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A continuum damage model for the high-cycle fatigue life prediction of styrene-butadiene rubber under multiaxial loading

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ABSTRACT

In the present contribution, the relationship between the fatigue life of styrene-butadiene rubber (SBR) and the stretch amplitude was established. Focusing on the multiaxial loading effect on the life duration of SBR, experimental tests were conducted using cylindrical specimens subjected to tension and torsion loadings under constant and variable amplitudes. Based upon the continuum damage mechanics approach, a three-dimensional model was derived and coupled with the cracking energy density criterion to predict the fatigue life of SBR. The capabilities of the model, which requires only three damage parameters to be identified, were analysed and a good agreement between predicted values and experimental data were clearly highlighted for tension and torsion loadings both in constant and variable amplitudes.

1. Introduction

Elastomeric materials are used in industrial applications such as tires, hoses, dampers for the automotive/aircraft industry. These applications require a good performance under static loading and durability under cyclic loading. Rubber components of mechanical structures could be subjected to variable loads leading to fatigue fracture. Early in the product development process, engineers need simulation software capable of predicting stress and strain histories in the purpose of modelling and designing for mechanical fatigue. Therefore, understanding the damaging processes and predicting the life duration under multiaxial loading is a primary consideration for industrial design.

In a very useful background paper, Mars and Fatemi (2002) have widely reported the main approaches used to describe the fatigue of rubbers. As for most of materials, the fracture of rubbers under fatigue loading conditions could be described by two main mechanisms: nucleation of defects and propagation until complete failure of nucleated cracks. In the fatigue life duration of a rubber component, the time required to nucleate a defect of a given size and that necessary to propagate a defect until complete fracture depend on many parameters such as the geometry of the rubber specimen, the loading conditions, etc. So, generally, these two stages in fatigue investigation are often separately studied, although some authors have tried to give a unified approach but based on crack propagation.

Concerning the fatigue crack propagation, the fatigue life is defined as the number of cycles required by a pre-existing crack to grow until fracture. The strain energy release rate early introduced by Griffith (1920) and extended by Rivlin and Thomas (1953) to fracture of rubbers is generally used as a governing parameter to describe the crack growth and to build empirical laws (as that developed by Paris for metals but using the stress intensity factor).

When dealing with the crack nucleation, the fatigue life is generally taken as the number of cycles required to create a crack of a given size. It is often related to macroscopic mechanical quantities (such as stresses or strains) which are taken as indicators of fatigue loadings. Following the pioneering work of Wöhler (1867) for steels, Cadwell et al. (1940) extended this kind of approach to rubber components. The three most widely used predictor parameters for rubber fatigue are: (i) the maximum principal strain, (ii) the maximum principal Cauchy stress and (iii) the strain energy density (SED). More recently, (iv) the cracking energy density (CED) criterion proposed by Mars (2001, 2002) and (v) the criterion based on the configurational mechanics (Eshelby, 1951) – the Eshelby stress tensor – proposed by Verron and Andriyana (2008) constitute more elaborated approaches to investigate fatigue of elastomeric-like materials.

In the remainder of the introduction, literature results regarding these predictor parameters are briefly summarized.

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