COMPOSITES WITH NONLINEAR MATRIX FOR TRANSPORT MEANS – EXPERIMENTAL AND COMPUTATIONAL MODELING

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Abstract. The paper deals with experimental and computational modeling of tires as complex long-fiber composites with nonlinear matrix, namely radial tires for road vehicles. The automobile tires consist of elastomer parts and composite structure parts with textile- and steel-cords into the tire tread as reinforcements. It is important to design such structures that the tires would be as much resistant to any degradation type as possible. There are required complex approach to experiments and computation of tires from macrostructure and microstructure, too. For tire computational FEM modeling knowledge about static tests of tires is necessary. Also basic statical deformation characteristics of tires can be obtained from a device called statical adhesor, which is available to the authors. Material parameters of composite structural parts as the tire steel-belts are necessary input data for tire computational models.

Keywords: tire, long-fiber composite, elastomer, experiment, computational modeling.

Introduction

The complex composites with nonlinear matrix for transport means are tires. Tires can be classified as complex long-fiber composite structures consisting of polymer matrixes – rubbers (elastomer) and long-filament reinforcements – cords. Tires have got different constructions depending on the transport means type. E.g., one construction of tires is used for passenger cars, other constructions for trucks, off-highway cars and sports cars. The tires for air transportation, agricultural vehicles, mining machines and other transport means have got complicated structures in comparison with tires for passenger cars. There tire structures [1] are differentiated by:

- geometry parameters of tires;
- numbers of reinforcing plies in:
  - belt,
  - sidewall,
  - tread;
- construction of belts and cord-angles;
- width of belts;
- material and construction of cords etc.

The composite structure parts applied into radial tires for road vehicles are [2; 3]:

- textile tire carcass;
- textile overlap belt;
- steel-cord belt, which is the main structural element and the most complex composite part of radial tires. The tire belt consists of long steel-cord reinforcement – cords, elastomer drift and elastomer matrix.

High-strength steels are used exclusively for steel-cords production and good interface between elastomers and cords required. Steel-cord surfaces are modified by chemical-thermal treatment (braze or copperier) to achieve the best adhesive bond of steel cords and elastomer matrixes.

An example of a two-layer steel-cord belt is used with the construction of cords 2x0.30 mm HT with texture 961 (number of cords over meter width of one layer of belt) in radial tire 165/65 R13. The cord angle is ±23° and the layers are symmetrical [1].

Data about cross-sections, construction reinforcing plies etc. are necessary to creation of computational models of tires, too (see Figure 1).

