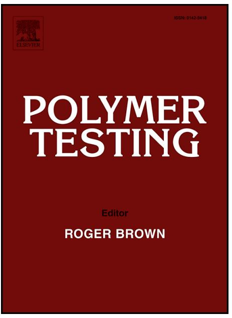

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Experimental set-up for determination of the large-strain tensile behaviour of polymers at low temperatures

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Abstract

In this study, we present a method to determine the large-strain tensile behaviour of polymers at low temperatures using a purpose-built temperature chamber made of polycarbonate (PC). This chamber allows for several cameras during testing. In our case, two digital cameras were utilized to monitor the two perpendicular surfaces of the test sample. Subsequently, the pictures were analysed with digital image correlation (DIC) software to determine the strain field on the surface of the specimen. In addition, a thermal camera was used to monitor self-heating during loading. It is demonstrated that the PC chamber does not influence the stress-strain curve as determined by DIC. Applying this set-up, a semi-crystalline cross-linked low-density polyethylene (XLPE) under quasi-static tensile loading has been successfully analysed using DIC at four different temperatures (25 °C, 0 °C, −15 °C, −30 °C). At the lower temperatures, the conventional method of applying a spray-paint speckle failed due to embrittlement and cracking of the spray-paint speckle when the tensile specimen deformed. An alternative method was developed utilising white grease with a black powder added as contrast. The results show a strong increase in both the Young's modulus and the flow stress for decreasing temperatures within the experimental range. We also observe that although the XLPE material is practically incompressible at room temperature, the volumetric strains reach a value of about 0.1 at the lower temperatures.

Keywords: XLPE, Digital image correlation (DIC), Tensile test, Low temperatures, Large strains, Polymeric material, Temperature chamber

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1. Introduction

Polymeric materials are used in a variety of applications in the oil industry, e.g. thermal insulation coatings of pipelines, pressure barriers, and insulation of umbilical cables. Estimates from The United States Geological Survey (USGS) indicate that large amounts of the world's undiscovered oil and gas resources are located north of the Arctic Circle [1]. Consequently, the material behaviour at low temperatures is of increasing interest for the oil industry. The effect of temperature on the material behaviour needs to be understood for different complex load cases, such as reeling/unreeling of pipelines, and impact on various structures and components involving polymeric materials. It is therefore necessary to obtain reliable material data even at lower temperatures, because a reduction in temperature tends to reduce the ductility. Relevant input, such as true stress-strain curves for large deformations, volumetric strain to incorporate damage, temperature to include material softening, and rate effects on flow stress, is needed for the material models implemented in finite element (FE) software to predict the material response as accurately as possible. It is therefore essential to obtain precise data at large deformations from experiments in order to analyse such complex load cases successfully.

Several studies have been conducted addressing the performance of polymeric materials at elevated temperatures [2–8]. Fewer studies have been carried out with emphasis on the material behaviour at low temperatures, in particular with attention to the material response at large strains. Bauwens and Bauwens-Crowet with co-workers [9–12] published a series of papers on the relation between yield stress and temperature. Jang et al. [13] investigated the ductile-brittle transition in polypropylene and reported relevant stress-strain data.

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