Experimentální Analýza Napětí 2011
Experimental Stress Analysis

Strength analysis of unidirectional carbon fibre reinforced plastic under biaxial loading

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Abstract: Unidirectional carbon fibre reinforced plastic was exposed to the combination of tension in the fibre direction and localized compression in the transverse direction. The specimens were cut using water jet from composite plates. The unidirectional composite plates were made from prepreg which consists of high strength carbon fibers and epoxy resin. Standard testing machine Zwick/Roell Z050 was supplemented by second loading axes for the localized compression. Dependence of the tensile strength in the fibre direction on the localized compression in the transverse direction was investigated.

Keywords: Biaxial test, Combination of tension and localized compression, Experiment, Unidirectional composite.

1. Introduction

The capability of failure prediction is an important part of knowledge of mechanical engineering. Mechanical engineer cannot design safe and simultaneously cheap construction without this capability. Failure of composite materials is very complex problem. Failure of composite is influenced by type of loading, material of constituents (fibre and resin), lay-up of layers, etc. The failure of composite material is well predictable only in basic case of loading. For many combinations of state of stress, failure of unidirectional composites cannot be predicted with existing failure criteria.

A biaxial test was proposed for testing of predictive capability of the failure criteria for unidirectional composite material. Rectangular specimens were loaded in two mutually perpendicular directions. Dependence of specimen strength on the ratio of tension in the longitudinal and compression in transverse direction was investigated.

2. Biaxial test

Biaxial test was proposed for failure analysis of unidirectional fibre reinforced plastics. Schema of the biaxial test is illustrated in Fig. 1, where b = 5 mm is width of the specimen, h = 2.2 mm is thickness, l = 240 mm is overall length of the specimen, w = 20 mm is width of the compression element, v = 10 mm is length of the compression element and R = 1 mm is edge radius.

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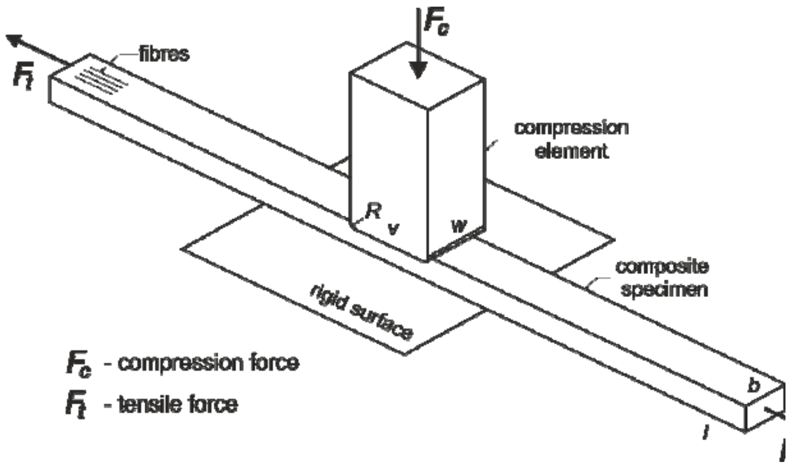

Fig. 1. Schema of biaxial test

Experimental specimens were loaded in two mutually perpendicular directions. The specimens were exposed to the combination of tension in the fibre direction and localized compression in the transverse direction. Standard testing machine Zwick/Roell Z050 was supplemented by second loading axis for the localized compression (see Fig. 2). The second loading axis consisted of power machine vise VMC-130 and HBM C9B compact force transducer.

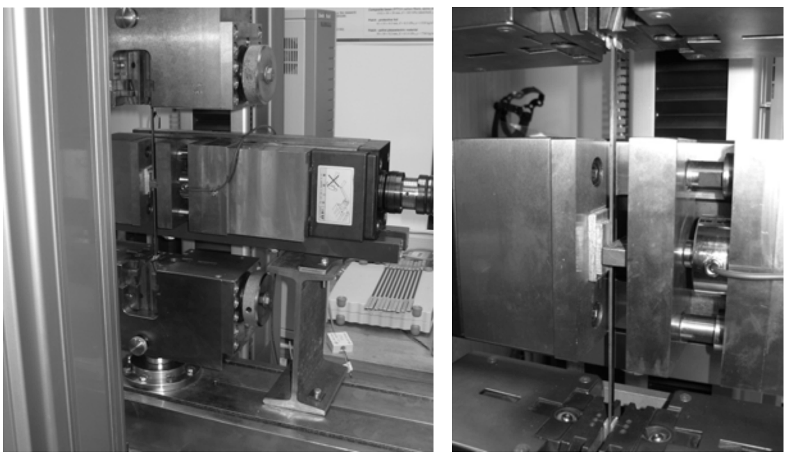

Fig. 2. Testing machine with additional compression device

The loading was applied in two basic steps (see Fig. 3). In the first step, the specimen was loaded by tensile force F_t in the longitudinal (fibre) direction. In the second step, the specimen was loaded by localized compression F_c in the transverse direction.

