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Shear characterisation of uni-directional fibre reinforced thermoplastic melts by means of torsion

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ABSTRACT

Intra-ply shear appears during the forming process of hot thermoplastic laminates with a uni-directional fibre reinforcement. This paper proposes a torsion bar test to characterise the longitudinal shear mechanism, which can be performed with a standard rheometer. Sensitivity analyses showed that most reliable shear property measurements can be obtained by using torsion bar specimens with a close to square cross section. The method is implemented in practise and critically evaluated. Storage and loss moduli were determined for carbon UD/PEEK specimens at high temperatures. Non-linear material behaviour was found for relatively small shear strains. The linear regime was focussed on subsequently, where the characteristics were found to be similar to that of a visco-elastic solid or weak gel, confirmed by a dominant storage modulus and a weak frequency dependency. Future work is recommended to be focussed on the large strain regime, for which this paper provides a found basis.

1. Introduction

Thermoforming of fibre reinforced thermoplastic laminates is ideally suited for the production of thin-walled products with complex curvatures. Nevertheless, process induced defects appear frequently, such as the wrinkling shown in Fig. 1. Better anticipation on such defects facilitates the tooling design process by which significant lead-time reductions can be achieved. Analyses of uni-directional (UD) carbon fibre reinforced thermoplastics have been reported for decades already [1]. Nevertheless, textile reinforced thermoplastics or fabrics were favoured due to their ease of forming onto complex shaped moulds. However, it is believed that the high directional strength and stiffness properties of UD material can be fully exploited with the aid of sophisticated deposition tooling, such as tape placement robots [2]. A subsequent forming operation of so-called tailored blanks can be carried out. These possibilities revive the interest in UD material for forming applications again.

The forming process of UD reinforced thermoplastic laminates involves several deformation processes which were previously categorised by Cogswell [3,4]. Inter-ply slip is identified as the mechanism where individual plies slide relatively to each other, implying a discontinuous displacement field over the laminate thickness. Laminates with good consolidation quality and equally oriented plies show a more continuous intra-ply shearing deformation [5]. Intra-ply shear refers to the shearing process within a UD reinforced ply. Two intra-ply shearing deformations are usually distinguished [6]. The first considers parallel sliding of individual fibre filaments, which is indicated as axial or longitudinal intra-ply shearing. The second is transverse intra-ply shearing, which is the relative movement of the fibres normal to the fibre directions. These mechanisms are schematically shown in Fig. 2. They appear simultaneously when forming a doubly curved part, which in addition induces (out-of-plane) bending of the laminate. The final product shape will be determined by the complex interaction of intra-ply shear, inter-ply slippage, and bending.

The wrinkles in Fig. 1 can be avoided by ensuring that the longitudinal shearing mechanism is more pronounced. The transverse shear mechanism is of less importance, when solving such forming issues. In order to predict the defects in the early product design phase, it is important to have a proper description of the longitudinal shearing mechanism. An overview of available shear characterisation tests is presented, after supplying some background about the modelling of anisotropic media and the basis of Linear Visco-Elasticity (LVE) theory [7]. The need for another shear characterisation tests is explained next, followed by the introduction of the torsion bar method (Fig. 3). The kinematics of a torsionally loaded rectangular bar will be analysed resulting in guidelines for specimen geometry. Experiments are subsequently presented for specimens that consist of AS4 carbon fibres with a polyetheretherketone (PEEK) matrix. This pre-preg material is shown in Fig. 4. The micrograph gives an impression of the fibrous structure. Specimen responses are analysed in detail in order to explore the conditions that lead to linear and non-linear material behaviour. The first

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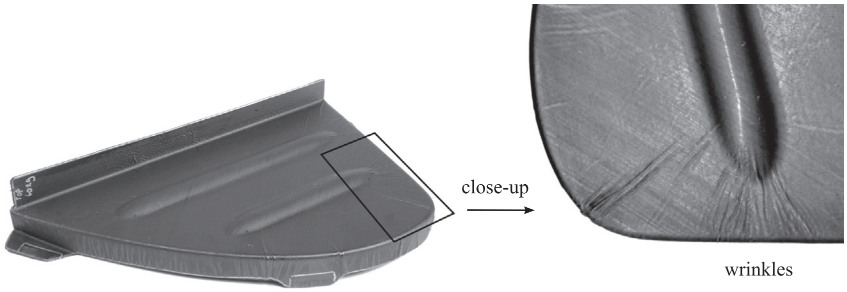

Fig. 1. Process induced defects.

