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Study of bending properties of thin walled carbon and flax composite rods winded of prepreg fibers

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Abstract. Mechanical testing of composite parts and materials in order to obtain basic mechanical parametres is a time consuming often difficult process. However, due to rising prices of materials and the high energy demand plays reduction of weight of final products an important role through almost all manufacturing sectors [1]. When replacing conventional materials by composites it is important to know the exact mechanical properties, because just with an appropriate combination of individual layers, dispersion and matrix we can achieve the solution tailored to the specific application. Therefore the aim of the carried work was experimentally and by using appropriate numerical and material models describe the behavior of the two kinds of composite rods during classical three-point bending test. A difference in the behavior of both structures was clearly noticeable during the experiment. The flax material endured lesser strain and also the arising deformations had distinctly different character. At the same time in the ACP module of ANSYS was created model as a tool for verification of the obtained data. The initial data obtained from the model and experiment were in quite good agreement until the first peak of maximal strength, when in a real case occurs warping of the rod shape, fiber rupture and delamination. This in the experiment caused significant decrease of the strength, but in the model, however, the force still continues to grow. For this reason is for advanced modeling necessary to supplement the model of cohesive interlayers and failure criterion.

Introduction

Composite materials are used especially because of their low weight, very high strength and offer also solution for applications subjected to fatigue loadings. Whereas metal materials show one failure mode i.e. cracking, composites can exhibit one or a combination of failure modes, including fiber rupture, matrix cracking, delamination, interface debonding and void growth [2].

Mechanical testing is, however essential process, and according to Camanho [2] can be simplified by testing of simple structures, such as flat coupons. With this absolutely did not agree Wang [3] who mentioned that the laboratory samples and real parts show considerable differences in the obtained mechanical properties. The use of flexural tests to determine the mechanical properties is widespread to the relative simplicity of the test method and required equipment. Using a short beam it is also possible to make flexure tests to determine the interlaminar shear strength of a laminate. The stiffness of anisotropic composite plates depends on several factors, i.e. fiber orientation, laminate stacking, surface waviness and molding temperature. The modes of failure in a bending with large deflection and destruction of the samples describe [4, 5]. In their works is possible to find description how in fiber composites begins damage at micro-scale with matrix cracking, fibre matrix debonding and fibre failure. This is followed by meso-scale damage such as intra-yarn cracking and inter-ply delamination.

Materials

Plastics materials reinforced by long fibers are widely used because of their high strength and modulus to density ratio [6]. The high strength composite materials are capable to transform stress only in the fiber direction (Fig. 1). Tensile strength in the direction perpendicular to the direction of longitudinal fibers is even lower than the ultimate strength of the matrix itself, which is caused by the concentration of local stress on their interface [1]. The main constituent of tested samples are carbon and flax fibers (Tab.1) pre-impregnated with resins. The used material is an epoxy UD prepreg with thickness of 0.2 mm. According to conducted measurements and to [7] is the final thickness after polymerization approximately 85 % of the original one. Three plies (45/0/-45) was layered on a nonbearing mandrel with the outer diameter 24 mm.

