INTER-PLY SLIP CHARACTERISATION IN THERMOPLASTIC LAMINATES FOR THE DEVELOPMENT OF FE THERMOFORMING SIMULATIONS

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Introduction

To support the development of new manufacturing processes, simulation models based on Finite Element (FE) methods are often used. Thermoforming simulations consist in modelling the forming process of thermoplastic blanks. The development of such simulation models requires the characterisation of intra-ply properties, e.g. out-of-plane bending and intra-ply shear, as well as contact properties, i.e. friction (tool-ply interactions) and inter-ply slip (ply-ply interactions). Investigations of the latter are of particular importance since inter-ply slip was identified as playing a major role in the development of out-of-plane wrinkles during thermoforming processes [1]. This work presents, on the one hand, a new test setup to characterise inter-ply slip in composite laminates and, on the other hand, experimental results for a unidirectional fibre-reinforced thermoplastic material.

Development of a frictional test setup

An enhanced version of the test setup presented in norm DIN EN 14882 [2] is developed (see Figure 1). Contact properties are investigated when a carrier, below which is fixed a piece of material B, is pulled over a support, on top of which lays a piece of material A. In order to control testing environment, the new test setup can be mounted on a universal testing machine and enclosed in an environmental chamber. This enables the application of test speeds up to 400 mm/min and temperatures up to + 350 °C. Furthermore, the load applied on the carrier can be varied. Three load levels can be selected: about 5 kPa, about 8 kPa and about 11 kPa. The modular assembly of the new test setup ensures efficient specimen replacement as well as easy mounting/dismounting operations.

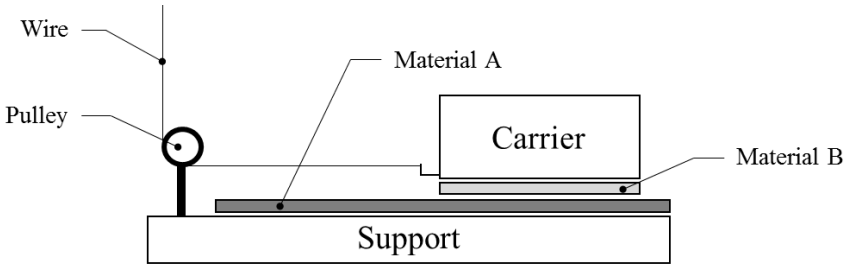

Figure 1: *Schematic of the frictional test setup presented in DIN 14882 (adapted from [2])*

Inter-ply slip in unidirectional laminates

The frictional test setup is used to characterise inter-ply slip in thermoplastic laminates under environmental forming conditions, i.e. above melting temperature. Experiments are performed at 235°C with a carbon fibre reinforced polyamide 6 (PA6) composite material. Investigations are conducted between molten unidirectional (0°/0°), cross-plied (0°/90°) and orthogonal (90°/90°) laminates for several different test speeds. A typical outcome of a friction test performed between two molten thermoplastic specimens is presented in Figure 2 left. The force reaches a peak before decreasing to a constant level. Such behaviour is in good agreement with observations made by other researchers [3-5].

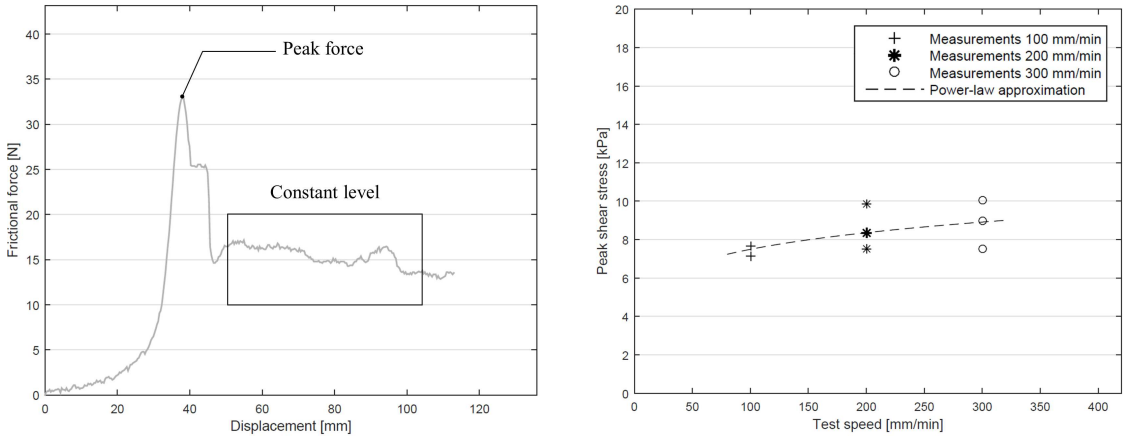

Figure 2: *(Left) Typical force vs displacement test result; (Right) Evolution of peak shear stresses with respect to test speeds for 0°/0° inter-ply slip experiments*

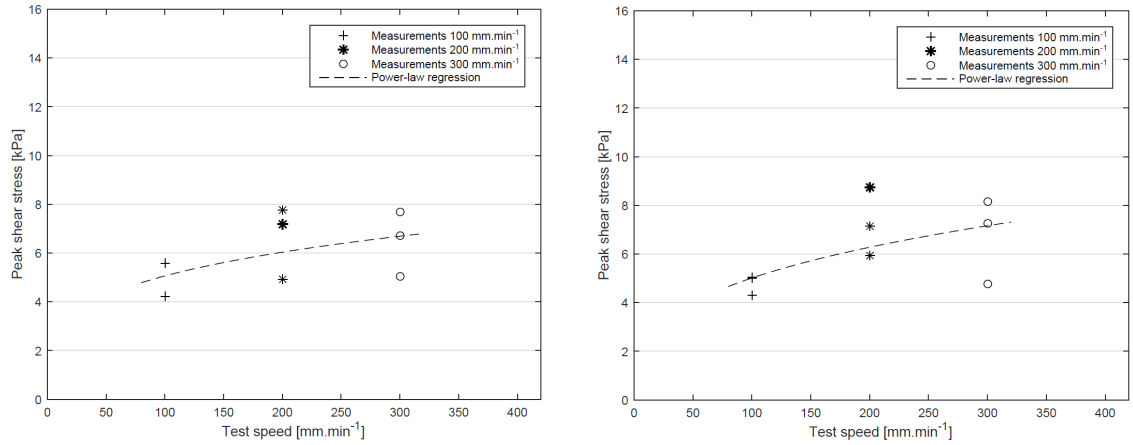

Figure 3: *Evolution of peak shear stresses with respect to test speeds for inter-ply slip experiments (left) 0°/90° (right) 90°/90°*

Peak shear stresses which are determined as the ratio between peak forces and the nominal contact area are subsequently calculated. Steady-state shear stresses are determined in a similar manner as the ratio between constant level forces and the nominal contact area. Peak and steady-state shear stresses are eventually plotted against test speeds to determine potential dependencies. For all tested configurations, peak shear stresses are found to increase with test speeds (see Figure 2 right and Figure 3).

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