Modelling material parameters of selected composite structures of tires

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Introduction

Tires have an important role in the field of driving characteristics of vehicles, their dynamic characteristics and active safety. The tire represents a relatively complex composite assembly, see Fig. 1 - 3 [1], whose properties and behaviour are not known precisely because of the large number of design, material and operational parameters. Composite materials of selected tire parts (casing, breaker, etc.) have a considerable influence on the tire. Current models describing the effect of orthotropic composites are only approximate with a great deal of simplification. Finite element models typically use an isotropic model of material behaviour, including composites, which distorts reality. The solution is to consider orthotropic models of the behaviour of these materials. In general, the material parameters are not known precisely, e.g. Poisson's constants and Young's modules of reinforcing materials (rayon, nylon); if known, they are presented in a wide range of values. This is because they are massively influenced by the processing technology (composition, vulcanization temperature, etc.). The authors tried to create a spatial model of composite casing and breaker samples of a particular selected tire with given material properties of individual structures. Creating the model required relatively accurate knowledge of material parameters of the matrix and reinforcement composite samples. Material parameters were obtained from static tensile tests. For reinforcement, this information could not be obtained due to the protection of the company technology. Therefore, this information was a part of the modelling output and experiment of purposefully separated tire casing parts. Elastomers (natural and synthetic rubbers) are the basic structural components of a tire; they are macromolecular substances capable of undergoing vulcanization while transforming from plastic to elastic state. The reinforcing materials are, for example, nylon, which is a fibre of synthetic polyamides, or raylon, which is a cellulose fibre (viscose silk). The breaker is made of crosslinked rubber cord. The bead wires consist of steel wires or strips. For modelling purposes we can describe the tire from the geometrical point of view as a toroid, in terms of strength it is a pressure vessel where the walls can be replaced by membranes. In terms of material, the tire is a body with anisotropic properties, which is a substance with a rectangular structure.

Objectives

In general, tire material is divided into three basic components, namely elastomers (80 - 85%), fibres and reinforcing textile materials (12 - 16%) and steel wire or plastic mesh (2 - 3%). The reinforcing rubber composite is made of polymer, black carbon black, oil, chemical additives, bead wires and textiles (viscose, polyamide, polyester and steel fibres).

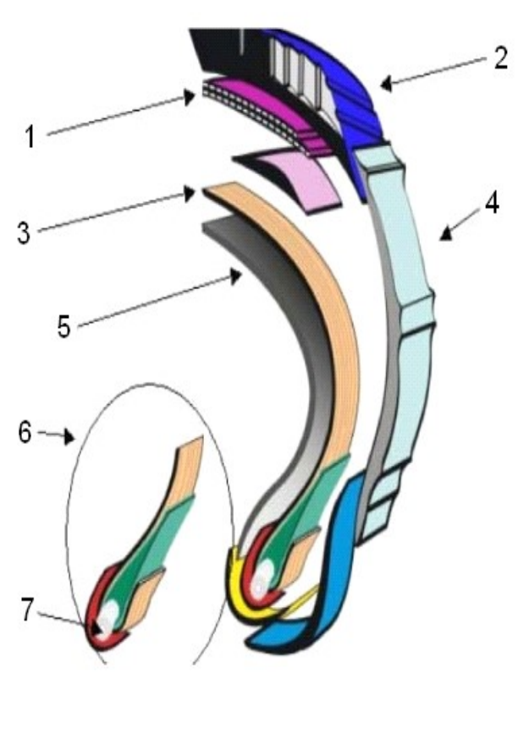


Fig. 1 Tire casing construction


Fig. 2 Breaker


Fig. 3 Tread

Legend to Fig. 1: 1 - breaker, 2 - tread, 3 - casing, 4 - sidewall, 5 – inner liner, 6 - bead, 7 – bead wire

Method

Tire testing

During the project realization, tests with a real tire were carried out. There are several groups of static and dynamic tests that include:

1. Production testing (appearance, weight, X-ray, peripheral unevenness, balance).
2. Inspection tests (tensile strength, radial, tangential, lateral and torsional stiffness, compressive strength, mandrel puncture, destruction speed, durability, rolling resistance, tire contact with road surface, tread wear, etc.).
3. In-service testing on a dynamometer trailer or on a real road (not carried out in the research project).
4. Laboratory tests of components, mixtures and chemicals (a large number of tests is carried out during tire production; the results are not intended for publication).
5. Special tests of separate composite samples performed for the purposes of this research.