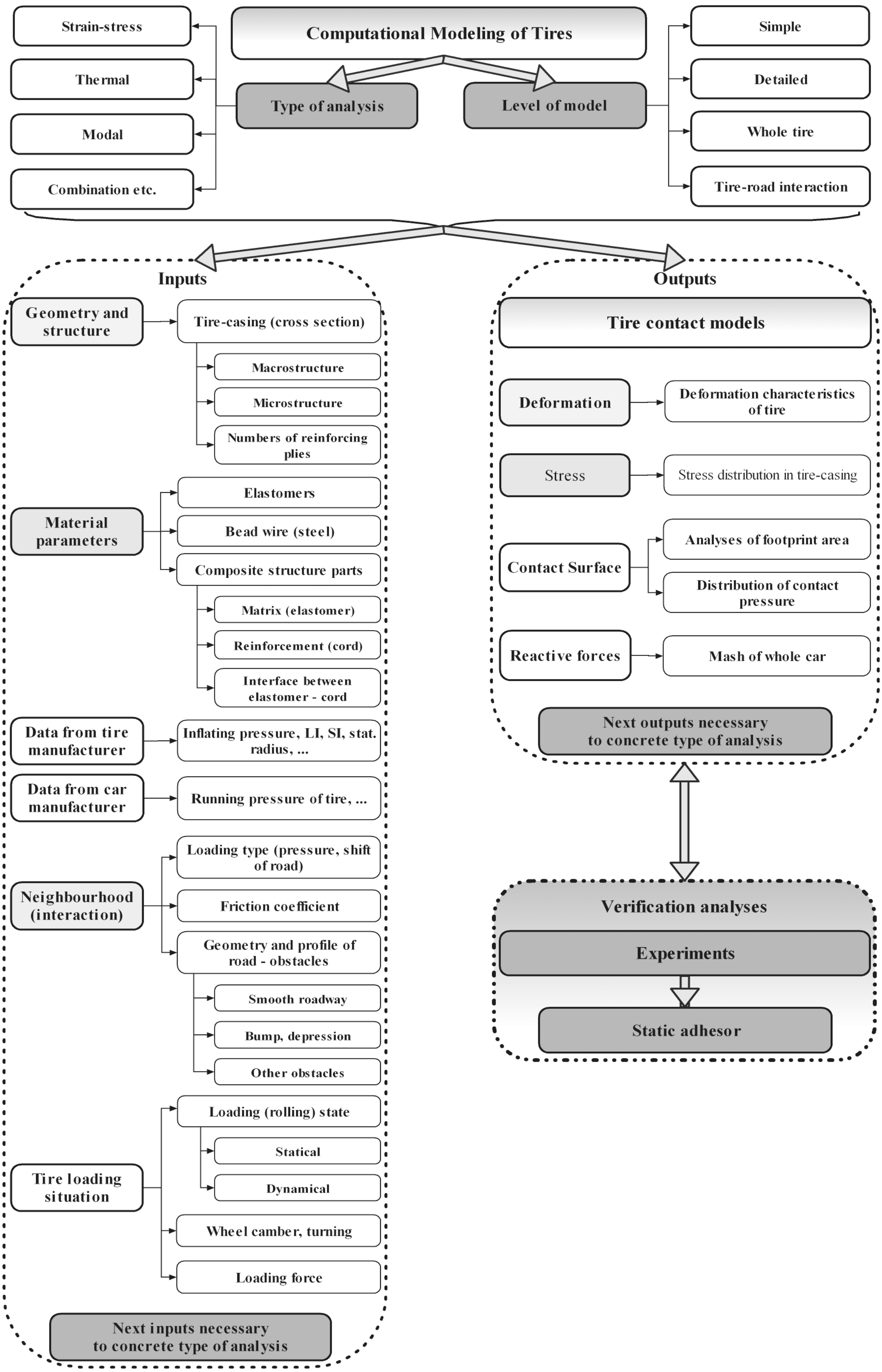

Fig. 1. **Necessary inputs to computational models of interaction of tires with road**

Computational modeling of tire

Figure 1 presents a diagram of the necessary inputs for computational model of tires and the obtained outputs. Some of the outputs are possible for verification with experiments. For complex approach of experiments and computation of tires and their parts, there is a requirement for knowledge of tire-casing from macrostructure and microstructure (e.g., microlocality of steel-cords – elastomer), too.

The Finite Element Method (FEM) using the program system ANSYS is applied to the computational modeling. Meshing of the model of the concrete radial tire 165/65 R13 is shown in Figure 2. The main requirements for creation the computational model are:

- not only its usability for the strain-stress analyses, but the model must also be "opened" for other usage-analyses. E.g., after supplementation of the necessary input data, the model will be possibly expanded for using for analyses of thermal field, analyses of dynamical loaded tire, modal analyses, eventually a combination these loading states;
- the model must include all material parameters obtained from the experiments of the parts of tire;
- the computational time must be optimized with regards to useful number of elements.

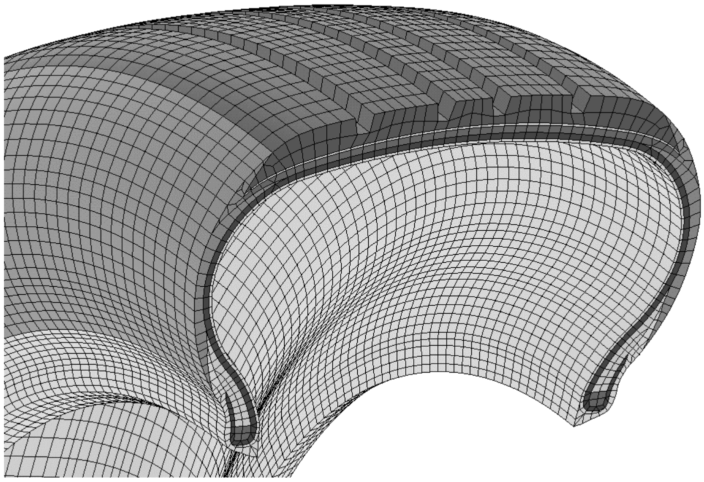

Fig. 2. **Meshing of computational model of tire 165/65 R13 for strain-stress analysis**