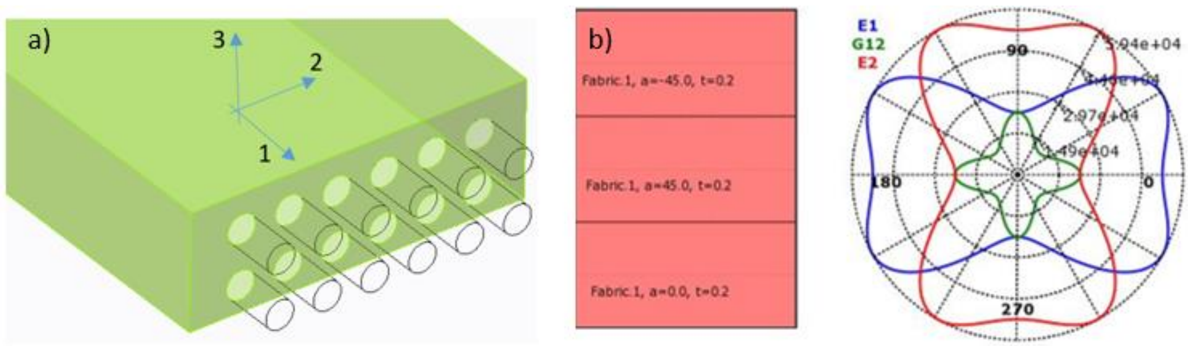

Fig. 1 UD composite: a) Convention of the global coordinate axis b) Polar properties of the created carbon stackup (45, 0,-45)

Tab. 1 material properties of used UD prepreg materials

	E1 [MPa]	E2 [MPa]	ρ [g/cm^3]	μ [-]	Ductility [%]
Flax	10 100	6 000	1,5	0,21	2
Carbon	101 000	9 000	1,9	0,25	lim -> 0

In the view of homogenization a transversally isotropic behaviour is commonly assumed for the composite [8]. Consequently, the stiffness could be described by a set of five parameters: young-moduli ($E_{11}$and E_{22}), poisson's ratios (ν_{12} and ν_{23}) and a shear-modulus (G_{12}). With the help of homogenization techniques these five parameters describing the stiffness behaviour of the composite can be derived. It is necessary to mention that this idea is valid only with an assumption of a really perfect alignment of fibres. Then the compliance matrix can be rewritten in terms of the engineering constants (1).

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \sigma_3\\ \tau_{23}\\ \tau_{31}\\ \tau_{12}\end{bmatrix} = \begin{bmatrix}\frac{1}{E_1} & -\frac{\mu_{12}}{E_1} & -\frac{\mu_{13}}{E_1} & 0 & 0 & 0\\ -\frac{\mu_{21}}{E_2} & \frac{1}{E_2} & -\frac{\mu_{23}}{E_2} & 0 & 0 & 0\\ -\frac{\mu_{31}}{E_3} & -\frac{\mu_{32}}{E_3} & \frac{1}{E_3} & 0 & 0 & 0\\ 0 & 0 & 0 & \frac{1}{G_{23}} & 0 & 0\\ 0 & 0 & 0 & 0 & \frac{1}{G_{31}} & 0\\ 0 & 0 & 0 & 0 & 0 & \frac{1}{G_{12}}\end{bmatrix} \begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \varepsilon_3\\ \gamma_{23}\\ \gamma_{31}\\ \gamma_{12}\end{bmatrix} \quad (1)$$

Experiment

The flexural strength of a material is the maximum stress that material subjected to bending load could resist before failure [9] Chung. The aim of the carried experiment was to study behaviour of two kind of tubes in flexural stress. The applied quasi static loading had increased with step 0,5 mm /s [10] until caused the final 80 mm displacement of used indenter - measured from the point of a first touch with the tube (Fig. 2). The distance *l* between the supports is in our case equal to 380 mm.

The basic force equilibrium equation at a point (x, z) in the beam is given by (2).

$$\frac{d\sigma}{dx} - \frac{d\tau}{dz} = 0 \quad (2)$$

Where σ and τ are the respectively normal and shear stresses.
Because for composite the mid plane is not exactly in the center of a tested sample, we need to distinguish h measured from the neutral plane to the bottom of the beam and ht to the top in equation (3).

$$\int_{-h_b}^{0} \sigma_T\, dz + \int_{0}^{h_t} \sigma_c\, dz' = 0 \quad (3)$$

Where indexes T and C denote tension and compression, and h_b + h_t are equal to the outer diameter of tested rod.