Specifically, it was the wear of tire treads made of different compounds (13 types of compounds in total). These were particularly tensile tests, Fig. 4 (INSTRON testing machine) [2], impact resilience tests, Fig. 5 [2], IRHD hardness tests, dynamic behaviour (DMA) tests and durability and wear tests, Fig. 6 [11]] and 7 [2]. An example of the measured tensile strength values is in Table. 1. A graphical representation of the tensile strength and elongation for the 13 specimens is shown in Figure 8.

Table 1 Measured values of tensile strength

Type of mixture	1	2	3	4	5	6	7
Tensile strength [MPa]	7.76	20.01	8.25	10.96	9.92	18.12	18.12
Type of mixture	8	9	10	11	12	13	14
Tensile strength [MPa]	14.11	18.52	14.02	15.21	16.47	10.09	-


Fig. 4 Tensile strength measuring equipment

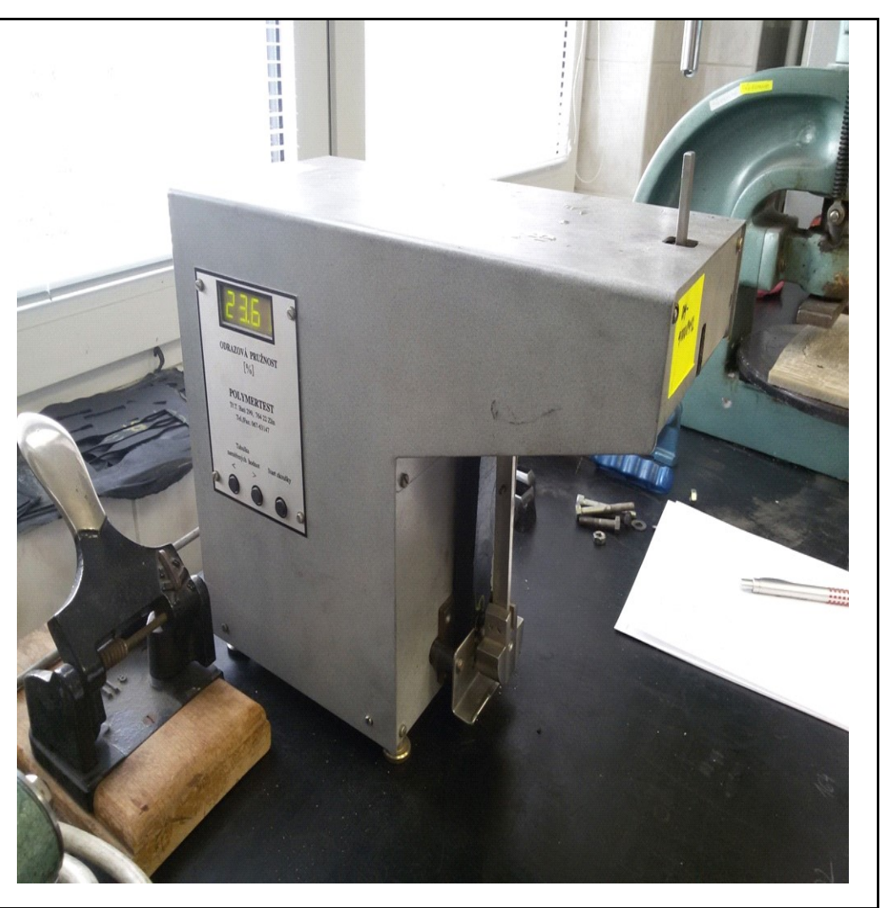


Fig. 5 Impact resilience measuring equipment

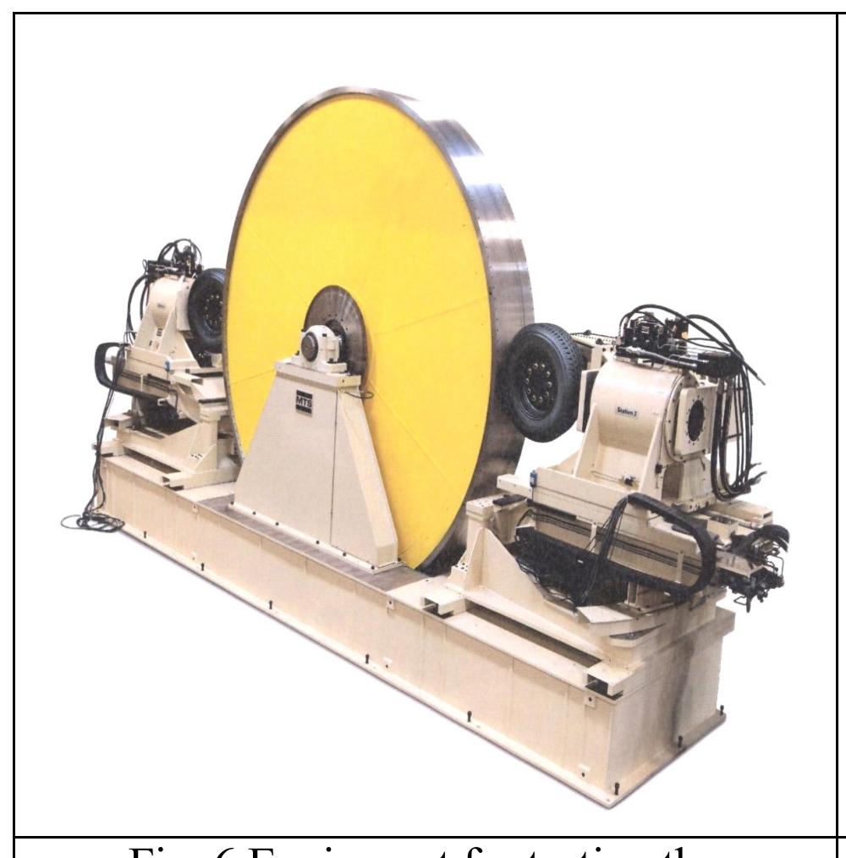
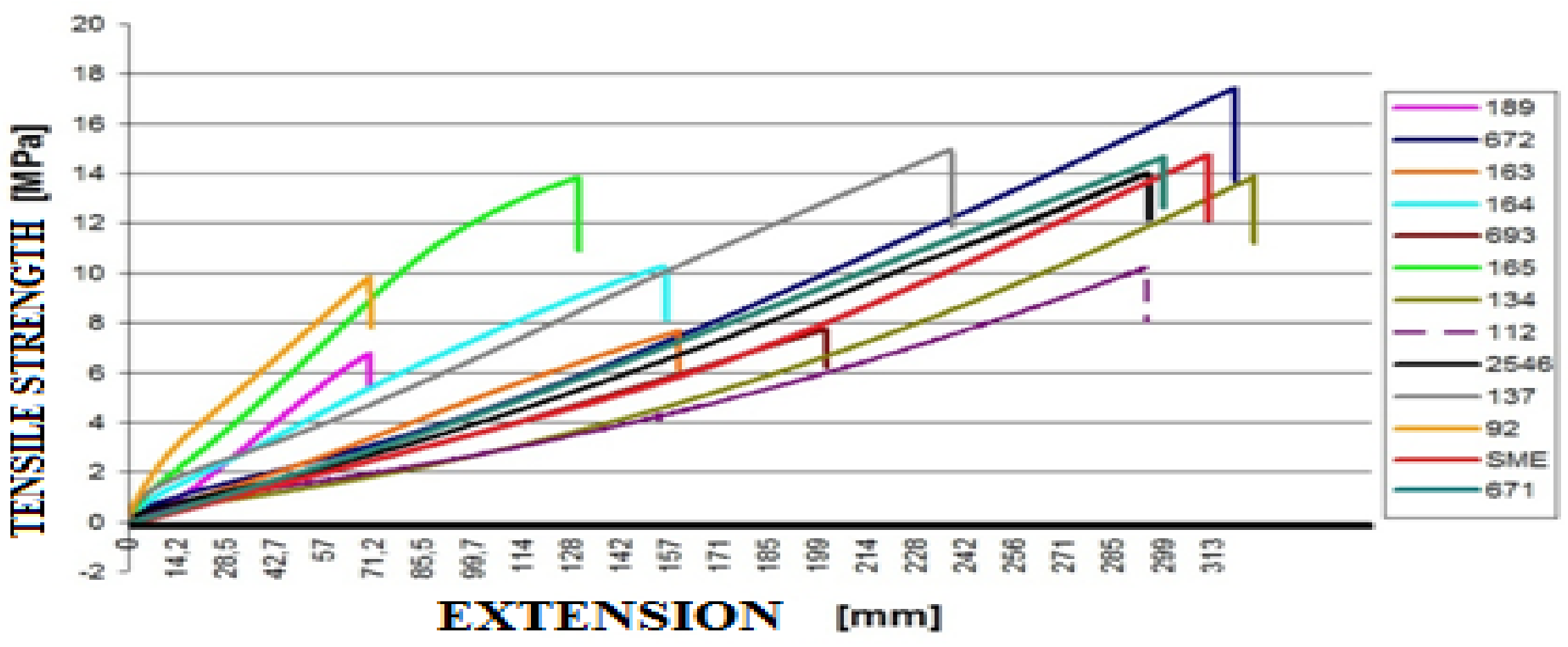


