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FINITE ELEMENT SIMULATION OF INELASTIC AND VISCOELASTIC EFFECTS USING A MICROSTRUCTURE BASED MODEL FOR FILLED ELASTOMERS

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The properties of filled elastomer like rubber, reinforced with fillers such as carbon black or silica show an improved characteristics in order to have an enhanced potential to higher loads. Besides making the elastomer stiffer and tougher, the incorporation of filler results in a strong nonlinear deformations with inelastic effects. One such effect studied by Mullins is stress softening [1], where the stress drop occurs not only during the quasi-static multi cyclic deformation loop, but also after the loading history has gone beyond the previous maximum. In addition to this, hysteresis is another characteristic effect caused by fillers which is related to the dissipation of mechanical energy. The origin of these effects is related to the interaction between polymer and filler.

During vulcanization of rubber, in addition to the process of polymer network cross-linking, the filler particles form clusters due to higher temperature. The process of formation of cluster-cluster aggregation can also be called flocculation. The resulting filler structure essentially determines the mechanical behavior of the entire polymer filler network. Unlike phenomenological models, the so-called Dynamic Flocculation Model (DFM) [2], which is developed on a physically motivated framework is able to describe a wide range of nonlinear and inelastic material properties of filled elastomers. It couples the entropic driven material behaviour of the polymer network with the polymer-filler and filler-filler interaction by considering the breakage and re-agglomeration of filler clusters in the polymer matrix during repeated loading cycles [3]. The finite element implementation of model has been realised using representative direction concept [4], which shows a very good fit to standard multi-hysteresis tests. The main advantage is that the constitutive behaviour of the model mimics the material response of the filled elastomer with its material parameters aligned to real physical quantities.

In this contribution, the DFM will be further developed to include time dependent effects where the limit of frequency and temperature range is given by the glass transition of the polymer composite. Generally, viscoelastic models are constituted with basic hyperelastic model in parallel with series of Maxwell elements [5, 6], but they reproduce linear viscoelastic response. Although some of the recent models are developed in the non-linear viscoelastic framework [7, 8, 9], they predict material response in macroscopic level and moreover they are developed on phenomenological approach. Whereas to study the phenomenon like viscoelasticity at microscopic level, the DFM can be modified to consider time dependent effects. Since the time dependent effects are mainly driven by filler-filler interactions, their influence is described explicitly by the parameters s_d and s_v in the DFM as the strength of damaged and virgin filler clusters, respectively. Henceforth these material parameters can be decoupled into equilibrium constants ($s_{d,eq}$ & $s_{v,eq}$) and time-dependent functions ($s_{d,t}$ & $s_{v,t}$). The time-dependent function can either be described by a series of Maxwell elements, or by a new kind of relaxation function which is physically related to DFM [10]. The complexity of the functions has to be analyzed and verified by corresponding experiments. Therefore, rate-dependent multi-cycle tests, relaxation tests and DMA measurements will be considered.

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