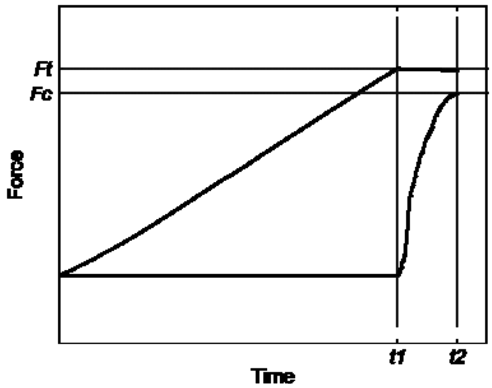

Fig. 3. Dependence of loading forces on time

In case of high value of tensile force, failure of specimens (without aluminium pads) occurred in grips because of its rough surface. Therefore, the specimens were equipped with aluminium pads on both sides (see Fig. 4). All pads were bonded on the specimens by Araldit AV 138M + HV 998 adhesive.

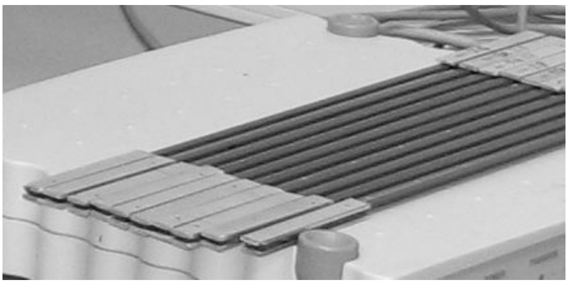

Fig. 4. Specimens with aluminium pads

3. Material properties

The specimens were cut using water jet from unidirectional composite plates, which were made from 8 layers of prepreg. Composite material consisted of Tenax HTS 5631 high strength carbon fibres and epoxy resin. Identification of mechanical properties of this unidirectional composite material was carried out in [3] by means of tensile and compressive tests. The identified mechanical properties are presented in Table 1. Identification was carried out for transversely isotropic material model. Failure criterion LaRC04 was used for the identification of strength parameters. The nonlinear function with constant asymptote [1, 3] was used for shear modulus G_{12} in the process of identification in form

$$G_{12}(\gamma_{12}) = \frac{G_{12}^0}{\left[1 + \left(\frac{G_{12}^0 \cdot \gamma_{12}}{\tau_{12}^0}\right)^{n_{12}}\right]^{1+\frac{1}{n_{12}}}}, \tag{1}$$

where G_{12}^0 is initial shear modulus, γ_{12} is shear strain, τ_{12}^0 is asymptote value of shear stress and n_{12} is shape parameter.

Table 1. Mechanical Properties

Linear model				Nonlinear model									
E_1	E_2	υ_{12}	G_{12}	G_{12}^0	τ_{12}^0	n_{12}	X^T	X^C	Y^T	Y^C	S^L	α_0
[GPa]	[GPa]	[-]	[GPa]	[GPa]	[GPa]	[-]	[MPa]	[MPa]	[MPa]	[MPa]	[MPa]	[°]
120.0	8.0	0.337	4.0	4.8	100.0	1.11	1800	850	55	213	82	57

4. Results

Dependence of the specimen strength on ratio of the tensile and compression forces was investigated (see Fig. 5). Dots in the graph represent failure of matrix (see Fig. 6), crosses represent failure of fibres (see Fig. 7).