The outputs from the computational modeling composite structure parts will be used as inputs into the computational modeling of the dynamic states of the tire composites structure and the strain-stress analyses of the tire and other analyses.

Experiments of tires on statical adhesor

The static deformation characteristics of tires and further data are possible to be obtained by experiments on the test machine – statical adhesor (Figure 3), which is available to the authors. It is possible to obtain outputs as:

- radial deformation characteristic (by radial force loading of tire);
- radial stiffness (in vertical load force / radial displacement, $N\cdot mm^{-1}$);
- torsion (longitudinal) deformation characteristic (slip curve by twist moment);
- torsion stiffness (in twist moment / rim angle, $Nm\cdot(°)^{-1}$) and secondary longitudinal stiffness (in tangential force / tangential displacement, $N\cdot mm^{-1}$);
- contact patch (footprint shape and size) with contact pressure in contact patch (distribution of contact pressure by pressure FUJIFILM Fuji Prescale® indicating film).

At following conditions:

- Loading (radial force, twist moment);
- Radial deformation (size);
- Tire inflation pressure (under-inflation, overinflated tire, specified pressure);
- Unevenness (shape, surface roughness) etc.

The laboratory with the statical adhesor after innovation in 2011 consists of modern sensors and the data logger. On the statical adhesor it is possible to test tires with radius from R13 to maximum R17 and maximum width of the tire-carcass c. 235 mm.

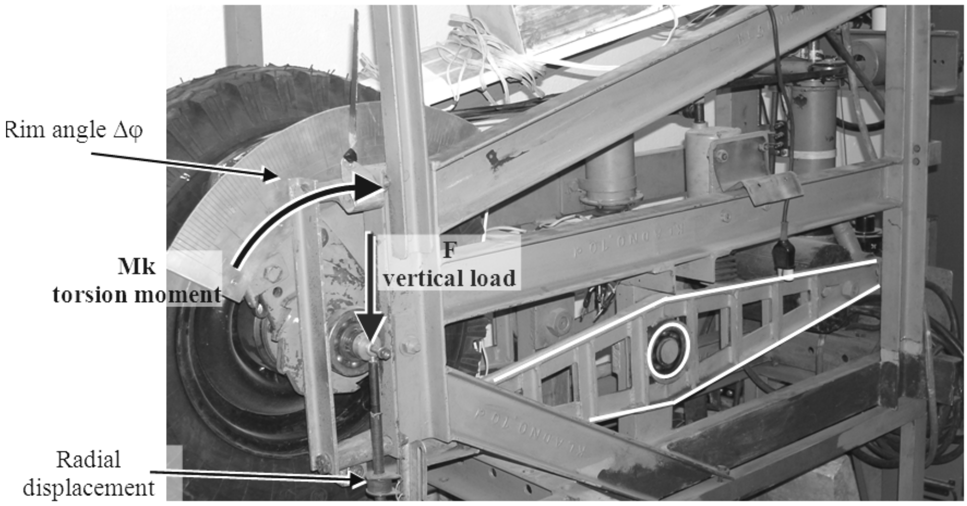

Fig. 3. **Statical adhesor with define of force loading**

Results and discussion

The results from the experiments on the statical adhesor for the selected tire Matador 165/65 R13 MP16 77 T are presented by:

- Radial deformation characteristic;
- Contact patch and its size;
- Values of radial stiffness, which is calculated by Formula 1.

$$\text{Radial (vertical) stiffness, N} \cdot \text{mm}^{-1} = \\ = \frac{\text{(vertical load force for 125 \% load - vertical load force for 75 \% load), N}}{\text{(radial deformation for 125 \% load - radial deformation for 75 \% load), mm}} \quad (1)$$

The tire was prepared and the experiments were performed by special standards for tires [4-8]. The Ultra Low Film (LLLW Fuji Prescale®, for contact pressure 2-6 kg·cm^{-2}) with exposure time 2 minutes and 30 seconds was used for contact patches.

