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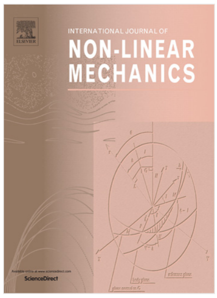

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Numerical modeling of thermal ageing in steady state rolling tires

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Abstract

In this contribution, thermal material degradation in steady state rolling tires is numerically studied. A phenomenological time-dependent thermal damage approach from the field of continuum damage mechanics (CDM) is implemented into a modular simulation environment [Behnke & Kaliske IJNLM 68 (2015)], which allows the thermo-mechanically coupled analysis of axisymmetric tires in steady state motion via the finite element method within an Arbitrary Lagrangian Eulerian framework. Within the numerical model, rubber compounds of the tire are represented by their temperature-dependent viscoelastic properties at finite deformations. Energy losses as heat source terms, computed on a physical basis from the dissipative material properties (non-equilibrium stresses), are used to predict the heat build-up in the tire under severe service conditions. Model parameters for the time-dependent thermal damage approach are identified from previously published experimental investigations on thermally aged rubber compounds in order to link the temperature increase and the evolution of thermal damage (thermal ageing). The thermal damage approach qualitatively captures the irreversible changes of the rubber compounds' mechanical properties, which, in turn, lead to an alteration of the entire structural response of the thermally damaged tire.

Keywords: Elastomers, thermal ageing, thermal damage, thermo-mechanics, steady state rolling, tires

1. Introduction

Elastomer components (e.g. tires) can be found in many engineering applications. Under service conditions, these components are commonly subjected to various load combinations, e.g. forces, internal or external heat exposure, cyclic loading. Furthermore, different environmental conditions such as radiation, salt water, oil, chemical or biological contamination, humidity as well as temperature act in a more or less pronounced manner (interactions) on rubber components [1]. Degradation or damage of the elastomer material has to be avoided since in the long term, damage of elastomer compounds affects the entire structural behavior causing structural failure. Failure of elastomer compounds [2] does not only constitute a high safety risk, but is also linked to cost-intensive replacement costs (operating time is reduced) and loss of working hours.

High temperatures stimulate the ageing of elastomer blends by oxygen and other chemical reactions, see e.g. [3] for a numerical simulation of thermal oxidation in automotive tires. These reactions will result in an altered mechanical behavior of the component. In an idealized manner, three phases of material alteration are observable in case of increasing temperature. First at moderate temperatures, additional crosslinks are formed leading to hardening of the elastomer (increase of the modulus of elasticity, formation of a secondary network [4]). Second, a further temperature increase triggers scission of crosslinks [5, 6] and leads to mechanical softening of the material (decrease of the modulus of elasticity) [7]. Third, at the ultimate temperature, the main chains of the elastomer network will break causing failure of the material [8]. The thermal damage of the elastomer will be a function of its chemical formulation, its exposure time to the relevant temperature and the presence of oxygen acting as an accelerator depending on the geometry of the specimen (compact form or thin specimen, i.e. ageing might occur inhomogeneously). In consequence, at least a time and temperature dependency has to be considered for the evolution of thermally triggered damage at the material scale.

The self-heating of elastomer components or especially tires under steady state loading conditions can become significant and finally reach a critical value, e.g. as recently reported in [10]. Self-heating is triggered by the dissipative nature of the elastomer compounds. In general, elastomers show properties of a hyperelastic solid in combination with more or less pronounced viscoelastic and elastoplastic features. In consequence, permanent service of the tire under severe conditions including heat generation or heat exposure triggers thermal damage. Ultimate service temperatures of different elastomer types are discussed in [11]. But also for standard service conditions, temperatures up to 60°C can be reached in the tire cross-section leading to an onset of material alteration (embrittlement of the rubber matrix).

The study of thermal ageing is dominated by experimental investigations, see e.g. [12, 13]. Recently, studies with respect to fatigue crack growth characteristics of thermally aged rubber [14] and its intrinsic strength with respect to fracture [15] have been carried out on the material scale. Although the phe-

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