TIRE CASINGS AND THEIR MATERIAL CHARACTERISTICS FOR COMPUTATIONAL MODELING OF TIRES

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Abstract. The report is focused on determination of the material parameters from experimental data, which will be used as input data to computational modeling of radial tires for passenger vehicles. It is necessary to have knowledge about the geometry, material parameters, cross-section and structure of tire casing (number of layers of the belt and carcass, information about the bead and cap ply) for creation of computational models of tire casing for stress-strain analysis of a tire under vertical load, modal analysis etc. The tire casing parts in computational models are partially replaced with material and geometrical parameters with specified stiffness. The Finite Element Method using the program system ANSYS is applied to the computational modeling. The experiments of total tires are needed for verification analyses between computational results and experimental data. The experiments of parts of the tire casing such as parts of tread and next rubber parts of tire are needed for determination of the parameters of constitutive models of rubber elasticity such as the parameters of hyperelastic Mooney-Rivlin model. The report describes the result for two tires 165/65 R13 and 215/40 R17 as samples. The structures of the tire-crown with geometrical and material parameters are presented. The authors used orthotropic material parameters for determination of the structure parts of tire as the steel-cord belt. The values of modules of elasticity and Poisson ratios are presented for 165/65 R13. The orthotropic material parameters for definition of the tire-crown of 215/40 R17 are determined as input data to the computational model of tire.

Keywords: tire, composite, rubber, FEM, ANSYS, Mooney-Rivlin.

Introduction

The report is closely related to the contribution *Composites with Nonlinear Matrix for Transport Means - Experimental and Computational Modeling* presented at the conference *Engineering for Rural Development* in 2011 [1]. Radial tire for passenger vehicles can be classified as polycomponent composite with a rubber matrix reinforced with textile and steel cords [2]. The structure parts applied into these tires are the textile carcass, textile overlap belt and steel-cord belt. These structures of tire have got a different cord-angle and numbers of layers, e.g. Figure 1a for tire 165/65 R13 for standard cars and Figure 1b for tire 215/40 R17 (low profile, extra load) for sport cars as samples of cross-sections. The maximal inflation pressure of tire 215/40 R17 is 3.4 bars and maximal load is 545 kg (load index is 87), the tire 165/65 R13 has 3.0 bars as the maximum inflation pressure and 412 kg as maximum load (load index is 77). The truck tires or agriculture tires have different structures [3; 4].
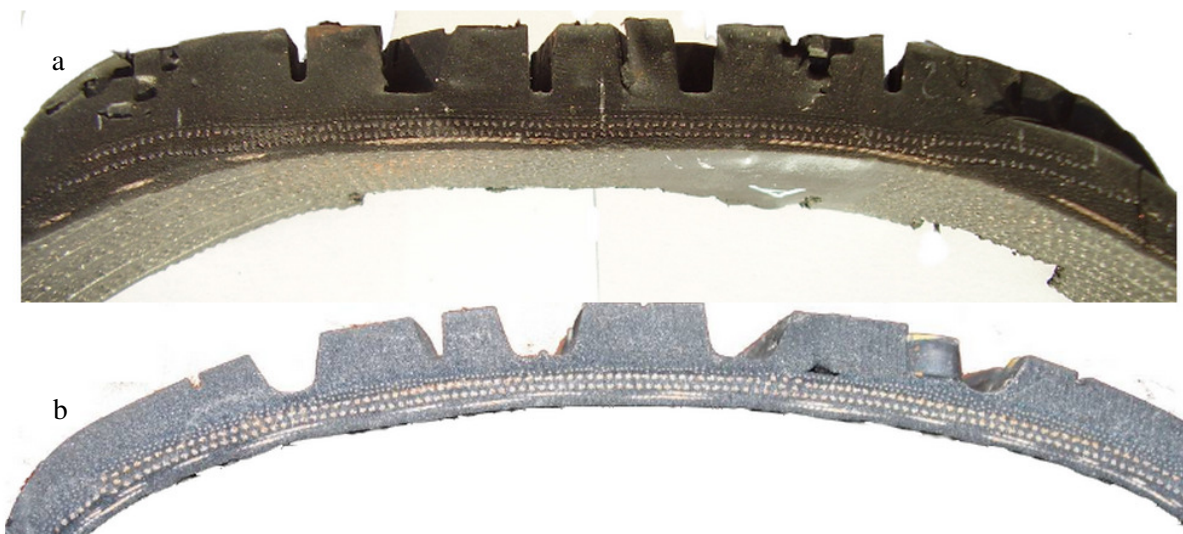

Fig. 1. **Tire-crown area:** a – tire 165/65 R13; b – tire 215/40 R17

Fig. 2 presents details of the structure in the tire-crown of tires. The tire 165/65 R13 has a tire carcass which consists of one layer of polyester and the tread consists of two layers of the steel-cord belt and two layers of the polyamide belt. The steel-cord belt density is 96.1 ends per decimeter.

