Description of Uncured Rubber for Tire Moulding Simulation

C. Zopf\textsuperscript{1}, M. Kaliske\textsuperscript{2}, C. Brüggemann\textsuperscript{3}, E. Goudswaard\textsuperscript{4}

\textsuperscript{1} Technische Universität Dresden, Germany, christoph.zopf@tu-dresden.de
\textsuperscript{2} Technische Universität Dresden, Germany, michael.kaliske@tu-dresden.de
\textsuperscript{3} Continental Reifen Deutschland GmbH, Germany, carina.brueggemann@conti.de
\textsuperscript{4} Continental Reifen Deutschland GmbH, Germany, edwin.goudswaard@conti.de

Tire production and tire development are quite complex processes. The production of a tire starts with the manufacturing of a so-called green tire. This pre-product consists of all required, but uncured rubber components and fiber reinforcements, and it has no tread pattern yet. In a curing press, the green tire is inmoulded and heated, in order to cross-link the polymer chains. Afterwards, the tire has its cured tire dimensions and typical properties. In the development departments of tire manufactures, numerical simulation tools, based on the Finite Element Method (FEM), are standard for the performance prediction of new tire designs. In the first stage of the development, the FEM is used to predict the performance of a new design defined by cured tire dimensions under consideration of all requirements. Secondly, the mould contour, the tire components and the processing have to be defined to obtain this tire design in the production. Currently, the latter process is based on expert knowledge and on practical experience. So far, FEM simulations are not used as standard approach for the investigation of the green tire moulding. Thus, the goal of this paper is the development of a reliable tire moulding prediction.

Moulding simulation is a physical model of the rubber forming process before curing. This description delivers realistic results only if the basic conditions of the model are appropriate. Hence, it is important to implement the geometry, the moulding process and the material characterisation into the virtual model. The properties of the uncured rubber have an influence on the forming process, which is one main focus of the presented research work. The material formulation is used for the characterisation of the different uncured rubber compounds. Reinforcements as well as the modelling of the interaction between reinforcements and rubber is also included in the green tire model.

In order to obtain a realistic constitutive approach of the elastomeric material, all uncured compounds which are used in the forming process need to be characterised throughout several tests. These rubber compounds consist of natural or synthetic caoutchouc and of a wide range of additives, for example carbon black, polymer plasticiser, oil and sulphur. For a realistic constitutive description of the elastomer, extensive material tests under consideration of different states of strain and different strain rates are required. During the authors’ research work, compression, tensile and pure shear tests have been carried out. Compression and tensile tests consider a uniaxial state of strain. Planar deformation can be taken into account by pure shear tests. In order to describe the viscous effects of the rubber material, cyclic and relaxation tests are undertaken. Furthermore, the long term irreversible part of the deformation is determined with the help of a specific cyclic test.

A realistic material approach of the uncured rubber can only be found by using a model which considers elastic, viscous and irreversible properties at finite strains. Hence, the rheological formulation illustrated in Figure 1 is chosen. This approach consists of two springs and two fractional elements. The mathematical description of the two nonlinear elastic springs is given in dependency of the volumetric and the deviatoric part of the strain energy density function. The general basic formulation with respect to the strain energy density function and several constitutive models are given in Kaliske and Rothert
Marckmann and Verron [2] compared different approaches of rubber-like material and identified the tube model (see [3]) as the most appropriate one. The inelastic parts of deformation are described using fractional rheological elements. The stress tensor $\sigma$ within a fractional element

$$\sigma = p \frac{d^\alpha}{dt^\alpha} \varepsilon$$

is defined as the time-derivative of the strain tensor $\varepsilon$ with an order of $\alpha$ multiplied with the material parameter $p$. The order of the fractional derivative $\alpha$ is a material parameter between zero and one. Therefore, the differential equation (1) of the fractional element can be identified with the differential equation of a spring ($\alpha = 0$) and of a dashpot ($\alpha = 1$) as limiting cases. The theory of fractional calculus is the mathematical basis for the used model. Oldham and Spanier [4] give a historical and general survey about the theory of differentiation and integration of arbitrary order $\alpha$. Some basic ideas for the use of fractional calculus in the field of viscoelasticity are given by Bagley and Torvik [5].

Figure 1: fractional Zener model in series with a single fractional element

The description of the inelastic material behaviour follows partly the paper of Dal and Kaliske [6]. The constitutive concept is obtained by a fractional time derivative of the evolution law of the viscoelastic and the irreversible part of the material model.

After identifying the material parameters of the model under consideration of all material tests, validations are required in order to evaluate its performance. In a first validation step, a moulding test is carried out. Here, a rubber block with the shape of a cuboid is formed into a rigid mould. Hence, it is possible to compare the numerical and the experimental moulding force and the shape of the cuboid surface after moulding.

Finally, a first tire moulding simulation of a truck tire is realised. The truck tire is modeled by using different rubber compounds and it includes fiber reinforcements, e.g. carcass, belt and bead wire.

The Leibniz Institute of Polymer Research in Dresden is gratefully acknowledged for conducting the material tests. Special thanks go to the Continental Reifen Deutschland GmbH for providing the rubber compounds, the validation test data and the financial support of the research work.

References