On the basis on Matador Databook 2010 this tire 165/65 R13 has the maximum inflation pressure 3.0 bar and maximum vertical load 412 kg (it is the Load Index, marked as LI=100 % LI) and radial deformation for 412 kg and 3.0 bar is c. 28.0 mm. The static radius of the tire is c. 248 mm. The tire was measured by different conditions on the basic practice tire inflation pressures: 1.8, 2.1 and 2.5 bar.

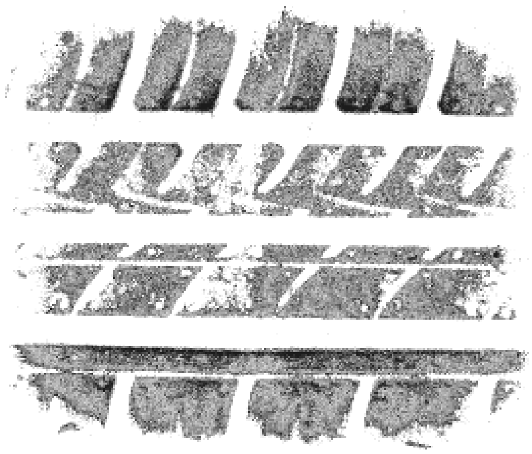

Fig. 4. **Tire 165/65 R13 – contact patch for load 412 kg and 2.5 bar**

The contact patch for 412 kg (as 100 % LI) and 2.5 bar is shown in Figure 4. The size of the contact patch is c. 10 125 mm^2. The radial deformation is 23.1 mm.

The tire was measured by vertical load weight from 0 to 740 kg. The 740 kg is 180 % of LI (180 % of 412 kg) – much overloaded tire! The radial deformation for overload 740 kg is 36.8 mm.

The value of the radial stiffness is c. 185.0 N/mm. Figure 5 represents the radial deformation characteristic and confrontation between the experiment and FEM computation.

The contact patch from FEM computation for radial deformation 25.0 mm is shown in Figure 6.