The aim of the study is to create a computational model, which describes the static and dynamic loading of tire for given inflation pressure. For creation of computational models strain-stress analyses of the tire are necessary to have a good knowledge about the geometrical parameters of the structure of tire-casing and material parameters of cords and rubbers into tire.
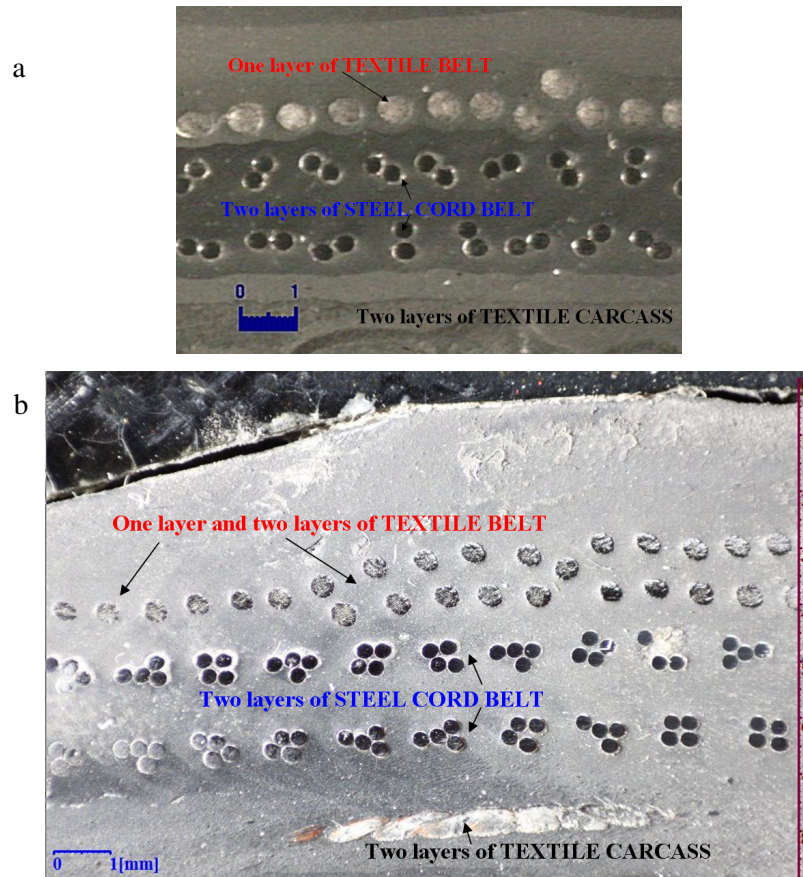

Fig. 2. **Detail of structure tire-crown:** a – tire 165/65 R13; b – tire 215/40 R17

Materials and methods

Geometrical parameters of the structure parts of tire 215/40 R17 as the diameters of cords are given in Figure 3 and Table 1. The cord angle us not measured. For the description of elastomer parts of tires the hyperelastic Mooney-Rivlin model is used, which is described by the two Mooney-Rivlin parameters. The Mooney-Rivlin model can be well applied for the range of elongation up to 150%. To determine the basic Mooney-Rivlin parameters C_{10} and C_{01} it is necessary to carry out the mechanical tensile test for a sample from the given elastomer [5]. The authors used the FEM program ANSYS for determination of the Mooney-Rivlin parameters from tensile tests of elastomers. The values of the Mooney-Rivlin parameters are given in Table 2 for the tire 165/65 R13 as a sample of the results.