Fig. 6 Equipment for testing the durability and wear of the whole tire


Fig. 7 Equipment for testing the durability and wear of the sample

Fig. 8 Relation of tensile strength and extension



Results

Modelling of tires

In general, the tire and its parts can be modelled analytically and numetically, for example using the Finite Element Method (FEM). Criteria for selecting this advanced method were the purpose of the model (simulation of a dynamic tire system, the physical model of the tire, the influence of the structure on the tire properties), the approach to modelling (purely empirical, derived from basic measured courses, mathematical descriptions based on physical descriptions, advanced finite element models), conditions of use (steady, unsteady and transient states) and the complexity of the model (by physical nature, friction ratios, so-called slip models, according to frequency range, etc.) [3, 4]. The finite element method allows the simulation of stress, strain, frequencies, flow, etc., using the created physical model. The principle is based on the discretization of a continuous continuum into a finite number of elements, the parameters being determined at individual node points. It is based on the Lagrange principle, which states that a body is in equilibrium if the total potential energy of the system deformation is minimal. The finite element method is based on variational calculus, looking for a minimum of some functional (mapping from a set of functions to a set of numbers) [5 - 10]. The mathematical model was created for a specific 165/65 R 13 tire, where only 1/8 of the tire sample was used for modelling due to the symmetry of the test sample. Fibre orientation (5x transverse, 1x longitudinal), dimensions 120x30 mm, cord diameter (0.62 mm), layer thickness (0.96 mm), number of cord threads (105 pcs/100 mm) and fibre material (raylon) were the basic data for the textile casing liner model, Fig. 9.

