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Determination of the Composite Tube Mechanical Properties

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Abstract. Traditional materials mechanical properties are currently amply described. The situation is different for composite materials because the final part mechanical properties depend on the composite production method (material of fibers and their distribution, filler type and density). Determination of the composite part properties is necessary for FEM calculations during the assembly design, so the composite structure model is created by FEM software. Because the real composite material can be different from the ideal FEM model, it is highly advisable to verify the model results by real specimens measuring. Determination of the composite tube mechanical properties used in automotive industry is described in this paper.

Introduction

A classical car tailgate production (sheet metal pressing) is now replaced by new technology. The tailgate is assembled from a supporting frame on which interior and exterior panels are anchored. The supporting frame is made from a steel tube and panels may be plastic or glass. This tailgate is termed as the hybrid tailgate. The most recent research in this area solves replacement of the steel frame tube by composite materials tube. A composite tube is composed from a polyurethane core on which a composite layer is made (Fig. 1).

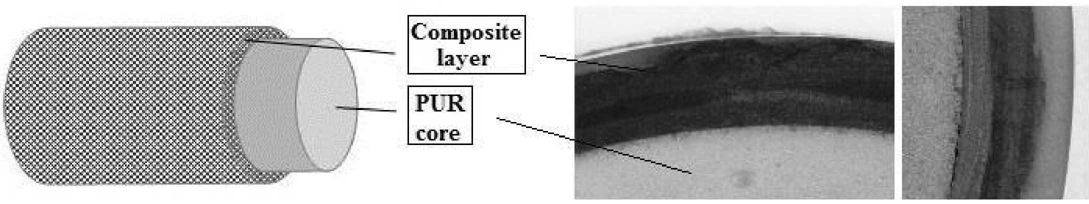

Fig. 1. The composite tube structure: schema (left), real tube (right).

The polyurethane core has no significant mechanical properties, it is used only as a support of fibers during the composite layer production. Generally, the composite layer determines the tube mechanical properties and they depend on a material of fibers, their distribution and on a filler type and density. Knowledge of its mechanical properties is necessary for CAD modeling and FEM calculations during the tailgate design, so the composite tube structure model was created at the FEM software [1, 2, 3]. Because the real composite material can be different from the ideal FEM model due to manufacture in accuracies, it is highly advisable to verify the model results by specimens measuring. The composite tube usually has very good mechanical properties in its axial direction but it is very soft in its cross section. This raised problems with specimen clamping during measurement and special clamping jaws have to be designed for this measurement.

Composite Tube FEM Modeling

The composite tube FEM model was created in this study. This FEM model has three layers (0°, -45°, 45°) with mechanical properties by Table 1.

Table 1. Physical parameters of the material in FEM simulation.

Material	Density [kg.m^{-3}]	Module of elasticity [GPa]	Tensile strength [GPa]	Elongation [%]
Fibers of carbon	1750±150	250	2.3	1.14
Epoxy resin (matrix)	1150±370	3.2	0.067	1.1
Core (PU foam)	50±0.36	2.6	-	-

The multiphase composite tube (core - fiber - matrix) can be optimized by directional fiber orientation α on the constant distance *l* using a numerical model solved by finite element method (Fig. 2). Where the fibers are disposed in two perpendicular directions (layer 1 ⊥ layer 2), there transverse fibers only minimally contribute to the longitudinal strength in a tensile test (Eq. 1).

$$\sigma_m^1 >> \sigma_m^2\Big|_{1=0^\circ,2=90^\circ} \qquad (1)$$

Tensile strength of the transverse fibers begins to change with the orientation angle α. With the angle of 45 ° or 30 ° or 60 ° the composite tube gains quasi-isotropic behavior the optimal fiber orientation with respect to the requirements for the final construction mechanical properties can be found.