Parameter d is incompressibility parameter and this parameter is calculated by formula (1).

$$d = \frac{2(1-2PR)}{C_{10}(5PR-2)+C_{01}(11PR-5)} \ , \tag{1}$$

where C_{10}, C_{01} – material parameters of Mooney-Rivlin model, MPa;
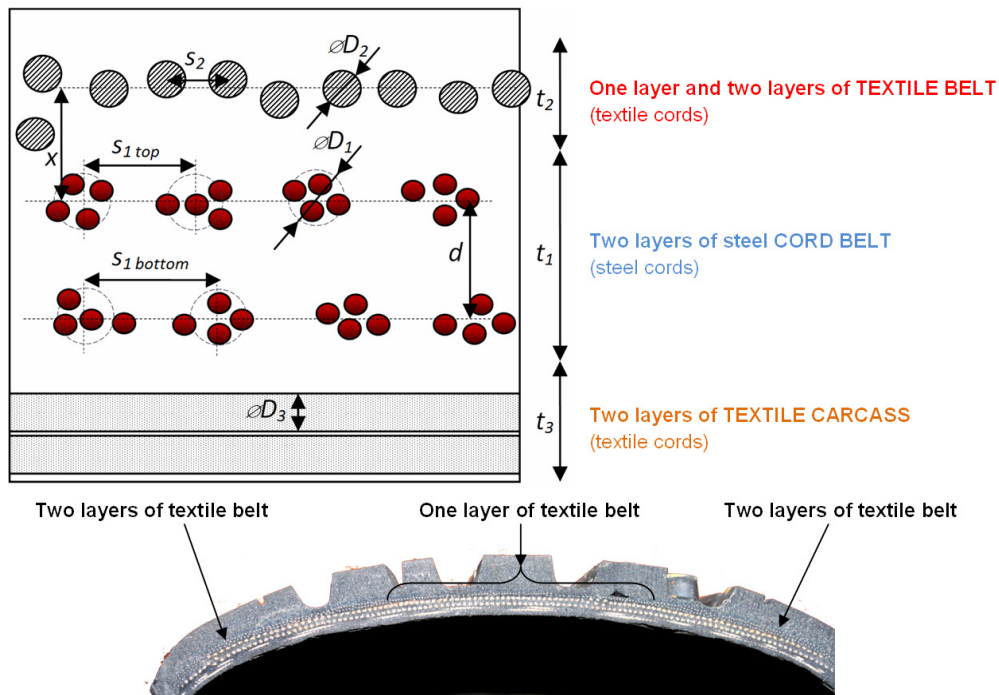PR – Poisson ration (for rubber it is 0.5).

Fig. 3. **Legend of geometrical parameters of structure parts of tire 215/40 R17**

Table 1

Values of geometrical parameters of structure parts of tire 215/40 R17

Structure parts of tire	Steel-cord belt	Textile overlap belt	Textile carcass
Number of layers	2	1 and 2	2
Thickness of layers t, mm	t_1 2x(1.38÷1.44)	t_2 1.10 and 1.75	t_3 1.40÷1.50
Diameter of cords D, mm	D_1 0.80	D_2 0.44	D_3 0.50
Construction of steel-cords	2+2x0.30 (4x0.30)	-	-
Distance between middles of steel-cords in top and bottom layers d, mm	d 1.45÷1.55	-	-
Spacing between middles of cords in layer s, mm	$s_{1\,top}$ 1.35 for top layer $s_{1\,bottom}$ 1.40÷1.55 for bottom layer	s_2 0.70÷0.75	-
Number of steel-cords per decimeter width of one steel-cord belt layer, 10 cm^{-1}	68 for top layer 66÷62 for bottom layer	-	-
Distance between middles of steel-cords in top layer of steel-cord belt and middles of textile cords in textile belt x, mm	x 1.20÷1.40		-

The accuracy of the parameters is 95 %.

Different descriptions of the structure parts of the tire-casing into the computational model of tire are possible, see Fig. 4. In relation to the computational models, the structure parts (textile carcass, textile overlap belt and steel-cord belt) are not able to be implemented up to the level of reinforcing cords because of the time difficulty as well as the large number of the finite elements. The structure parts are partially taken into account in the form of specified stiffness, or in other words, the composite component parts are partially replaced with some specified stiffness.

