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Creep Behaviour of Viscoelastic Polymer Materials

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Abstract. The non-linear creep compliance of a polypropylene (PP) was studied at 30, 40 and 50°C, for tensile stresses between 2 and 10 MPa. The model developed, which is based on physical mechanisms (at the molecular scale) responsible for the material's behaviour, yields very good agreement with the experimental data and physically meaningful theoretical parameter values.

Introduction

Previous models for the interpretation of the creep behaviour of polymers are mainly empirical or semi-empirical, and do not take into direct account the physical (molecular) underlying mechanisms responsible for the material's non-linear viscoelastic behaviour. In the present study, a physical model is developed to describe the creep compliance of polymer materials (applicable to both amorphous and semi-crystalline polymers), at varying tensile stresses and ambient temperatures.

Experimental

This particular work focused on a semi-crystalline polymer – polypropylene - as 150 mm x 10 mm x 4 mm test specimens, cut and adequately machined from sheets.
The creep measurements were carried out with a Zwick Z100 Universal Tensile Testing Machine, equipped with a 2.5 kN load cell and using a Macro extensometer with a deformation measurement range of 100 mm. The strain/force vs. time experimental data were automatically recorded, stored and treated on a personal computer. The test specimens were previously conditioned at 23°C, and the creep tests were conducted at each selected temperature (30, 40 and 50°C) in a thermostatic chamber, under applied stresses of 2, 4, 6, 8 and 10 MPa.

Creep Theoretical Model

The main characteristic of a polymer creep process (far from rupture) is a progressive strain increase at a decreasing rate, until this rate reaches either a constant (under viscous flow) or a zero value (for cross-linked amorphous or semi-crystalline polymers).

By generalizing Voigt-Kelvin's linear viscoelastic model, it is possible to write the creep compliance as

$$D(t) = D_0 + \int_{-\infty}^{+\infty} L(\tau)(1 - e^{-\frac{t}{\tau}}) d\ln\tau + \frac{t}{\eta}, \qquad (1)$$

where D_0 is the instantaneous (t = 0) elastic compliance, $L(\tau)$ is the retardation time spectrum and the term t / η represents, at least approximately, the viscous flow and τ is the retardation time.

Feltham [1] has suggested and justified a log-normal relaxation, $H(\theta)$, and retardation time, $L(\tau)$, spectra to interpret the elementary (conformational transition) processes responsible for stress relaxation and creep. Thus, we may write, for the retardation spectrum,

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