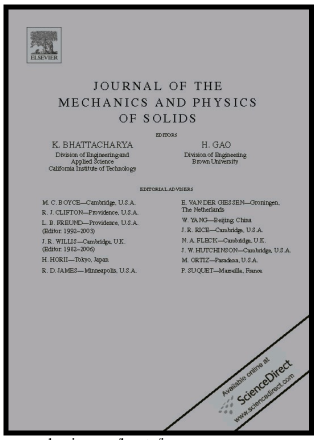

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Application of the Virtual Fields Method to a relaxation behaviour of rubbers

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This paper presents the application of the Virtual Fields Method (VFM) for the characterization of viscoelastic behaviour of rubbers. The relaxation behaviour of the rubbers following a dynamic loading event is characterised using the dynamic VFM in which full-field (two dimensional) strain and acceleration data, obtained from high-speed imaging, are analysed by the principle of virtual work without traction force data, instead using the acceleration fields in the specimen to provide stress information. Two (silicone and nitrile) rubbers were tested in tension using a drop-weight apparatus. It is assumed that the dynamic behaviour is described by the combination of hyperelastic and Prony series models. A VFM based procedure is designed and used to produce the identification of the modulus term of a hyperelastic model and the Prony series parameters within a time scale determined by two experimental factors: imaging speed and loading duration. Then, the time range of the data is extended using experiments at different temperatures combined with the time-temperature superposition principle. Prior to these experimental analyses, finite element simulations were performed to validate the application of the proposed VFM analysis. Therefore, for the first time, it has been possible to identify relaxation behaviour of a material following dynamic loading, using a technique that can be applied to both small and large deformations.

KEYWORD: Rubber, Viscoelasticity, Mechanical characterization, Virtual fields method

1. INTRODUCTION

The loading rate dependency of the response of rubbers to mechanical deformation is mainly due to time-dependent motion of the polymer chains when topologically constrained by a molecular network. At a high enough global deformation rate, the free chain is affinely strained with the network. If the deformation is applied slowly, there is sufficient time for the chain to move to a more relaxed configuration (Bergström and Boyce, 1998). Many rubbers are highly viscoelastic; hence, the stress-strain relationship is clearly different even for modest changes in strain rate. Much research has therefore been conducted to characterize distinctive mechanical behaviours of rubber at different loading rates, often using the split Hopkinson compression bar (SHPB) for dynamic experiments (Chen, 2016; Gray and Blumenthal, 2000; Siviour and Jordan, 2016). There are two significant challenges in performing these experiments: in order to use the established analysis, the specimen size must be small so that the specimen can reach a state of stress equilibrium on the time scale of the dynamic experiment, and the forces supported by the specimen are often small, requiring sensitive instrumentation. To address this issue, the conventional SHPB has been modified by using: polymeric bars (Bacon, 1998; Harrigan et al., 2014), hollow metallic bars (Chen et al., 1999), piezoelectric sensors (Chen et al., 2000; Kendall et al., 2014) and pulse shaping (Song and Chen, 2003).

A number of authors have conducted dynamic tensile tests on elastomers with some modifications to the traditional split Hopkinson tension bar (SHTB), which was first developed for