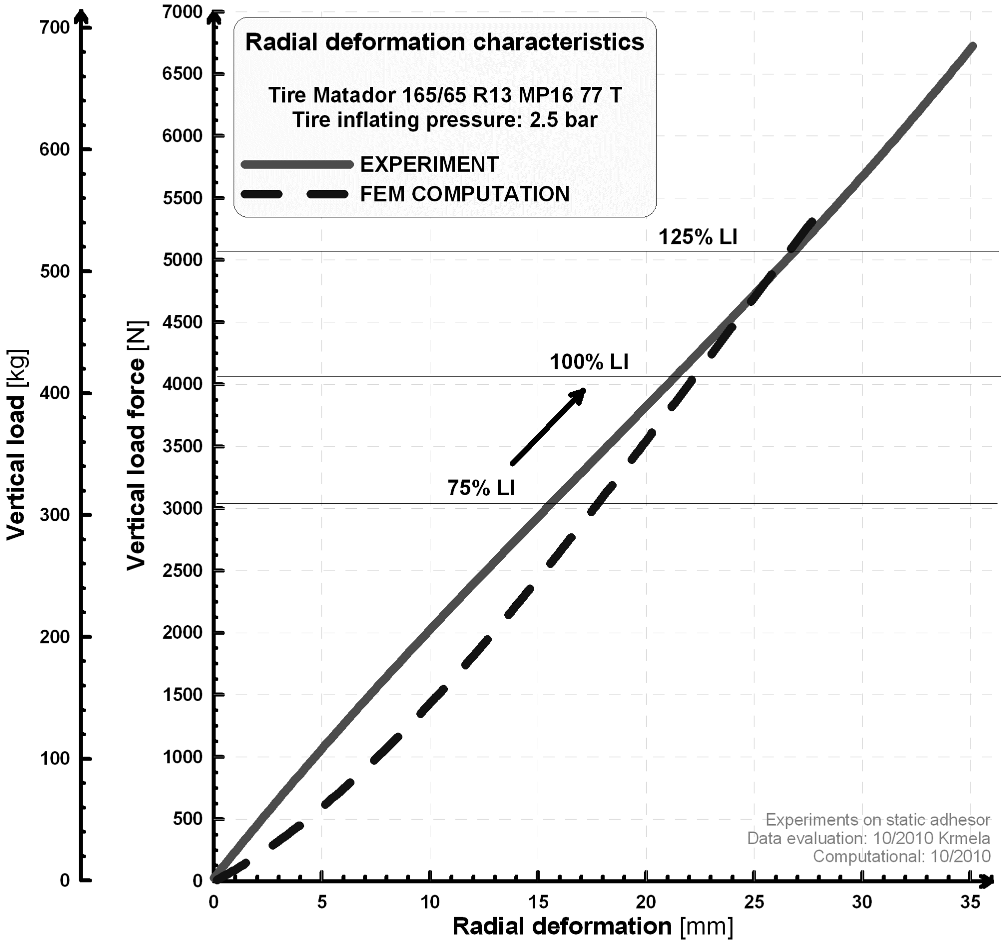

Fig. 5. **Tire 165/65 R13 – radial deformation characteristics from experiment and FEM computational modeling for 2.5 bar**

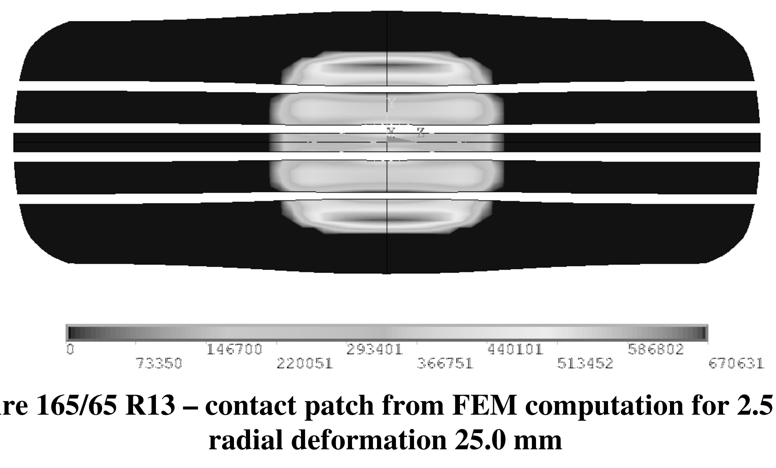

Fig. 6. **Tire 165/65 R13 – contact patch from FEM computation for 2.5 bar and radial deformation 25.0 mm**

Conclusions

The paper describes only parts of the lecture and research area of experimental and computational modeling of tires. The approach to the computational modeling of the tires includes the necessary inputs shown in Figure 1, it can be applied also to other construction types of tires, different sizes etc.

Interlace of the experiments with computational modeling was oriented for a concrete selected radial tire Matador 165/65 R13 for passenger car as a sample.

The value of the radial stiffness from the experiments for the selected tire is c. 185.0 $N \cdot mm^{-1}$ for inflation pressure 2.5 bar. For lower inflation pressure 1.8 bar the radial stiffness is c. 152.5 $N \cdot mm^{-1}$. The tires must be measured by practice conditions.

The confrontation between the experiment and FEM computation by radial deformation characteristics is good. The knowledge obtained from the experiments and computational modeling was parallel confronted with the computing centre of the tire producer.

The FEM computation of the selected tire gives good results but it will be necessary specify the material parameters of the tire structure parts to computational modeling, namely material parameters of concrete steel-cord belts.

The laboratory with the test machine for static deformation of tires – statical adhesor is a complexly laboratory at universities in the Czech Republic and Slovakia, which enabling on-line measurements and evaluation of all outputs from the experiments of all tires for cars. In future in contemplation test machine next innovation by special pressure measurement such as TireScan™ System [9] and also construction design of adhesor for quasi-dynamically tests of tires could be used.

There is possible co-operation in the lecture and research area of tires – experimental and computational modeling of tires and composites, too.

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