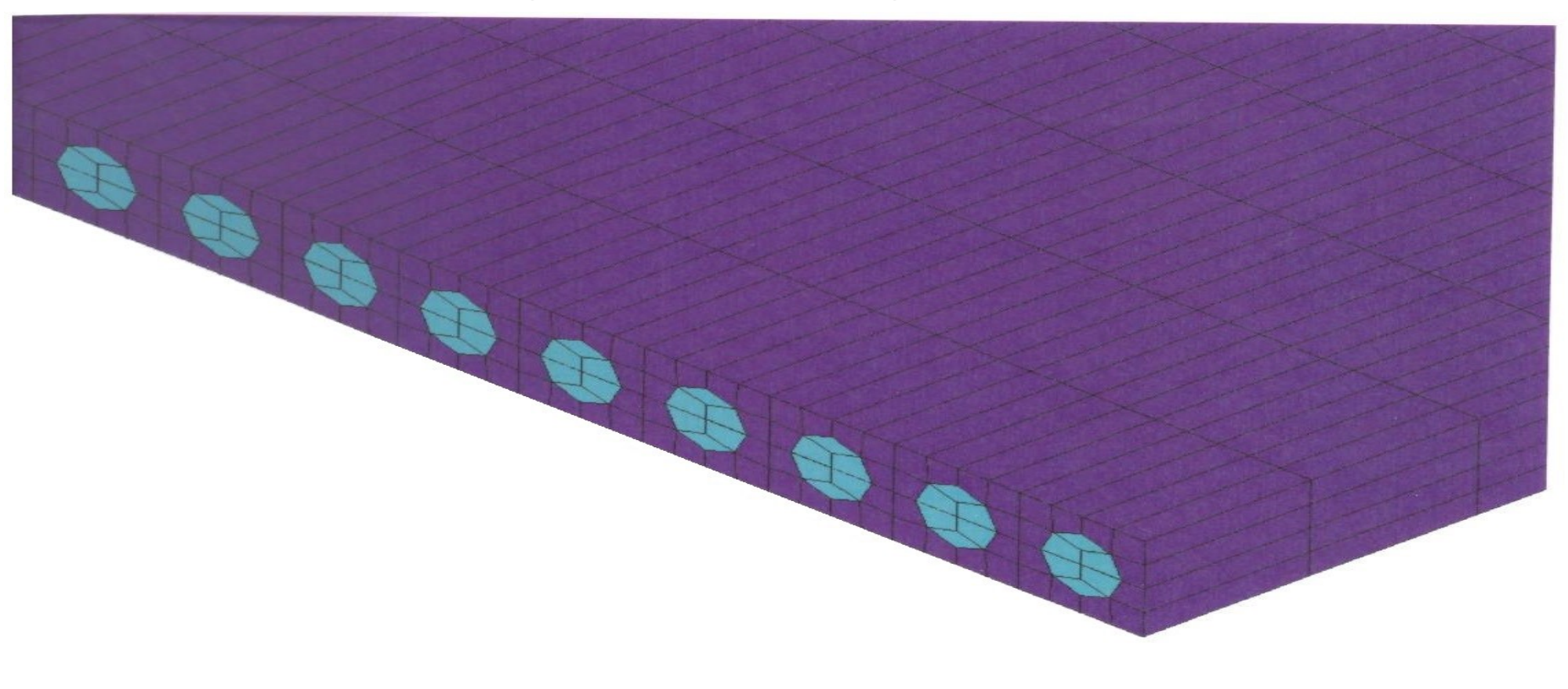


Fig. 9 Model for textile casing liner (rough discretization of the sample)

The entire procedure included the creation of a CAD model, rough sample discretization, 3 displacement equations to the respective axes (x, y, z), calculation of deformation equations (6 equations in total) and 6 stress equations, expressing of displacement function (polynomial), introduction of boundary conditions, calculation of a system of linear algebraic equations, calculation of deformations and stresses at individual nodal points [4], graphical representation and listing of important results. The model was created in ANSYS software environment. An example calculation for a casing with longitudinally oriented fibres (columns 1-3) and transversely oriented fibres (columns 4-6) is given in Table 2. Examples of modelling the displacement distribution of the textile casing liner in the transverse and longitudinal directions are shown in Figures 10 and 11.

Table 2 Example of results of computational casing modelling

Lenght [mm]	Elongation [mm]	Force [N]	Length [mm]	Elongation [mm]	Force [N]
0.20	0.167	260	1.50	1.27	7.90
0.40	0.334	520	3.00	2.54	14.9
0.70	0.584	904	5.25	4.45	24.1
1.10	0.917	1410	8.25	6.99	34.6
1.50	1.251	1907	11.25	9.53	43.5
1.75	1.459	2214	15.00	12.72	53.1
2.00	1.668	2518	20.00	16.96	63.9
2.50	2.085	3118	30.00	25.44	81.8

