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A Meshfree Procedure for the Microscopic Simulation and Design of Rubber Compounds and its Application to Multi-Scale Simulation of Tires

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ABSTRACT

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Macroscopic characteristics of tires, such as rolling resistance, wear and braking performance, are affected not only by the construction and shape of the tire but also the microscopic mechanical characteristics of the rubber compound. It is important to investigate the micro- and macro-scale structural behaviors in the tire simultaneously. To work it out with reasonable computational cost, a decoupled micro-macro finite element analysis procedure based on homogenization theory has been developed [1] and has been applied to multi-scale simulation of tires [2].

Meshfree methods [3-5] circumvent many difficulties which arise simulating and designing microscopic rubber compounds in tires using Finite Element Method. The main difficulty is the inability of the Finite Element Method to handle severe large deformation. The mesh-based nature of Finite Element Method also creates difficulties in modeling rubber compounds with internal features such as material interfaces, sliding interfaces and cracks.

In this study, we first establish a meshfree process for the microscopic simulation and design of rubber compounds including the imposition of a periodic boundary condition. To effectively handle the essential boundary conditions as well as to improve the efficiency in the analysis, a modified Maximum-entropy (MAXENT) approximation with stabilization technique is presented. Compared to the original local MAXENT approximation [6], the modified MAXENT approximation utilizes the compact-supported kernel functions to introduce the locality and to improve the efficiency in the large-scale computation. The periodic boundary conditions can be enforced by solving the multiple constrained equations based on the periodicity.

Secondly in this study, we apply the meshfree microscopic analysis of carbon black filled rubber to the multi-scale simulation of tires. In this procedure, the existence of homogenized constitutive law is assumed, and multi-point constraint technique is introduced for subjecting the micro-scale model to macroscopic constant stress/strain in periodic boundary conditions so that the two-scale boundary value problem derived from homogenization theory can be solved approximately.

The developed capabilities have been tuned for a vector and parallel processing supercomputer, NEC's SX-8. The procedure efficiently solves extremely large deformations of rubber compounds subjected periodic boundary condition. It is useful for practical multi-scale simulation of tires and other rubber products.

The meshfree method has been found to be an effective approach for numerical modeling and design of rubber compounds under both small and large deformation. Our result shows that the conformation change of fillers during large deformation characterizes the macroscopic mechanical property of a rubber compound. The conformation change may be the principal cause of mechanical loss of rubber compound. Several issues involving the influence of morphology of fillers to the mechanical properties of a rubber compound are addressed including 3D multi-scale simulation of a rubber compound and tire.

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