



Laboratoire de Mécanique des Solides

CNRS UMR 7649, X, Mines
École Polytechnique - 91128 Palaiseau Cedex
Tél. 01.69.33.57.03 (secrétariat) - Fax : 01.69.33.57.08



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ID: 858 6115 8496

Password: 020501

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Prof. Thomas Pardoen

Institute of Mechanics, Materials and Civil Engineering, Université Catholique de Louvain,
Place Sainte-Barbe, n2, L05.02.02, 1348, Louvain-la-Neuve, Belgium

thomas.pardoen@uclouvain.be

Micromechanics of deformation and fracture in highly cross-linked thermosets – Impact on composite modelling

Abstract: Advanced constitutive models for polymers have been essentially developed for thermoplastics with relatively limited applications/extensions to thermosets. Recent extensions of these constitutive models provide accurate predictions over a wide range of loading configurations, strain rates and temperature, encompassing below and above transition temperature regimes, although at the prize of a very large number of parameters, often larger than 30. Still, these models, mixing phenomenological and micromechanics ingredients, are often not rich enough to capture complex behaviors such as for instance severe non-linearity upon unloading or possible size effects, while missing also micromechanical connection to the failure process. This directly impacts the development of predictive multiscale models for polymer based composites.

Based on extensive experimental test program on the highly cross-linked RTM6 epoxy, the viscoplastic response is found very similar to thermoplastics, with hardening-softening-re-hardening, large back stress upon unloading and existence of shear band patterns at very small scale [1]. Furthermore, size effects are revealed when looking at nanoindentation data as well as indirectly when looking at the response of unidirectional composites. A molecular physics-based model of the deformation process occurring through the activation of nanometer scale shear transformation zones (STZ) has been worked out [2]. The viscoplastic deformation is the result of the cooperative activation of STZ's, sensitive to rate, temperature, stress state and stress level. This model involves only 7 parameters to identify, all with physical meaning. The model quantitatively captures the experimental trends, even some complicated responses during creep tests performed after plastic deformation at intermediate stress levels showing backward followed by forward creep. It also captures the size dependent strength resulting from large strain gradients putting a constraint on the development of the micro-shear banding process. In addition, a new

micromechanics-based fracture model based on the attainment of a local maximum principal stress at the tip of microdefects is proposed and validated for a wide range of stress states [3].

The implication of these results and micromechanical models on composite modelling is not straightforward. This is addressed through the analysis of in situ SEM compression tests on thick UD carbon fiber reinforced RTM6 matrix composite, involving the determination of digital image correlation strain fields [4]. Difficulties remain to quantitatively capture the experimental response with the models identified on bulk resin data.

References:

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