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Effects of crystal content on the mechanical behaviour of polyethylene under finite strains: Experiments and constitutive modelling

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ABSTRACT

The mechanical stress–strain behaviour of polyethylene (PE) materials under finite strains is studied both experimentally and theoretically. In order to gain insight into the structure and physical properties of investigated PE materials, a series of thermal (DSC and DMTA) and microstructural (small-angle X-ray scattering and AFM) characterizations have been undertaken. The influence of crystallinity on the various features of the tensile stress–strain response is considered over a large strain range, implying thermoplastic-like to elastomer-like mechanical behaviour. A physically-based hyperelastic–viscoplastic approach was adopted to develop a pertinent model for describing the mechanical behaviour of PE materials under finite strains. The semicrystalline polymer is being treated as a heterogeneous medium, and the model is based on a two-phase representation of the microstructure. The effective contribution of the crystalline and amorphous phases to the overall intermolecular resistance to deformation is treated in a composite framework, and coupled to a molecular network resistance to stretching and chain orientation capturing the overall strain hardening response. In order to extract the individual constitutive response of crystalline and amorphous phases, a proper identification scheme based on a deterministic approach was elaborated using the tensile test data of PE materials under different strain rates. Comparisons between the constitutive model and experiments show fair agreement over a wide range of crystallinities (from 15% to 72%) and strain rates. The constitutive model is found to successfully capture the important features of the observed monotonic stress–strain response: the thermoplastic-like behaviour for high crystallinity includes a stiff initial response, a yield-like event followed by a gradual increase of strain hardening at very large strains; for the elastomer-like behaviour observed in the low crystallinity material, the strain hardening response is largely predominant. Strain recovery upon unloading increases with decreasing crystallinity: this is quantitatively well reproduced for high crystallinity materials, whereas predictions significantly deviate from experiments at low crystallinity. Model refinements are finally proposed in order to improve the ability of the constitutive equations to predict the nonlinear unloading response whatever the crystal content.

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