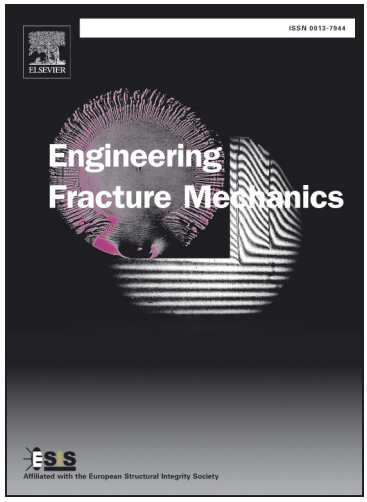

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Toughness of natural rubber compounds under biaxial loading

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Abstract

Strain induced molecular orientation effect on the fracture toughness of natural rubber based compounds was studied under biaxial loading conditions, using non-linear elastic fracture mechanics. The J-integral at fracture was evaluated using the finite element method. Fracture toughness can be severely influenced by strain induced molecular orientation up to a material dependent threshold, above which toughness becomes constant.

The effect of the fracture phenomenology shown by two carbon black filled compounds, for which propagation is preceded by branching at the tip (sideways crack propagation), is shown to remove any significant stress concentration at the original crack tip, enhancing the apparent fracture resistance.

Keywords: Natural Rubber Compounds, J-integral, biaxial tests

1. Introduction

It is well known that crystallising rubbers develop a strong strength anisotropy upon stretching: broadly speaking, if stretched along some direction they can become easier to break upon subsequent stretching perpendicularly to this direction [1–3]. This phenomenon is rather complicated and is linked with molecular orientation and stress induced crystallisation which have a significant impact on fracture toughness [4].

Gent and Kim [2] tested notched rubber strips that were stretched, before testing, in a direction perpendicular to the testing one; their grip system allowed them to keep the pre-stretching level fixed during testing. For crystallising rubbers, they found a very strong decrease of the tear energy of the material with increasing elongation.

In a previous work by some of the authors of this paper, natural rubber compounds were studied by applying a biaxial load using a cross-shaped specimen containing a central notch [3]. In those tests the samples were first stretched in a direction parallel to the notch, in order to induce a certain level of orientation in the material, and then the notch was opened by loading along the perpendicular direction. Different levels of orientation were induced in the material by applying different stretch levels during the first part of the test. The results were basically analysed in the framework of linear elastic fracture mechanics: an apparent critical stress intensity factor was evaluated from the fracture load at fracture initiation. The authors concluded that orientation produced a significant decrease in the resistance to crack propagation. Due to the non-linear nature of the materials used, such an analysis was to some extent not correct; in principle the trend observed could be apparent and caused by the use of a parameter which was not adequate to take into account the material behaviour and large deformations.

In addition to the uncertainties introduced by the analysis, further complications were brought in by the complex fracture phenomenology. Under certain conditions rubbers may exhibit a crack branching phenomenon that has been variously termed in literature as “sideways crack propagation” [3] or “knotty tearing” [2, 4, 5]. It takes place under load at the tip of a crack, where the front splits into two cracks that

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