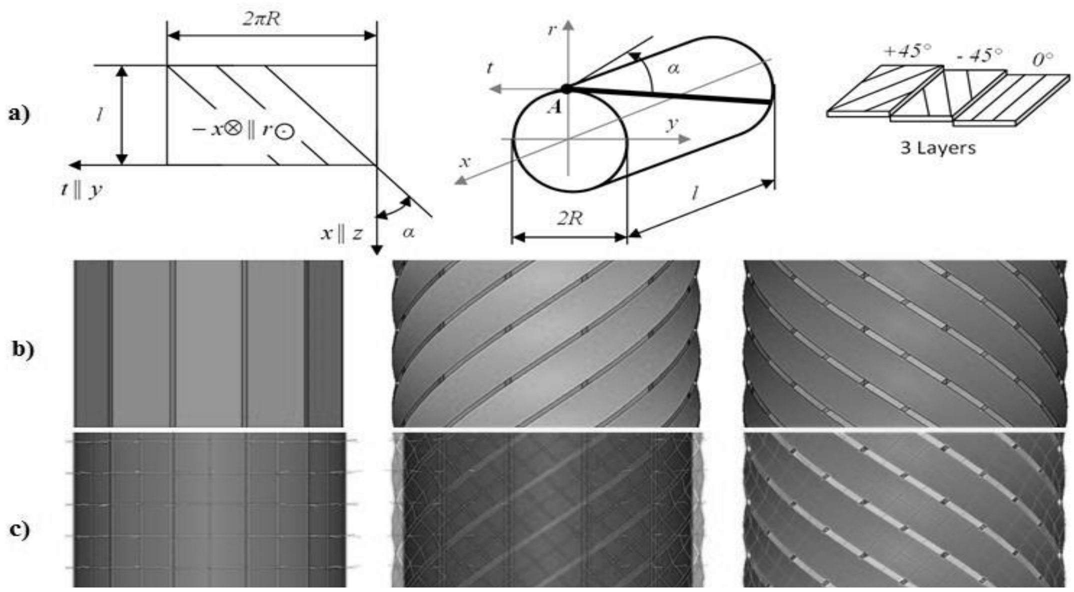

Fig. 2. Scheme of winding fibers (a), CAD model (b) and FEM model (c).

The composite tube axial force can be described by the next equation:

$$F_{11} = 2\pi R t \sigma_{11} \qquad (2)$$

where F_{11} is the composite tube axial force, R is the core radius, t is the layers total thickness and σ_{11} is the mayor stress, based on the generalized Hooke's law for inhomogeneous composite materials.

Verification Measurement

The classical tensile test was chosen for FEM model verification. Anchoring of the tube specimen is the biggest problem in its mechanical properties measurement. The axial force (Eq. 2) for tube rupture may be up to 50 kN so specimen anchoring to the clamps has to be excellent. Traditional clamps fail because the tube is very soft in the cross direction. A new method of anchoring had to be designed. End portion of the core was removed from the tube and the composite layer was glued to the metal jaw (Fig. 3). Of course, success of this principle depends on the suitable glue selection and therefore several types of epoxy glues have to be tested. The best result was achieved with epoxy glue Cyberbond CA 2000er Serie (1000 – 2999) where the glued bond endured until the specimen rupture. The glued joints can be disassembled after the test by jaws heating and the jaws can be used for the next test.

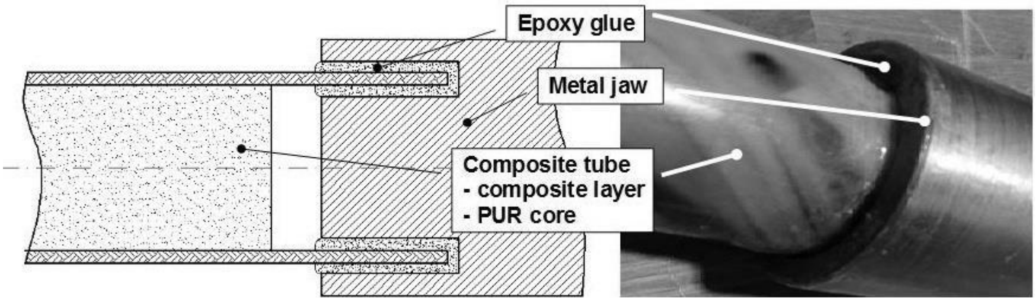

Fig. 3. The principle of tube specimen anchoring (left) and real measurement (right).

Extension measurement was a second problem which had to be solved. It is very difficult to estimate the maximal extension value for various prototype composite specimens and selecting of a necessary extensometer range is difficult, too. Also the specimen rupture in the end of the test can be dangerous for classical strain gauge extensometer. Therefore a contactless displacement incremental sensor was used for this measurement (Fig. 4). Two small plates with anchor edges were made. The incremental sensor reading head is mounted on the first one and the magnetic scale on the second. This scale can freely move under the reading head. If the specimen is loaded, the plates with anchor edges are moved together with the specimen surface and the scale is moved against the head. The extension measurement is very precise because the magnetic scale resolution is 1μm. The initial anchor edges distance is arbitrary and maximal extension value is limited only by used magnetic scale length. Therefore, this extensometer can also be used for non-standard length specimens.

