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Experimental investigations and modeling of volume change induced by void growth in polyamide 11

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ABSTRACT

Polymers are known to be sensitive to hydrostatic pressure. The influence of stress triaxiality ratio on cavitation and damage has been highlighted in numerous studies. This paper proposes experimental investigations allowing the control of both the stress triaxiality ratio and the void distribution via microscopic observations of microtome-cut surfaces from interrupted tests. With the help of a finite element code, the Gurson–Tvergaard–Needleman model was calibrated by using these multi-scale experimental data. Then comparison between both numerical and analytical models and experimental data was performed. Bridgman formulae were reported to be valid up to the peak load. Moreover, a better understanding of the time evolution of significant parameters such as the porosity (volume change) and the stress triaxiality ratio (hydrostatic pressure), was highlighted.

1. Introduction

Polymers are more and more used in a wide range of structural applications. Thus, it becomes fundamental to better understand and predict their mechanical response to assess their durability. Polymers exhibit a complex nonlinear behavior depending on external factors such as strain rate, temperature, hydrostatic pressure (stress triaxiality ratio), but also on morphological parameters, e.g., the molecular weight or the degree of crystallinity. This requires scientific investigations in order to develop predictive tools able to capture the mechanisms of deformation, damage and fracture.

Numerous studies have been carried out to develop constitutive equations for polymeric materials. Beyond the abovementioned external factors, modeling the mechanical response of polymers requires to account for large strain. Many papers dealing with mechanical response of polymers were reported in the literature but generally all these conditions were not totally fulfilled. Indeed, most of studies dealt with uniaxial tensile test, obviously modeled under one dimensional (1D) conditions where rheological schemes were often proposed. This first class of model was studied under small strain (up to necking) for rigid polymers. Exception can be noticed for elastomers that generally require finite strain assumption. Furthermore, visco-elastic/visco-plastic strains were investigated in such models by numerous authors. Popelar et al. (1990) and Zhang and Moore (1997) proposed viscoelastic models polyethylene. Khan and Zhang (2001) set up a viscoelastic–viscoplastic model to describe the inelastic response of polytetrafluoroethylene. Through a similar approach, Khan et al. (2006) captured the inelastic response at large strains of adiprene-L100. Other studies were devoted to the modeling of the viscoplastic behavior of polyamide 66 (Krempl et al., 1984; Krempl and Ho, 2000). To take the multiaxial stress-state under visco-elasticity and/or visco-plasticity constitutive models were recently developed by Van Domellen et al. (2003) under monotonic loading, by Drozdov (2010) and Ayoub et al. (2010, 2011) under strain reversal loading and by Ben Hadj Hamouda et al. (2007) and Regrain et al. (2009) for creep loading. These models generally take the degree of crystallinity into account but not the volume change.

The influence of hydrostatic pressure on polymeric materials was found to be worthy to investigate in these conditions. From experimental viewpoint, tensile tests under hydrostatic pressure or compressive tests were performed to evidence this influence (see for instance, Ghorbel, 2008; Hasanpour et al., 2009; Zaïri et al., 2005; Zaïri et al., 2008). Whitening of polymers is related to cavitation occurring within the material by void nucleation and growth which generates volume change (Schirrer et al., 1996). For elastomers, works of Ball (1982), Dorfmann et al. (2002), Gent and Lindley (1958), Hou and Abeyaratne (1992) depicted hydrostatic pressure *vs.* volume change plots in spite of the assumed incompressibility of such a material.

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