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Test equipment

A new multiaxial loading test for investigating the mechanical behaviour of polymers

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ABSTRACT

In order to investigate polymer mechanical behaviour more closely and define corresponding numerical behaviour models, a new experimental set-up was developed for performing multiaxial loading tests. Some of the loading possibilities are presented here for the case of a copolymer polypropylene (PPC7712). A single moulded sample of this material was mounted on this original apparatus, which was specially designed for studying complex trajectories, including proportional and non-proportional cycles, in which the axial and shear deformation can be simultaneously and independently controlled. Tension/compression/torsion tests were performed on the polypropylene material, spanning all four quadrants of the axial/torsional strain subspace. Under the conditions tested, the effect of strain history on the stress-strain response is hardly observed for this material. The qualitatively different behaviour observed depending on the strain path might be attributable to the asymmetry between the axial/torsional and tension/compression loads.

1. Introduction

The possibility of determining the mechanical behaviour of polymer materials under various multiaxial loading conditions ranging from small strains to loads resulting in failure is of crucial importance for simulating the loading of geometrically complex injected moulded components, using finite element codes. However, uniaxial tension tests are so far practically the sole loading method used experimentally in studies on the mechanical behaviour of polymeric materials subjected to large strains [1,2]. The compressive mode has been less frequently studied because it is difficult to prevent buckling of the specimens [3–5], and only a few studies have dealt with the shear deformation of polymers, although shearing is the basic mode of deformation observed at the microscopic level [6–9]. Accurate full-field displacement and strain measurements can now be performed on the specimen gauge area using Digital Image Correlation (DIC) techniques [10–12]. However, very few experimental multiaxial loading studies have been performed on polymer materials under cyclic loading conditions [13–15].

As regards material behaviour simulation, most of the numerical models developed so far have dealt mainly with the fitting of the stress-strain curves obtained under uniaxial conditions, and very few studies have focused on multiaxial loading conditions [16–19] or torsion tests [20,21]. Most of these tests were designed for studying the viscoelastic response of polymer materials below the yield point. Only a few models (e.g. [15]) can be used to predict the mechanical responses of semi-crystalline polymers, including both the loading and unloading paths, under non-proportional multiaxial test conditions.

The present study was intended to provide a means of studying the multiaxial mechanical behaviour of polymeric materials more closely. In section 2, a new experimental device is described in detail, with which multiaxial loads

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can be imposed on a single specimen, the shape of which is specially designed for performing these tests. With this set-up, the loading direction can be changed in the deviatoric strain plane during the tests. An in-depth analysis is conducted on the complex behaviour of a semicrystalline polymer, a copolymer polypropylene PPC7712, under various multiaxial loading conditions, with several radial paths and complex loading trajectories, including proportional and non-proportional cycles. Some of the loading possibilities are presented in section 3: these include simple uniaxial tests with or without loading cycles, as well as more complex tests such as combined box and butterfly tests spanning the complete tension/compression/torsion subspace. Extensometer and DIC measurements were both performed to determine the strain distribution. This strain distributions resulting from complex loading sequences and the path dependence of the polypropylene (PP) material under investigation are closely analysed. The results obtained under these loading conditions and the asymmetrical behaviour observed in the tension/compression/torsion tests are discussed. Some hypotheses possibly accounting for the results obtained are also briefly presented. The 3-D axial/torsional experimental data obtained here should provide a useful basis for cross-checking future models for polymer materials.

2. Experimental conditions

2.1. Description of the material studied

A commercial heterophasic copolymer polypropylene material, grade PPC7712 supplied by TOTAL Petrochemicals, was used to test the validity of the newly developed experimental set-up. This polypropylene is a semi-crystalline thermoplastic material which is widely used for industrial purposes because of its excellent mechanical properties, its resilience and the fact that it can be easily recycled. Tensile tests at low and high speeds on this material can be found in [22,23]. With these tests, the calibration and testing of a material model called the Hyper-Visco-Hysteresis (HVH) model have also been performed.

2.2. Geometry of the specimen

Studies on the mechanical behaviour of polymer materials always tend to raise questions about the relationships between the shape of the samples and their microstructure. Semi-crystalline polymers, like polypropylene, are composed of a crystalline phase combined with an amorphous phase. The degree of crystallinity and the size and distribution of the crystallites in a semi-crystalline polymer greatly affect the mechanical properties of these materials. A higher degree of crystallinity results in a harder, stiffer material showing less ductile behaviour [24]. In addition, the kinetics of the crystallization process depend on the chain structure, the cooling rate during injection moulding, and the annealing process [25]. The crystallization kinetics also depend on the size of the moulded parts. However, in previous studies, several specimens with different designs and geometries have been classically used to conduct experiments under various loading conditions (e.g. [21]). In view of the disadvantages of these moulded parts, we decided to develop a single sample which was able to support various multiaxial paths (such as those resulting from tension, compression and torsion loads) either simultaneously or independently.

The shape of the specimen used to carry out all the multiaxial tests is presented in Fig. 1. Specimens were moulded using an injection-moulding machine and a specially designed imprint mould with a classical circular cross section, a gage length of 60 mm and a diameter of 20 mm. The ends were hexagonal so that they could be introduced into the grips specially designed to apply all the multiaxial loads (see section 2.3). To design this specimen shape, several requirements were taken into account [26]. It was necessary:

- to be able to produce a uniform strain field throughout the surface of the gauge area. The homogeneity of this strain field was monitored by performing video strain measurements.
- to achieve axial and torsional stiffness matching the load and torque measurement capacity of a typical axial-torsion load cell.
- to be able to apply moderate compressive strains without inducing buckling.
- to achieve large axial and shear strain amplitudes.
- to design a specimen geometry which was compatible with the moulding techniques currently available.

After the injection process, specimens were annealed in a hygrometric chamber (SECASI Technologies, SLH 100/70 VRT) using a specific protocol consisting of a 2-hour annealing phase at a temperature of 120 °C, which is around the crystallization temperature of PPC7712,

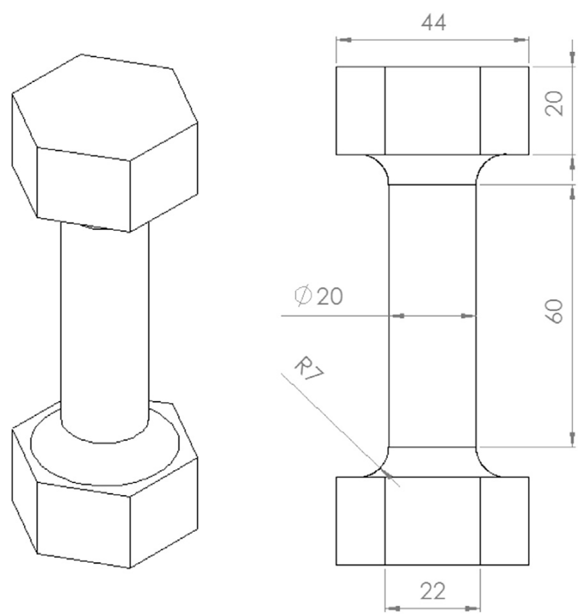

Fig. 1. Specimen subjected to multiaxial loading tests (the dimensions are given in mm).