n_{LT}$ and S^L are parameters of optimization. A comparison between linear and nonlinear models is shown in Fig. 7.

The strength criterion for unidirectional composite materials LaRC04 [4] was used for identification of shear strength S^L. The criterion LaRC04 was implemented in the used finite element system MSC.Marc [2].

The identification is performed with the use of numerical simulations of tests in finite element system MSC.Marc and optimization algorithms included in optiSlang software. By means of these optimization algorithms, the following function was minimized

$$R = \sum_j \frac{\sum_i \left(F_e(u_i,\theta_j) - F_n(u_i,\theta_j)\right)^2}{\max_i\left(F_e(u_i,\theta_j)\right)}, \qquad (3)$$

where F_e is force from experiment, F_n is force from numerical simulation and u is displacement. The whole process of the identification is managed by scripts written in Matlab software. A schema of identification process is illustrated in Fig. 8.

Table 4. Identified material parameters

Linear model				Nonlinear model								
E_L [GPa]	E_T [GPa]	υ_{LT} [-]	G_{LT} [GPa]	G_{LT}^0 [GPa]	τ_{LT}^0 [GPa]	n_{LT} [-]	X^T [MPa]	X^C [MPa]	Y^T [MPa]	Y^C [MPa]	S^L [MPa]	α_0 [°]
120.0	8.0	0.337	4.0	4.6	115.0	1.2	1480	850	55	213	82	57

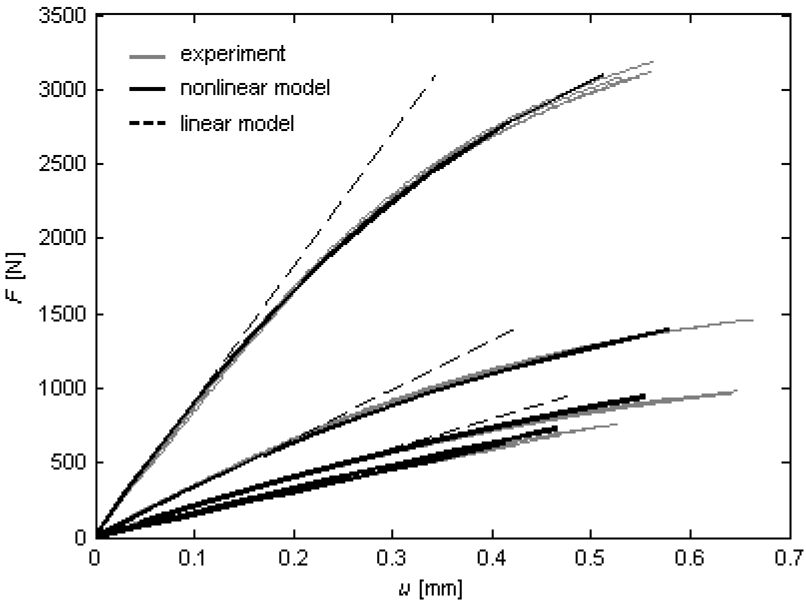

Fig. 7. Linear vs. nonlinear model.

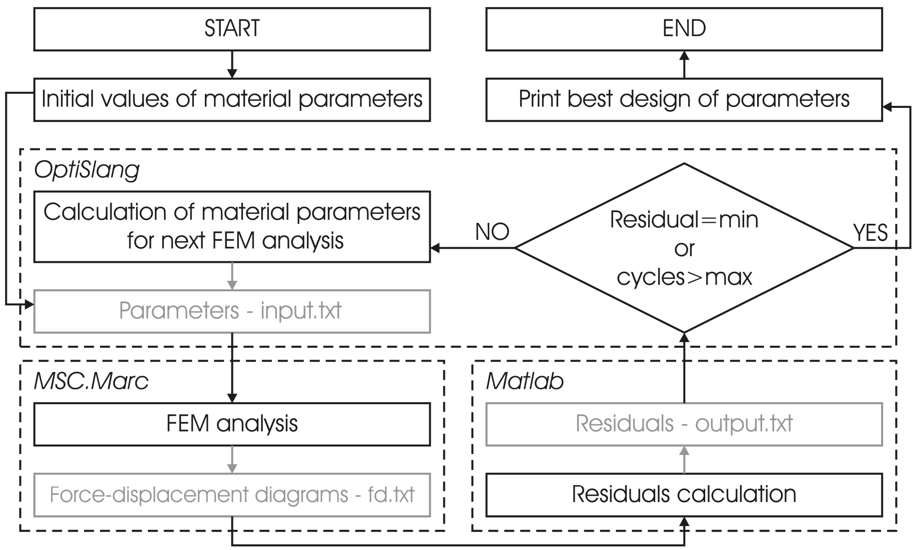

Fig. 8. Schema of identification process [3].

4. Conclusion

In the presented work, the identification of selected stiffness and strength parameters of unidirectional carbon fiber reinforced composite was performed. Specimens with different geometric properties were tested in tensile test and two types of compression tests.

The material parameters were identified with the use of numerical simulation of tests in finite element system MSC.Marc and optimization algorithms included in optiSlang software. Failure criterion LaRC04 was used for the identification of strength parameters.

The nonlinear function with constant asymptote had to be used for description of material behaviour up to fracture in the process of identification. In case of small displacements, the linear relationship can be used with sufficient accuracy.

Acknowledgements

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