Fig. 2 Shape of the deformed samples: a) flax fiber tube, b) carbon fiber tube

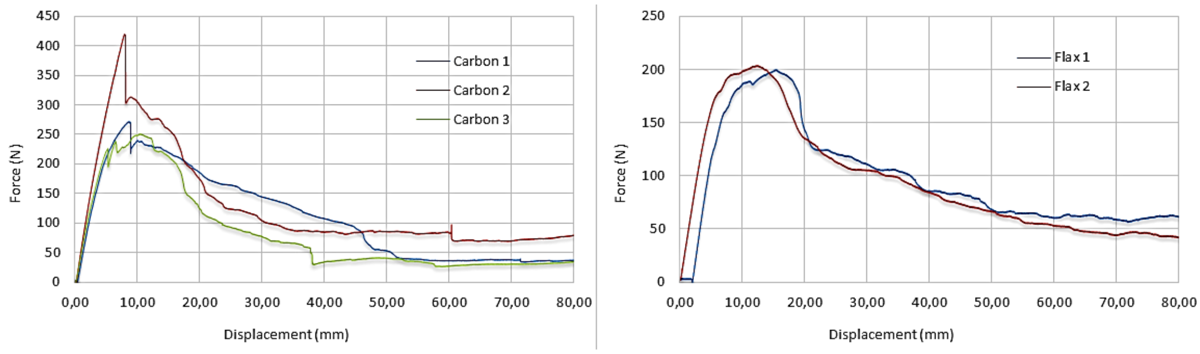

Fig. 3 Experiment, Force – Displacement relation for the tested rods a) Carbon b) Flax

Based on the measured deformation, it is possible to determine the flexion stress (4).

$$\sigma_O = \frac{M_{Omax}}{W_O} = \frac{F_{max} \cdot l}{4 \cdot W_O} \tag{4}$$

Numerical model of the solved problem.

Finite-element method (FEM) is a powerful tool without is today not possible to efficiently design composite parts. The prediction of their mechanical behaviour is very complex problem, because the process induces fiber orientation, interface of plies etc. Numerical analysis allows us to derive the different strain energies stored in the material directions of the constituents of composite materials [11]. Advanced methods could even describe the entire damage process from its initiation through evolution to a complete failure of a composite structure [12]. An unanswered question is, how accurate the simulation should be to be suitable [8].

Because the modeling of contact like in our case the between layered shell and solid element is very problematic. It is possible to find various simplifications, e.g. Gruber [8] created and simplified static model without use of any contact. The boundary conditions were applied just to the nodes as could be seen in Fig. 4a. During the test are the boundary of the plate considered to be free as the plate is supported at interior points, and no special treatment is required [13].

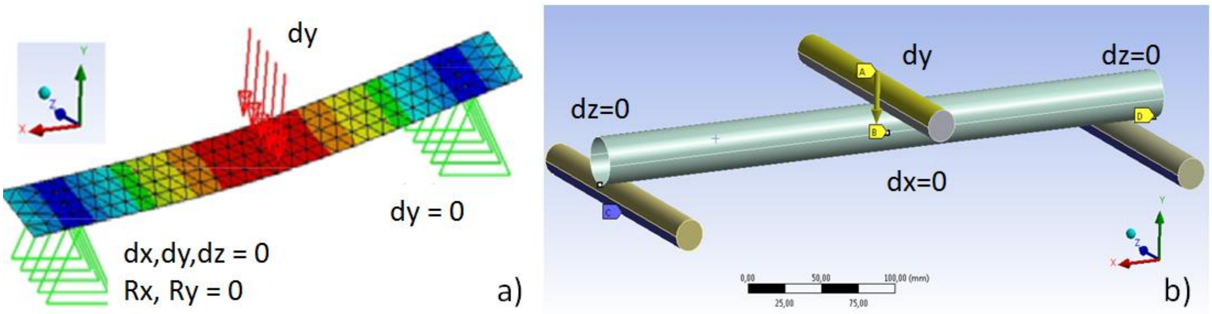

Fig. 4 Model of bending test: a) Simplified according to [8], b) Fully defined contact model

In our case, the model was solved as a fully contact task, Fix. 4b. The tested part was laid on two fixed supports. According to Sonner [14] it is better to use fixed constraint on the domain level than on the boundary. Then it is not necessary to solve for a lot of zeros in the internal of these domains. The frictional support with asymmetric behavior has been set.

