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Numerical prediction of mechanical properties of rubber composites reinforced by aramid fiber under large deformation

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Abstract Recently, rubber composites reinforced by short aramid fiber have been widely used in tires and have attracted considerable attention because of their excellent characteristics. In this study, uniaxial tests and scanning electron microscope experiments were performed to obtain the mechanical response and to study the microscopic structure of the composites, respectively. A finite element numerical model is proposed to predict the mechanical properties of rubber composites reinforced by short aramid fiber based on experimental observation. Using the random sequential adsorption algorithm, fibers were generated with embedded element technique; this makes finite element modeling more convenient and enables the analysis of two key issues: the large aspect ratio of the aramid fiber and large deformation of the rubber. The close agreement between the experimental results and numerical results verifies the reliability of the proposed finite element model for aramid-fiber-reinforced rubber.

Keywords: rubber, short fiber, numerical prediction, mechanical property, composites

1. Introduction

Recently, aramid fiber has been widely used in tires [1] for its excellent characteristics, such as high strength, high modulus, high temperature resistance, high chemical corrosion resistance, and high cutting resistance [2]. Generally, long aramid fibers are cut into short fibers, to add to the rubber compound. Then, by optimizing the recipe and the mixing process, the strength, wear resistance, and cutting resistance of the rubber composites are improved, and the energy lag loss is minimized [3]. In addition, rubber composites with short fibers can be produced without complicated processing technology, which improves the level of production automation and continuity. It has been proven that, during the molding process, the short fibers are always oriented along the rolling and flowing directions within the rubber composites [4]. The special shape factor of the short fiber, i.e. the aspect ratio, results in the composite’s many excellent mechanical properties, allowing for a large area for processing design of aramid-short-fiber-reinforced rubber composites (AFRCs) [5].

To predict the mechanical properties of a discontinuous-fiber-reinforced composite, theoretical analysis models and numerical methods are always employed. In terms of theoretical analysis methods, Eshelby’s equivalent inclusion theory [6] and the Mori-Tanaka modified theory [7] have been successfully used to predict the modulus of different composites with aligned fibers. In addition, the Halpin-Tsai equation [8] is a simple analytical model to describe the elastic response of composites with a variety of fiber geometries. By averaging the characteristic strain in all directions, Eshelby’s equivalent inclusion theory has been extended for use in composites with randomly distributed fibers [9]. In addition, the empirical formula based on the Halpin-Tsai equation offers a method to predict the modulus for a laminate with randomly distributed short fibers [8,10]. Tian et al. proposed a method of orientation averaging [11] to predict the effective elastic properties of short-fiber-reinforced composites. However, the aforementioned analytical models are all aimed at small deformation.

As we know, rubber presents an important characteristic of hyperelastic large deformation. Macroscopically, a rubber composite reinforced by randomly distributed fibers can be treated as an isotropic material such that the