The effect of fiber orientation on ply-ply friction of unidirectional C/LM-PAEK in melt

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Introduction

Understanding the interaction between prepreg plies during press forming is crucial for achieving defect-free composite parts. Excessive interply friction can restrict shear and lead to process-induced wrinkling defects [1]. Consequently, significant research effort has been devoted to developing methods for friction characterization [2]. The effects of temperature, pressure, and slip rate on the friction response have been extensively studied over the past decades. The influence of fiber orientation, however, has received far less attention, as most experimental approaches have focused on symmetric interfaces with fibers aligned in the slip direction.

To address this gap, we performed interply friction experiments using a newly developed test rig capable of measuring friction in asymmetric interfaces. The results reveal a clear dependence of friction on the relative fiber orientation between plies.

Materials and Methods

A unidirectional carbon fiber reinforced thermoplastic tape, designated TC1225 by Toray, was used for the characterization experiments. The tape has a thickness of 0.14 mm and a matrix content of 0.34 by weight. It consists of T700 fibers in an LM-PAEK matrix from Victrex, which has a glass transition temperature of of 147 °C and a melting temperature of 305 °C.

Pull-through experiments, schematically illustrated in Figure 1, were carried out using a purpose-built test rig [3]. The rig is equipped with a U-shaped fixture to clamp the outer plies at an arbitrary fiber orientation θ relative to center ply, which is oriented at 0° and aligned with the pulling direction. The measured pulling force F was used to calculate the averaged interfacial shear stress:

$$\tau = \frac{F}{2A},$$

with A the surface area of the platens.

The orientation dependence of friction was measured for outer fiber orientations θ of 0°, 3°, 5°, 10° and 30° with respect to the pulling direction at a slip rate of $25\,\mathrm{mm\,s^{-1}}$. The

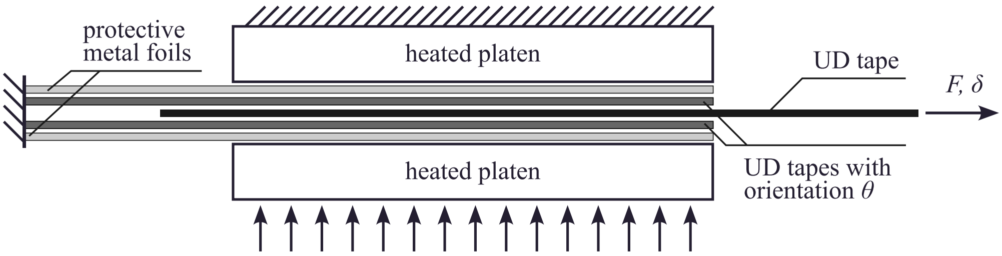

Figure 1: Schematic illustration of the pull-through friction test.

rate dependency of the friction response was measured for fiber orientations θ of 0°, 45° and 90° and slip rates of 5, 25, 40, 65 and 125 mm min^{-1}. The pressure and temperature were kept constant at 365 °C and 15 kPa, respectively, for all experiments.

Key Findings and Outlook

Figure 2 shows a photograph of a tested [45/0/45] specimen after testing. Although minor ply tearing and fiber reorientation was observed in the 45° plies near the start of the overlap, overall specimen integrity was maintained, suggesting that the measured response can indeed be attributed to slip at the interfaces. Similar behavior was observed for the other test configurations.

The left graph in Figure 3 shows the measured shear stress against displacement for various outer-ply fiber orientations θ. For relative fiber orientations of 45° and 90°, a distinct peak shear stress τ_p is followed by pronounced decay to a steady-state value τ_∞. This decay is much less pronounced as the orientation approaches 0°. Overall, the shear stress is highest when the fibers are aligned and decreases rapidly when the relative fiber orientation θ increases.

The right graph in the same figure shows a flow curve, with τ_p and τ_∞ plotted as a function of slip rate for different orientations. Here again, the [0/0] configuration shows the highest friction, while the [90/0] and [45/0] configurations show comparable values.