Table 2

Mooney-Rivlin parameters for elastomer parts of tire 165/65 R13

Mooney-Rivlin parameters	C10, MPa	C01, MPa	d, 1·MPa^{-1}
Tread	0.417	0.519	1.03E-01
Inner liner	0.109	0.259	2.06E-01
Bead elastomer	0.692	0.371	2.67E-01
Sidewall with Tread side edge	0.532	0.065	1.38E-01
Bead bundle	-0.111	1.945	8.77E-02
Elastomer drift for steel-cord belt	0.638	0.284	1.51E-01
Elastomer drift for textile overlap belt	0.548	0.112	5.64E-02
Elastomer drift for textile carcass	0.328	0.119	1.01E-01

The authors used orthotropic material parameters for determination of the structure parts of tire as the steel-cord belt. These parameters are determined from the material parameters of the elastomer matrix and reinforcements by laminated theory used, e.g. software CADEC [7]. Two layers of the steel-cord belt with symmetrically crossed reinforcements are homogenized together and they exhibit the properties of the orthotropic material, which represents the elastomeric layer with cords (homogenization of two layers in order to make only one layer). The mentioned replacement is often used in practice. The difficulty of this method is connected with correct determination of the Poisson's ratios, which have to be calculated in order to obtain the appropriate coordinate system of the computational model representing the tire casing. Based on the sensitive analysis, high sensitivity was determined for some Poisson's ratios and it means that only a slight change can cause a significant change in the stiffness parameters of the belt as well as the whole tire casing.
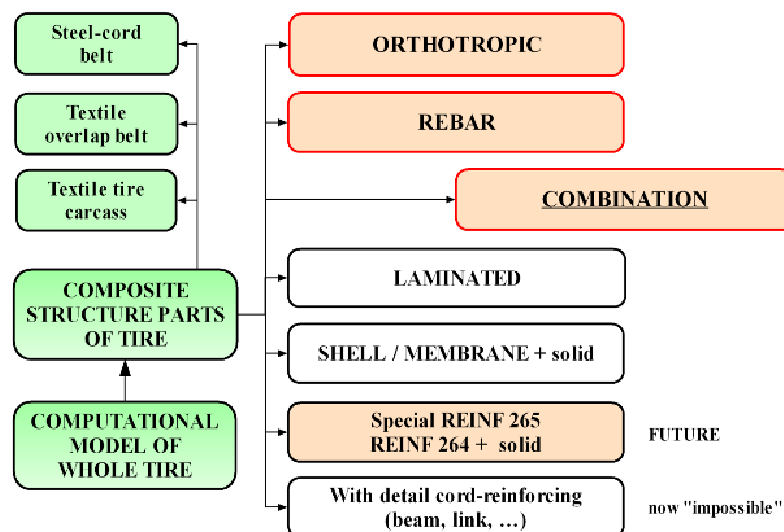

Fig. 4. **Descriptions of structure parts of tire-casing [6]**

Results and discussion

The values of modules of elasticity and Poisson ratios are given in Table 3 for the tire 165/65 R13. These parameters can be used for computational modeling by the orthotropic material model if all structure parts are included in the geometry of the computational model. If this tire would be used in computational modeling with the orthotropic material model for definition of the tire-crown of the tire 215/40 R17 (if the area of the tire crown describes as homogenous material with the orthotropic material model, which includes the textile carcass, textile overlap belt and steel-cord belt altogether) then the modules of elasticity must be defined as input material data with these values: 230 MPa for longitudinally direction, 215 MPa for transverse direction and 55 MPa for radial direction, see Fig. 5.

The values of elasticity were obtained from statical experiments of the parts of tires, according to the procedure, which was published in [8]. The computational model with these parameters is simple,

the advantage is fast computational time and the disadvantage is the accuracy of the results. For verification analysis of the results from computational modeling the experimental data, such as vertical force-deformation dependence, stiffness of tire and next tire characteristics [9], are necessary. The experimental value of vertical stiffness of tire 165/65 R13 is 185 N·mm^{-1} for 2.5 bar and load 412 kg. From computational modeling the value of vertical stiffness is 180 N·mm^{-1} for the same conditions. The experimental value of vertical stiffness of the low-profile tire 215/40 R17 is 260 N·mm^{-1} for 2.5 bar and load 545 kg.