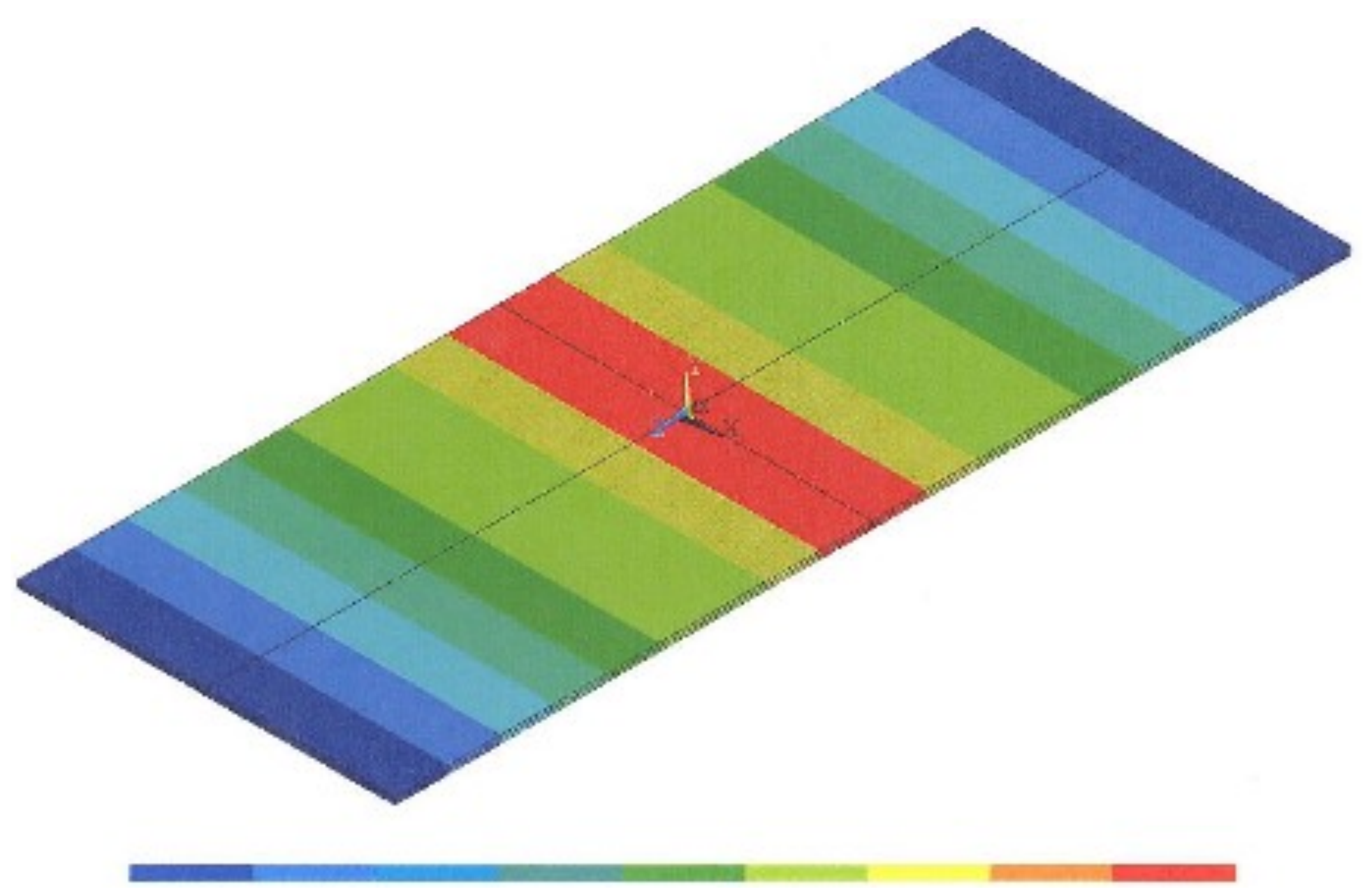


Fig. 10 Example of displacement of textile casing liner (in transverse direction)

