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Constitutive model for a semi-crystalline polymer under dynamic loading

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ABSTRACT

This paper deals with a viscoelastic–viscoplastic model for semi-crystalline polymers in crash applications. A polymer behaviour model is implemented in the commercial PAM CRASH© code thanks to a user material card. Global variables (load, displacement) and local variables (strain) are validated on flat and notched tensile specimens by comparing the numerical responses with data obtained by digital image correlation.

1. Introduction

Crashworthiness simulation is a major factor that has enabled automotive manufacturers to achieve a 30–50% reduction in development time and costs over the past decade. Today, this technology is a mature and proven design tool for the development of conventional 'ductile' automotive steel where the predominant energy absorption mechanisms are plastic bending and collapse. However, demand for greater weight savings and occupant protection has necessitated new design concepts and the use of new lightweight materials that often have high ductility and a complex failure. Polymers are good candidates to reach such objectives. There have been many studies on polymers in recent years, especially in quasi static states and two approaches are generally used. A phenomenological one, based on the models previously developed for metals, to introduce the viscoplasticity (van der Sluis et al., 2001; Ho and Krempl, 2002; Colak and Dusunceli, 2006; G'Sell and Jonas, 1979). A physical one where the strain hardening of a semi-crystalline polymer is interpreted as entropic forces needed to orient the macromolecular chains connected by cross-links for glassy polymers (Boyce and Arruda, 1990; Arruda et al., 1995; Wu and van der Giessen, 1995) or by considering a crystalline phase and an amorphous phase which will represent the intermolecular resistance to the deformation and the molecular network resistance to the stretching of the chains (Regrain et al., 2009; Lee et al., 1993; van Dommelen et al., 2003; Ben Hadj Hamouda et al., 2007; Drozdov, 2009; Ayoub et al., 2010; Ahzi et al., 2003; Ayoub et al., in press). Nevertheless, the isochoric deformation is generally the main assumption due to the difficulty of obtaining experimental data by classical extensometer with specimens which present an early necking. This deviation from the incompressibility is mainly due to crazing in glassy polymers and crystal fragmentation in semi-crystalline polymers. Moreover, the presence of particles, used to improve the behaviour of such polymers or to reduce the costs, introduces some debonding effects around rigid particles and then changes the incompressibility hypothesis again. To take the pressure dependency of the polymer matrix into account, some studies have been carried out by introducing damage models to overcome this problem. The main model used for damage is the Gurson model (Gurson, 1977; Lauro et al., 1997) which describes the growth of spherical cavities under hydrostatic stress (Laiarinandrasana et al., 2009; Challier et al., 2006; Zaïri et al., 2008; Zaïri et al., 2011). Introduction of this model and the partition in crystalline and amorphous phases result in very complex models in which parameters are difficult to identify for automotive applications, like the length of the macromolecular chain, the number of rigid links per chain, the initial porosity, etc. The behaviour also of the particles themselves has to be taken into account if their quantity in the matrix is enough important. The phenomenological approach is therefore more suitable if the non isochoric deformation is taken into account and if a new technique is used to identify behaviour laws at constant strain rates for a large strain rate range (Lauro et al., 2010). In this work, the behaviour of a semi-crystalline polypropylene, to which talc particles are added (20% of the volume), is modelled by both a non-linear visco-elasticity model, until a plasticity criterion which is pressure dependent, and a viscoplastic model, which represents the structural hardening. During the plastic deformation, the non isochoric deformation is introduced by means of a non associative return on

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