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Test Method

Uniaxial compression testing of polymeric materials

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ABSTRACT

Two methods for uniaxial compression testing were investigated and compared using polypropylene as a model material. An overview of various parameters affecting compression test results is provided with particular emphasis on friction between the specimen and the compression plate. A procedure for the determination of the compressive modulus is introduced and results are shown. To enable the detection of instability associated with friction and barreling and to calculate true stress-true strain curves, the measurement of transverse expansion of the specimen at large strains is necessary. Nominal and true Poisson's ratio values in the pre- and post-yield regime are presented and the resulting true stress-true strain curves are compared and discussed. While in the post-yield regime nominal stress values misleadingly result in strain hardening, significant strain softening was observed using true stress values representing the intrinsic material behavior.

1. Introduction

Polymeric materials and parts are frequently exposed to loading situations where compressive stresses occur and in many cases are even dominating. These compressive stresses may be either local or global, and they may be of different confinement levels (uniaxial and various degrees of multiaxiality). In terms of the type of loading, they may be monotonic, cyclic or long-term static.

Typical examples of compressive loading in practical applications of plastics include all structural components exposed to direct compressive or bending loads, rollers, gears, damping materials and the like [1]. On a regional and local scale, compressive stresses also play a major role in joint technologies (e.g., screw joints, clamping, fastening), in cutting processes and in tribological applications (i.e., friction, wear and scratch processes) also including fretting fatigue loads [2–5]. Another example for the development of local compressive stresses are polymer matrix composites, in which compressive stresses on a local scale develop around the reinforcing phase, even although the external load applied to the material may be a tensile load [6].

Considering that the behavior of polymeric materials under tension and compression may differ particularly in the yield and post-yield regimes [7–9], the need to characterize the compressive behavior of plastics becomes evident. Moreover, the above examples indicate the importance of compressive testing in a comprehensive manner under various loading modes and underline the need for appropriate test methodologies. Last but not least, adequate material data and material laws for compression are especially needed in advanced component design procedures and for structural reliability assessments based on modern simulation tools.

In performing compressive tests, several difficulties are usually encountered. In particular, the contact situation related to the details of load introduction is of prime importance, both in the low and high strain regimes. At low strain levels, a convex nonlinear force-displacement curve may develop as a result of misalignment of the compression plate and the specimen surface, and to a lesser degree also as a consequence of the microscopic roughness of the

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two contact surfaces. At higher strain levels, test set-up misalignment and off-axis loading may cause premature specimen failure by buckling. Finally, friction at the interface between specimen surface and compression plate becomes particularly important at high strain levels and in the post-yield regime, not only leading to a multiaxial stress state in the load introduction region, even in uniaxial tests, but also causing specimen barreling.

The objective of this paper is to describe a set of experimental procedures that allow for a comprehensive characterization of the compressive stress-strain behavior of plastics in a uniaxial stress state. In addition to details of the test set-up, information on suitable test and data reduction procedures is provided. The experiments were performed using polypropylene (PP) as a model material.

2. Experimental

2.1. Material

The material used in this study as a model material was a development grade polypropylene homopolymer PP(H), manufactured and delivered by Borealis Polyolefine GmbH (Linz, A) as injection molded plates, out of which all specimens were machined. The identical material was extensively characterized under monotonic tensile loading and in compressive relaxation tests [10,11].

2.2. Testing and test instrumentation

All tests were carried out on an electro-mechanical driven universal testing machine of the type Instron 4500 (Instron LTD; High Wycombe, UK). Depending on the specimen length, the tests were performed at a testing rate ranging from 0.069 to 0.173 mm/s, corresponding to a local strain rate of $8.7 \times 10^{-4}\ s^{-1}$, and under standardized climate conditions (23 °C/50% r.h.). Unless prior failure occurred, all tests were performed up to a compressive strain of 0.5.

In order to perform compressive tests on a universal testing machine, several modifications are necessary to ensure stable measurement conditions. To avoid wobbling of the loading pins around the center axis two options exist. One is to make use of a so-called reversal cage to apply compressive loads on the specimen with the testing machine itself working under tension [12]. While this configuration suppresses any misalignment from the mechanical set-up, it is disadvantageous in terms of the available working space and sight to the specimen, particularly when working with optical measurement devices to obtain transverse strain and full-field strain information. Another option, developed and applied in the test set-ups of this study, is the utilization of a special compression tool with aligning bars at each corner (Fig. 1). Due to the four ball linings and highly accurate aligning bars, a precise and reproducible movement of the upper and lower compression plate is guaranteed and any transverse forces and moments are avoided. As to the accurate determination of axial strain, an LVDT mounted between the two compression plates was used.

2.3. Test set-up and data reduction

The uniaxial compression test configuration with the cylindrical specimen between the two plates is shown in Fig. 1. The specimen diameter d was 8 mm, the length l of the most frequently used standard specimen in this study was 12 mm, resulting in a l/d ratio of 1.5. This specimen geometry was chosen taking the expected failure mode according to [13] into account: buckling for $l/d > 5$, shear failure for $2.5 < l/d < 5$, and double barreling for $2 < l/d < 2.5$. Also according to [13], short specimens with $l/d < 1.5$ are strongly affected by friction. To study effects of friction, a series of specimens with an l/d ratio varying from 1 to 2 was prepared.

Even when highly polished plates and a PTFE lubricant are used, friction is evident in compression testing and influences the test results, particularly at large strains. In order to reduce the influence of friction, the following measures were taken and evaluated:

- First, instead of utilizing a PTFE lubricant between the specimen and the compression plates, a direct method to solve the frictional problem is to use PTFE tape. However, due to the compliance of the PTFE tape, the simultaneous measurement of the compressive modulus on the same specimen is not possible. In our investigation the equivalent PTFE tape of the type 3M-5480 (3 M; St. Paul, MN, USA) used also in [14] was selected. The adhesive side of this single-side adhesive tape was positioned to face the specimen.
- The second approach applied was an indirect method to correct for frictional effects and was proposed originally by Cook and Larke [15]. Using a PTFE lubricant between

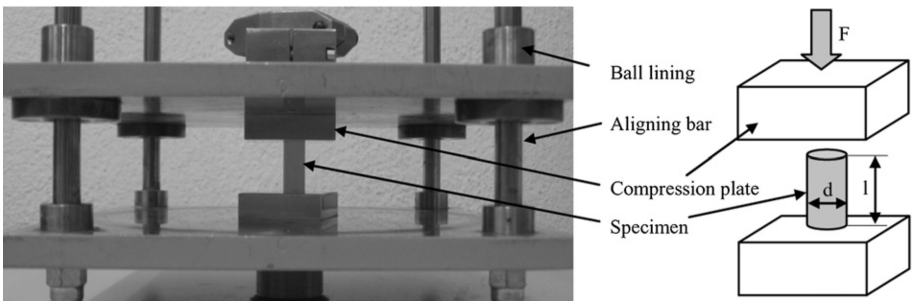

Fig. 1. Uniaxial compression set-up mounted in the compression tool used for all methods.