Replacement of belt structure for FEA of tire

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Abstract

The paper deals with computational modeling of radial tire for cars. The authors used FEA (Finite Element Analysis) utilizing program ANSYS. The authors are oriented not only to the strain-stress analyses of tire. In relation to the tire computational models, the composite structure parts (textile carcass, steel-cord belt and textile belt) cannot 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 composite structure parts are partially replaced with some specified stiffness. The paper describes the different ways of replacement of structure represented by the steel-cord belt. These replacements are used for FEA of tire.

Keywords: tire; composite; belt; FEA; ANSYS

1. Introduction

The tire-casing can be generally understood as a long-fiber composite material where there is an interaction of the elastomeric matrix (rubber) with steel as well as non-metallic reinforcements, namely textile cords (e.g. PA 6.6, PES textile fibers). The tire-casing as a specific composite with different cord angles, thicknesses of plies, cord materials, cord constructions and also materials of matrices (different chemical compositions of rubbers). The composite structure parts of the tire-casing are steel-cord belt, textile carcass and textile belt [1].

In relation to the computational modeling by the Finite Element Analysis (FEA), it is necessary to pay attention to the materials as well as geometric input data in order to make precise characteristics standing for composite – tire-casing. The short computational time is required during the application of the FEA. We need to find compromise between the discretization of the computational tire-casing model and required accuracy of the results. It is connected
with correct material description of the tire-casing. But the composite structure parts cannot be implemented up to the level of reinforcing cords because of the very long time as well as the large number of the finite elements.

The composite structure parts are partially replaced with some specified stiffness. The paper describes the different ways of replacement of structure represented by the steel-cord belt.

2. Construction of steel-cord belt of Matador tire

Steel-cord belt is the most complex composite part of radial tires because the steel-cord belt consists of long steel-cord reinforcement – cords with different constructions, elastomer drift and elastomer matrix.

For creations of the tire computational models is necessary to have a good knowledge about structure of tire-casing as a whole (e.g. [2–4]) and material parameters of matrix and reinforcing cords [5, 6], too. These parameters are obtained by experiments.

The cord angles between 21° and 27° are applied for steel-cord belt. The radial tire Matador 165/65 R13 has two-layer steel-cord belt with construction of cords 2x0.30 mm HT and with cord angle ± 23° [7]. The layers of belt are symmetrical. The texture, which is defined as a number of cords over meter width of one layer of belt, is 961. The geometric configuration of reinforcing cords in steel-cords belts and tire-crown of this tire is on Fig. 1.

![Fig. 1. Detail of steel-cord belt and tire-crown.](image)

This is very simply structure of steel-cord belt but tires for can consist of more than two layers and these layers can be nonsymmetrical. The geometric configuration of the reinforcements is the main factor for the specification of the materials parameters which should be used for description of the whole steel-cord belt or the whole area of tire-casing under the tread. The parameters for steel-cord belt of this tire, which are obtained on the basic on measurement into cross-section etc., are introduced in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
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<tbody>
<tr>
<td>Number of layers (-)</td>
<td>2</td>
</tr>
<tr>
<td>Thickness of each layer (mm)</td>
<td>0.95</td>
</tr>
<tr>
<td>Diameter of cord (mm)</td>
<td>0.60</td>
</tr>
<tr>
<td>Cord angle (°)</td>
<td>23</td>
</tr>
<tr>
<td>Cord texture (m⁻¹)</td>
<td>961</td>
</tr>
<tr>
<td>Spacing between cords (mm)</td>
<td>1.04</td>
</tr>
<tr>
<td>Volume of cord in layer (%)</td>
<td>28.6</td>
</tr>
<tr>
<td>Tensile elasticity modulus of matrix (MPa)</td>
<td>12</td>
</tr>
<tr>
<td>Poisson ratio of matrix (-)</td>
<td>0.4995</td>
</tr>
<tr>
<td>Tensile elasticity modulus of cord (MPa)</td>
<td>180 000</td>
</tr>
<tr>
<td>Poisson ratio of cord (-)</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Steel reinforcement is described by linear isotropic material model. If the Mooney-Rivlin two parameters hyperelastic material model are used for elastomer matrix then these parameters are 0.638 and 0.284 MPa on the basic on statical uniaxial tensile tests.

3. Possible ways of material replacement of steel-cord belt

For computational modeling of tire-casing [8] the homogenization of systems cord – elastomer into tire is required (Fig. 2). You can see different descriptions of steel-cord belt as well as other composite structure parts of tire-casing into tire computational models in Fig. 3.

Fig. 2. Finite element model of Matador tire.

Fig. 3. Different ways of replacement of steel-cord belt into tire computational models [9].