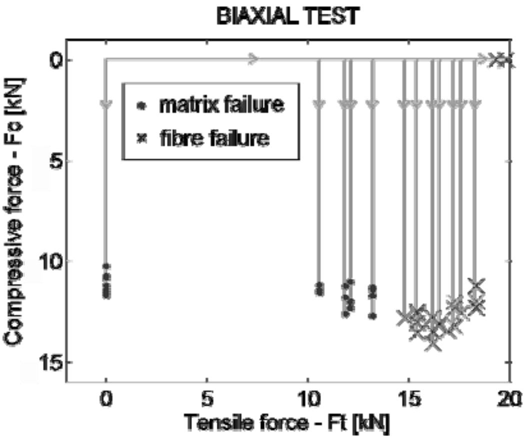

Fig. 5. Dependence of specimen strength on the combination of tensile and compression forces

In case of matrix failure, it is obvious from the mentioned dependencies that the compressive strength is increasing with the tensile force. Numerical simulations of biaxial test were carried out in [2]. In this work, it was found that only adjusted LaRC04 criterion showed acceptable agreement for matrix failure.

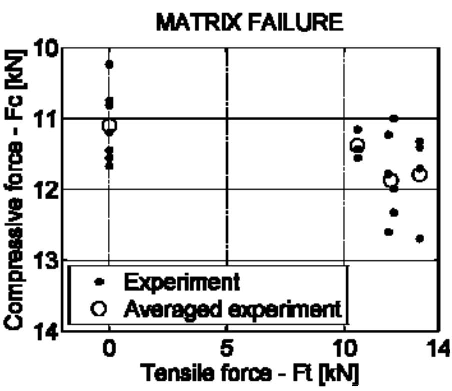

Fig. 6. Matrix failure

In case of fibre failure, the tensile strength is decreasing with the compressive loading. No criterion described the trend correctly in [2]. The function describing experimental failure envelopes was sought. The function of experimental failure envelopes (see Fig. 8) was propose in this form

$$\sigma_2 = P_1 \cdot \text{arcsinh}\left[P_2\left(\sigma_1 - X^{\mathrm{T}}\right)\right], \tag{2}$$

where σ_1 and σ_2 are stresses in longitudinal and transverse direction, P_1 and P_2 are adjusting parameters and X^{T} is tensile strength in fibre direction.

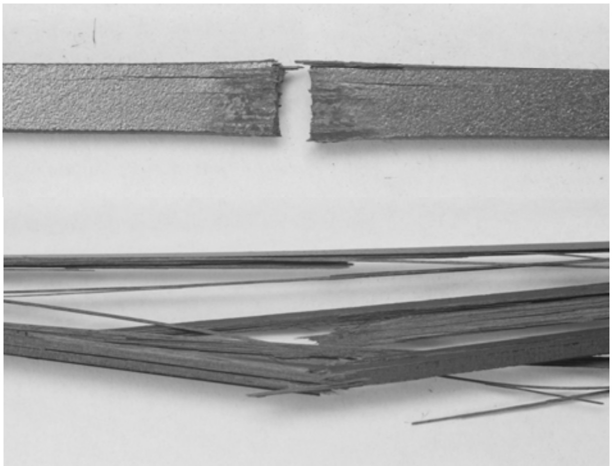

Fig. 7. Fibre failure

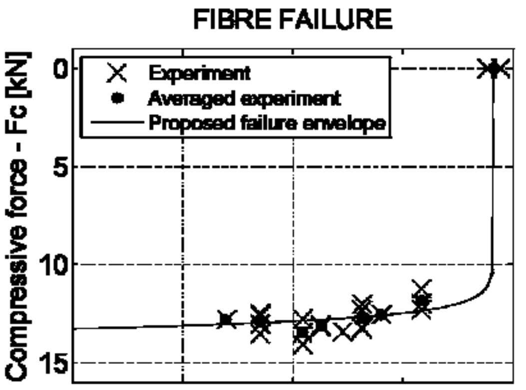

Fig. 8. Failure envelope (fibre failure)

5. Conclusion

Biaxial test for unidirectional carbon fibre reinforced plastic was carried out in this work. Composite material consisted of high strength carbon fibres and epoxy resin. The specimens were loaded in two mutually perpendicular directions, tension in the longitudinal (fibre) direction and localized compression in the transverse direction.

The compressive strength is increasing with the tensile force. Whereas, the tensile strength is decreasing with the compressive loading. Function with arcsinh was propose for experimental failure envelope in case of fibre failure.

Acknowledgements

The work has been supported by the research project of the Ministry of Education of Czech Republic no. MSM 4977751303, the research project MŠMT 1M0519 – Research Centre of Rail Vehicles supported by the Czech Ministry of Education, the European project NTIS – New Technologies for Information Society No.: CZ.1.05/1.1.00/02.0090 and the project of Ministry of Education SGS-2010-046.

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