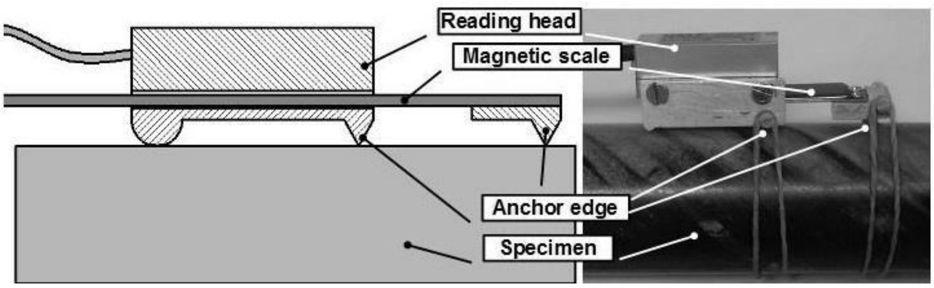

Fig. 4. The contactless incremental extensometer.

Results

The FEM model stress distribution, real specimen rupture and comparison of the FEM model and real tensile test results are shown in Fig. 5. Continuous curve shows finally good specimen anchoring (full load until tube rupture). The tube rupture force was 54kN and this value very well corresponds to the FEM model results. The example of the bad anchoring is shown by dashed curve (the specimen was pulled out of the jaws).

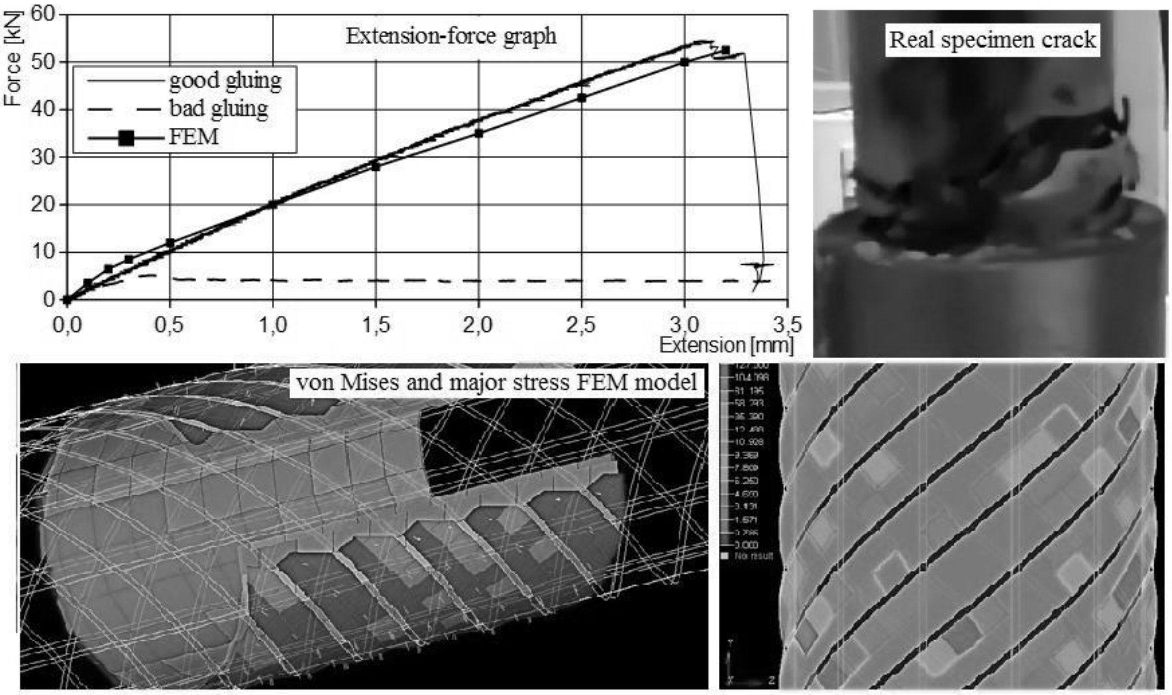

Fig. 5. Comparison of the FEM model and real tensile test results.

Conclusions and Acknowledgements

FEM model of the composite tube and methodology for its mechanical properties measurement were resolved in this work. A tailgate supporting frame prototype is being prepared now and its composite tube has a non-circular cross section. Proven FEM modeling principles and created mechanical properties measurement methodology will be now applied to this real composite tube. It is expected that the epoxy glue anchoring system will be very suitable especially for non-circular specimens.

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References

[1] M. Petrů, O. Novák, P. Lepšík, Numerical and experimental analysis of composite reinforcements applicable for a car seat innovation, Technolog 6 (2014) 25-30.

[2] H. Qing, L. Mishnaevsky, Unidirectional high fibre content composites automatic 3D FE model generation and damage simulation, Computer Material Science 47 (2009) 548-55.

[3] M. Petrů, O. Novák, L. Ševčík, P. Lepšík, Numerical and experimental research of design optimization of baths for production of nanofibers by the electrospinning, Applied Mechanics and Materials 486 (2014) 157-162.