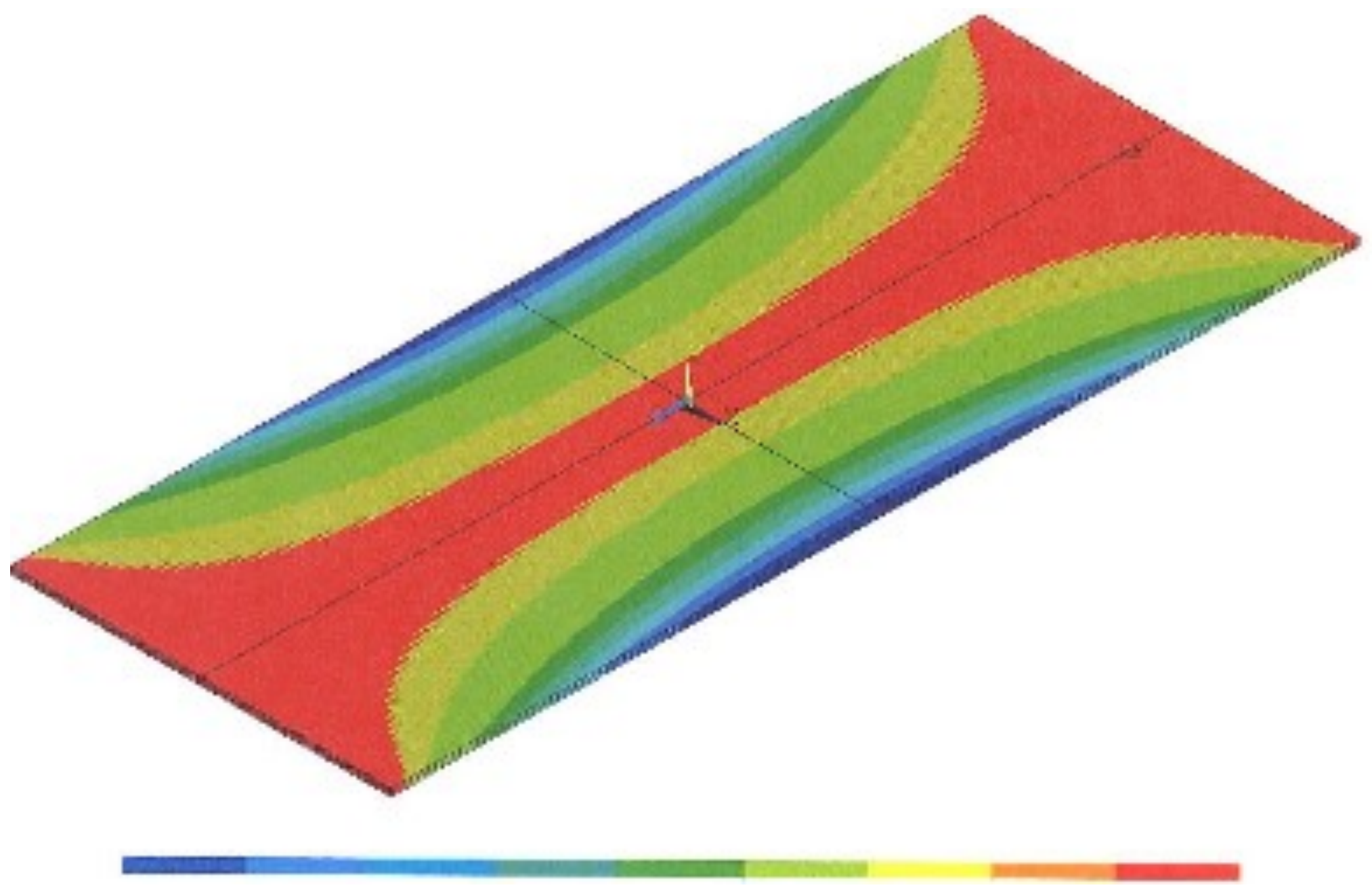


Fig. 11 Example of displacement of textile casing liners (in tension direction)