For combination of solid and shell elements the pure penalty formulation with nodal-normal detection of integration points was used. The chosen basic normal stiffness 1e-002 could be additionally adjusted by program. The simplest way of handling an initially unconstrained model was to add weak springs. The spring constant can be made dependent on the load parameter, so that the spring has effect only in the beginning of the simulation [15].

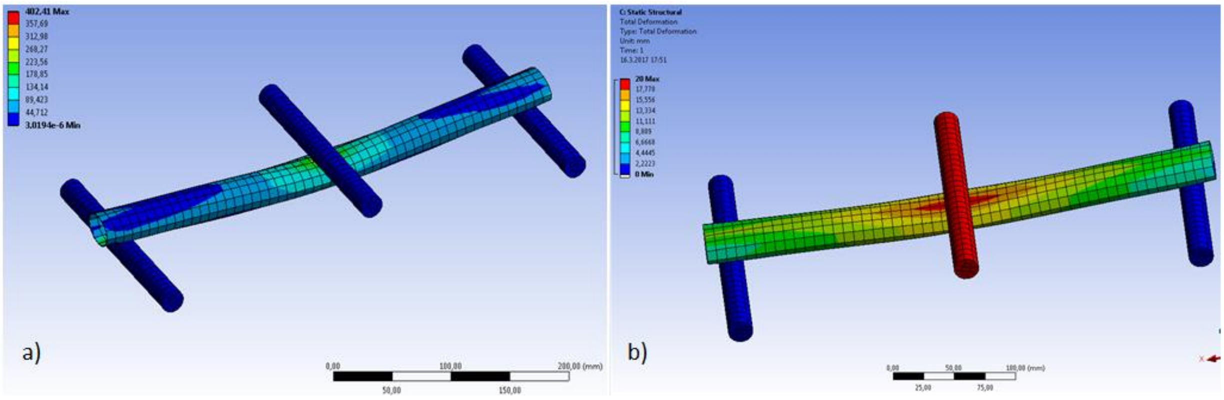

Fig. 5 Results of the carried simulation for the stacked layer a) The Equivalent stress, b) Directional displacement

Results and discussions.

The carried model (Fig. 5) was in a good agreement for approx. first 10 - 20 mm, it means to the point where the maximal strength and subsequent deformation of the tested parts are. Then, in the real case start the force decreasing because of arising nonlinear deformations, delamination, rupture etc. meanwhile the force in model is still exponencially increasing. One example of the experimental results and deformed model are shown in Fig. 2, 3. The deviation between the experiment and model was higher for the flax tube (Tab. 2). This could be mainly caused that the material model of flax prepreg is not sufficiently precise. With this idea also agrees the fact that for structure designing and numerical simulation is flax material not too common as e.g. the carbon one.

Tab. 2 Resultant values from experiment compared with the numerical model

	Displacement	**F_{max}**		**σ_{omax}**	
	at Fmax	Experiment	Model	Experiment	Model
Carbon	8,2 mm	305 N	338 N	98 MPa	134 MPa
Flax	13 mm	220 N	308 N	68 MPa	104 MPa

Conclusions

During the experiment we have obtained significantly different behaviour of the two tested kind of prepregs. There was not only the expected earlier rupture of flax fibers, but also fundamentally different fracture mechanisms, delamination and the resulting deformation of the entire test rods. The significant influence of these elements was evaluated using numerical model, created in ACP preprocessor. Until a moment of the experimentally found maximal strength, were results of the carried model and experiment in a very good agreement. But without an additional function of sophisticated post-procesor, we are not able to recognize the maximal values and the force would still just increase. It means, if we would like to know the entire process of composite deformation is the classical nonlinear static model, used e.g. for conventional steel parts insufficient. It is necessary to change the actually used shell composite model to a solid model suplemented by an interphase, cohesive elements, failure criteria etc. which would be the next step in our future work.

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