Table 3

Material parameters for composite structure of tire 165/65 R13

Material parameters	Stress modules _Ex / Ey / Ez_, MPa	Main Poisson ratios _PRxy / PRyz / PRxz_	Shear modules _Gxy / Gyz / Gxz_, MPa
Steel-cord belt	12.0 / 23.1 / 717.0	0.3122 / 0.0740 / -0.0234	5.6 / 16.7 / 12.4
Textile overlap belt	21.0 / 25.4 / 745.3	0.8227 / 0.0174 / 0.0132	6.0 / 23.4 / 19.9
Textile carcass	12.0 / 745.1 / 21.8	0.0076 / 0.4776 / 0.5481	11.6 / 20.6 / 4.5

Legend: x – radial direction, y – transverse direction, z – longitudinally direction
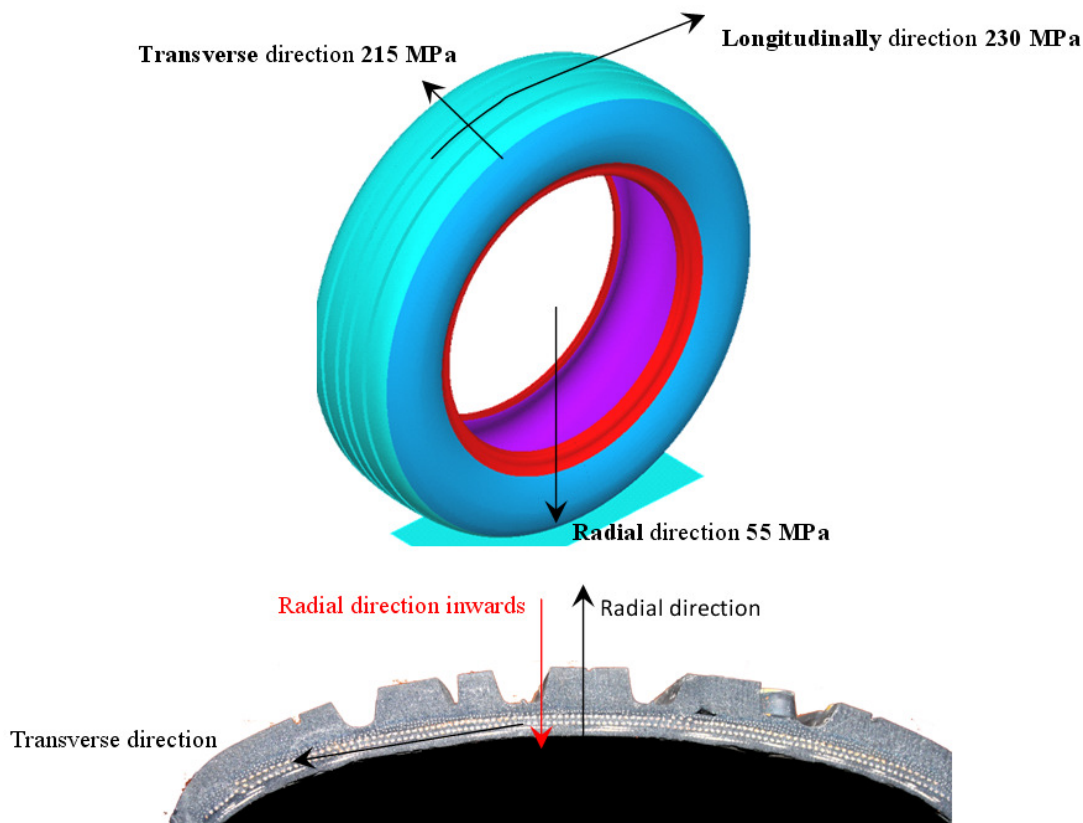

Fig. 5. **Modules of elasticity of tire-crown of 215/40 R17**

Next results of determination of material parameters for computational modeling and comparison (such as the size of the contact areas for different inflation pressures) between standard profile tire 165/65 R13 and low-profile tire 215/40 R17 will be also published in the new monograph with the title "Tires casing and their material characteristics for computational modeling" at the end of 2017.

Conclusions

1. It is necessary to also know the other material parameters of each individual elastomeric and reinforcing part of the tire casing for computational modeling of tires. These are the Mooney-Rivlin parameters of the tread, the drift rubber of carcass layers, the inner rubber, the sidewalls, the core, the bead, lateral wedge and modules of elasticity of reinforcement materials.

2. The orthotropic material has quite good response to the surrounding environment. Therefore, the orthotropic material is often used as a replacement of, e.g., the steel-cord belt of the tire casing.
3. The geometrical and material parameters are used as inputs into the computational model of tires for strain-stress analyses of the tire. Relating to the description of the steel-cord belt for the tire-casing, special types of elements are recommended during the operation in ANSYS and these elements are, e.g., Reinf265, which is assigned to the areas of the steel-cord belt with Solid186 type of element.

Acknowledgement

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