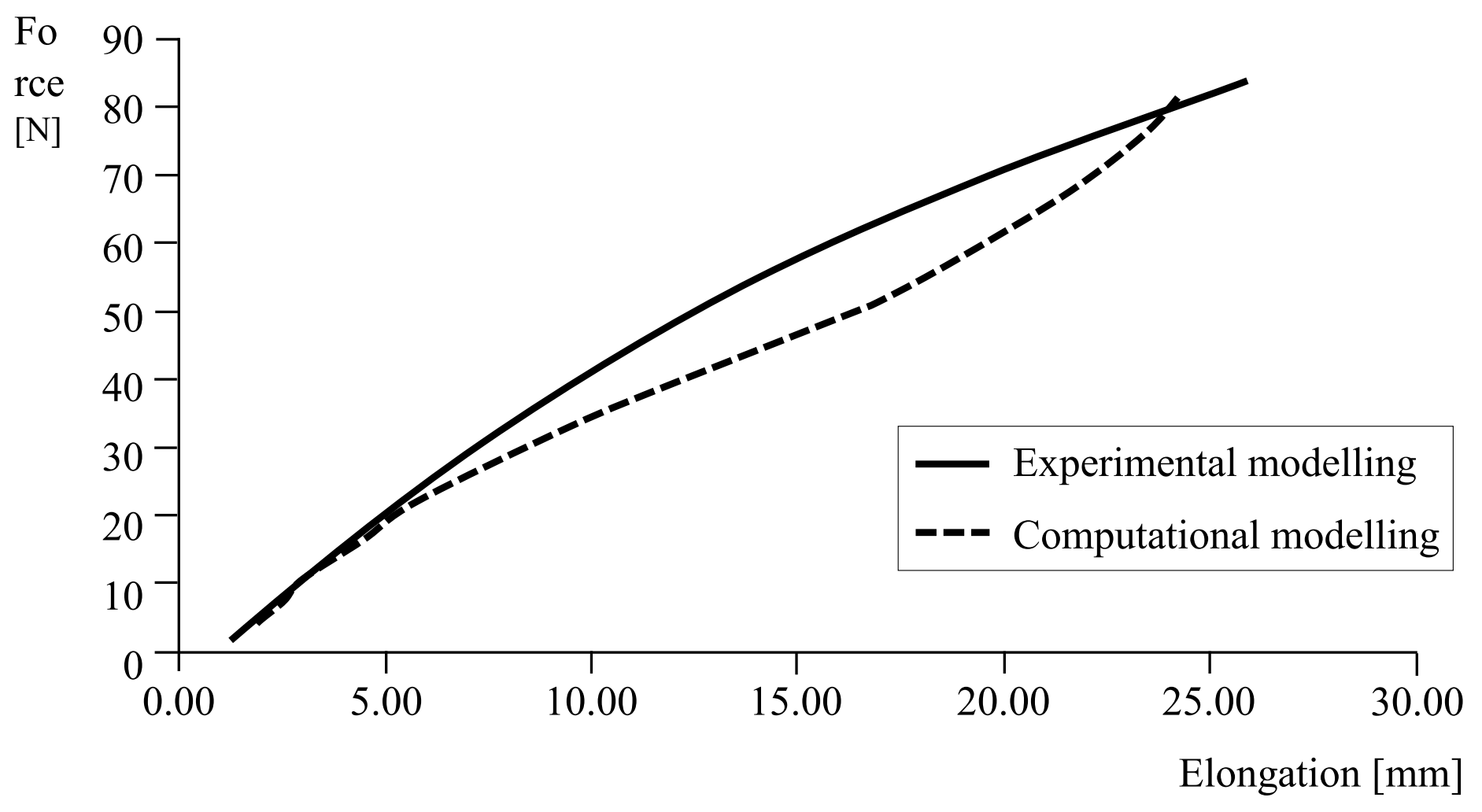


Fig. 12 Example of comparing the experiment and computational modelling (textile casing liner with transversely oriented fibres)

Discussion

For samples with the transverse and longitudinal orientation of the textile casing fibres, several calculations were performed, which differed by Young's modules (0.35 and 0.45 [-]) and Poisson's constants (1700, 2550, 3400, 5000, 7500 and 10000 [MPa]). It has been proved that changes in some material parameters do not affect the results. An example of the calculation verification with the experiment carried out for the textile casing liner with transversely oriented fibres is in Fig. 12. Computational modelling achieved relatively good agreement with the experiment. The results also show that the elastomeric matrix would need to be modelled by another model describing the material behaviour, since the used model (Money-Rivinin) is less suitable for materials with high strain [3]. The authors believe that the Ogrden model is a suitable model. Young's modulus E = 8.4 MPa was obtained in the tensile test during the transversely oriented textile casing experiment. In the tensile test for the longitudinally oriented specimen, the Young's modulus E = 619 MPa was obtained during the experiment. The tensile force and the corresponding strain were measured during the test. The result of the computational modelling of the textile casing liner with longitudinally oriented fibres is the creation of a spatial model of the sample with textile reinforcement from raylon, which was the foundation for the calculations. On the basis of the calculations it was proved that the changes of Poisson's constant have no effect on the results, but on the contrary, by changing Young's module, the curve of the tensile force changes in dependence on the elongation. For a transversely oriented sample, both of these material parameters do not affect the results. For a textile overlapping breaker with longitudinally oriented fibres with nylon reinforcement, it has also been proved that the Poisson constant has no effect on the results, but the change in Young's modulus changes the slope of the tensile force-elongation curve. For the textile overlapping breaker with transversely oriented fibres, both material parameters do not affect the results.

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