The different descriptions of the composite structure parts in the tire computational models can be done [10]: replacement of steel-cord belt with orthotropic material, replacement of the areas with so called rebar reinforcing finite element, replacement based on combination of orthotropic material with rebar element, replacement of the areas with so called layered finite element or shell finite element and replacement of steel-cord belt by special reinforcing finite element type Reinf in ANSYS. The suitable selection of the mentioned replacements is influenced by the specific factors including computational time, knowledge of the required materials parameters and expected accuracy of results.
3.1. Replacement of steel-cord belt by orthotropic material

Two layers of 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). Materials parameters are specified with help of the experimental process on the basis of which the values of constants of elasticity for steel-cord belt in individual directions of tire-casing are obtained. The mentioned replacement is often used in practice. The difficulty of this method is connected with the correct determination of Poisson’s ratios which have to be calculated in order to obtain the appropriate coordinate system of 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 slight change can cause significant change in stiffness parameters of the belt as well as the whole tire-casing.

3.2. Replacement of the areas by rebar reinforcing finite element (designated as REBAR)

The area of the steel-cord belt is expressed by one homogeneous material with parameters which equal to materials parameters of matrix referring to linear isotropic material. The reinforcement can be defined by real constants including cord angles and volume measure of reinforcement with its specified cord material. The reinforcement can be simply expressed by help of volume ration but in relation to this volume ration, there is not real configuration of cords in belt. In comparison with orthotropic material, the utilization of the rebar element in computational model leads to the increase of the computational time because of more sensitive discretization.

3.3. Replacement based on combination of orthotropic material by rebar element (designated as COMBINATION)

This method represents the combination of the advantages relating to the both methods mentioned hereinbefore.

3.4. Replacement of the areas by layered (“laminated”) finite element (designated as LAMINATED) or shell finite element (designated as SHELL / MEMBRANE + solid)

This replacement of the steel-cord belt is based on assignation of real constants to the given type of element and the given constants include cord angles and the number of layers standing for the specified reinforcing element of tire-casing while the parameters of the orthotropic material are also assigned. It is necessary to point out that the given orthotropic material represents the homogenization of the individual steel-cord belt layers. Steel-cord belt with two layers consists of two layers which are positioned in a parallel way. The mentioned layers are described by help of real constants representing cord angles and by parameters of orthotropic material which is identical for both layers. In relation to the mentioned two layers, the third layer can be placed between these two layers and this third layer represents elastomeric interlayer which is between layers of steel-cord belt.

Poisson’s ratios of the orthotropic material describing each one layer of steel-cord belt can be determined more precisely in comparison with the case where the replacement of steel-cord belt is obtained with orthotropic material or in other word, by homogenization of two layers of steel-cord belt leading to creation of only one part.

3.5. Replacement of steel-cord belt by special reinforcing finite element

Relating to the description of the steel-cord belt for tire-casing, the special type of element is recommended during the operation in ANSYS software and this new special type of element is e.g. Reinf265 which is assigned to the areas of the steel-cord belt with Solid186 type of element. Considering FEA, there is not a lot of available information in relation to the mentioned type of the element and therefore, the utilization of Reinf is going to be the subject of authors’ investigation from the aspect of the replacement of the steel-cord belt as well as other tire composite structures.
4. Conclusion

The authors pay their attention to the orthotropic material which is often used as a replacement of the steel-cord belt (by homogenization of both layers together) because the given orthotropic material has quite good response to the surrounding environment.

The orthotropic material parameters (elasticity modules and main Poisson ratios) in standard main material axes are listed in Table 2 (left). But for computational model the transformation of these parameters to other coordinate system are needed so that axis Z is equal to circumferential direction of tire-casing (Table 2, right). Tensile elasticity modules are determined by experiments. Other data are obtained by laminated theory with used software CADEC “Computer Aided Design Environment for Composites” [11]. These material parameters should represent real structure of the Matador tire.

Table 2. Orthotropic material parameters of two layers steel-cord belt in main material axes and for FEA tire models.

<table>
<thead>
<tr>
<th>In main material axes</th>
<th>For FEA tire models</th>
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<tbody>
<tr>
<td>Tensile elasticity modules</td>
<td>Main Poisson ratios</td>
</tr>
<tr>
<td>Ex / Ey / Ez (MPa)</td>
<td>PRxy / PRyz / PRxz (-)</td>
</tr>
<tr>
<td>717.0 / 23.1 / 12.0</td>
<td>2.3000 / -1.0400 / 0.6000</td>
</tr>
</tbody>
</table>

The computation modeling and calculations by namely laminated theory of long-fiber composites are very difficult because the accurate materials characteristics of matrixes and reinforcement are needed. The obtained information on geometric arrangement of reinforcements can be used also for optimization of arrangement of cords in the tire-casing in order to gain better stiffness parameters standing for individual directions.

The continued research work of authors will be the comparison of tires with analogous construction of cords but different radius and width of tire-casing.

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References