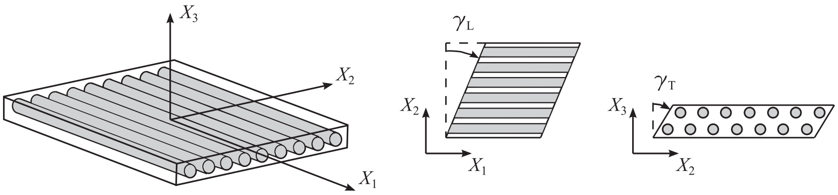

Fig. 2. Left: definition of the coordinate system with respect to the fibre direction. Centre: axial or longitudinal intra-ply shearing. Right: transverse intra-ply shearing.

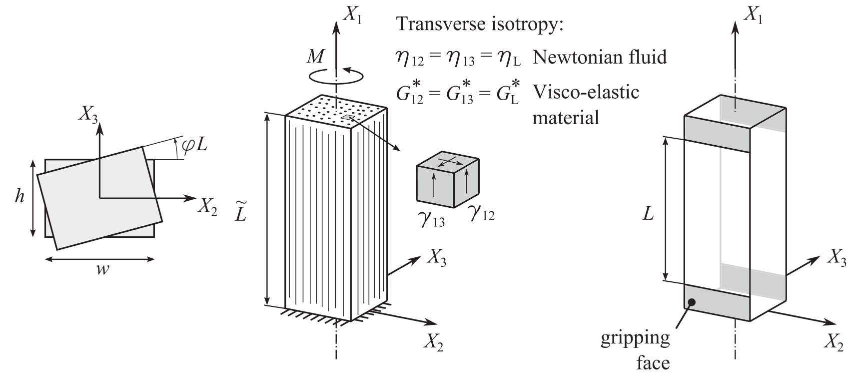

Fig. 3. Conceptual design of the torsion bar specimen. Left: cross sectional geometry. Centre: fibre reinforced rectangular bar. Torsional loading invokes longitudinal shear mechanisms as indicated by the elementary cube. Right: grey areas represent the aimed gripping faces to conduct torsional loads in practise.

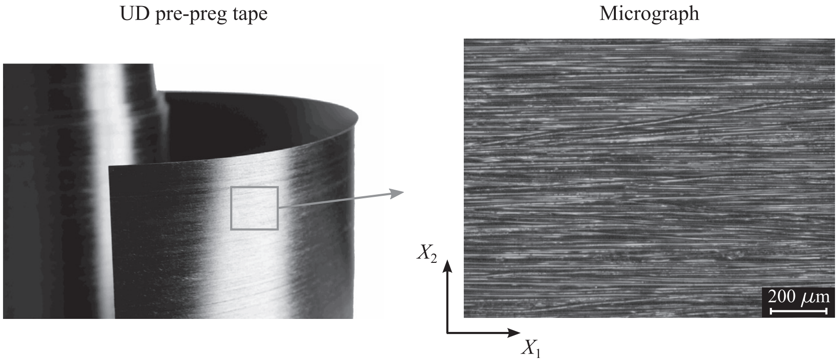

Fig. 4. Carbon UD/PEEK pre-preg tape and a micrograph giving an impression of its micro-structure.

implementation step of this method in practise involves the linear material behaviour during oscillatory small strain measurements. Transient responses are of interest for stamp forming applications and thus a translation from the dynamic moduli to the relaxation modulus will be obtained. Finally, recommendations are given for further development of the introduced torsion bar method.

2. Modelling of anisotropic media

Two approaches can be found in the literature to describe transversely isotropic viscous fluids. They differ in the assumption of the material form, which consists of continuously or discontinuously collimated fibres [8].