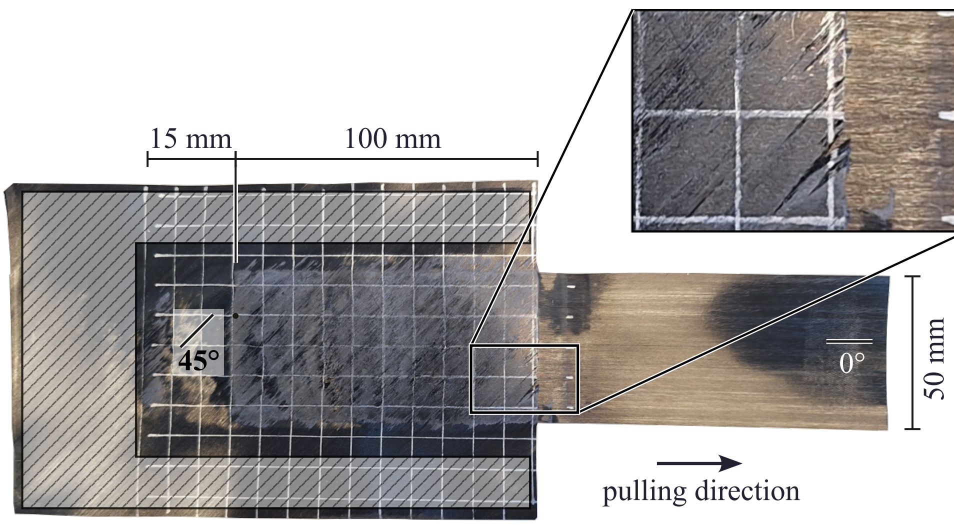

Figure 2: Photograph of a tested [45/0/45] specimen, showing minor ply tearing at the start of the overlap region. The shaded area represents the clamping location of the outer plies.

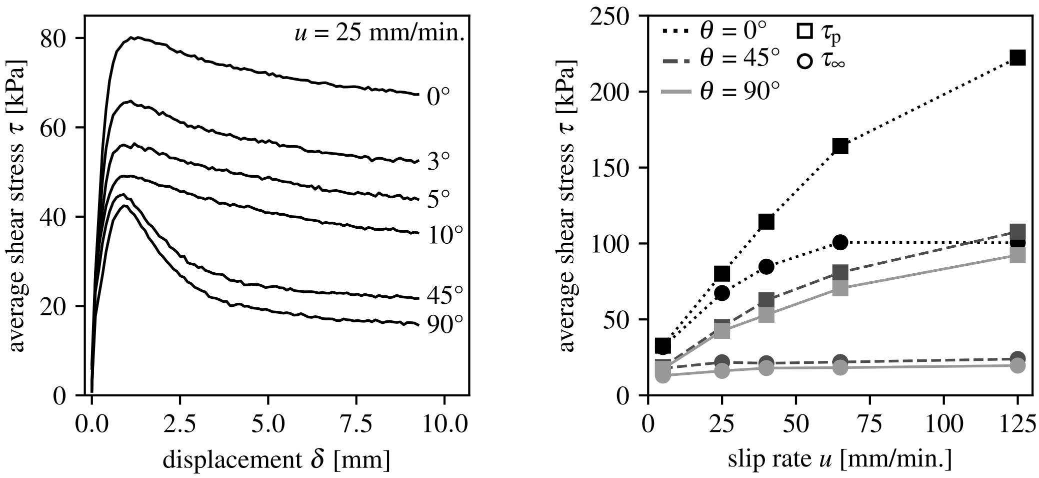

Figure 3: Effect of relative fiber orientation θ on measured shear stress (left), slip-rate dependence of the peak τ_p and steady-state τ_∞ shear stress (right). All experiments were performed at a temperature of 365 °C and a pressure of 15 kPa.

The observed orientation dependence of friction, and in particular the high friction for $\theta = 0°$ compared to $\theta = 45°$ or $90°$, appear consistent with (limited) findings reported in the literature [4, 5, 6]. We attribute this behavior to the orientation-dependent thickness distribution of the matrix interlayer between the two sliding plies, possibly enhanced by fiber-fiber interactions when the plies are increasingly aligned. Steady-state finite element simulations of the flow field in the interphase, for simplified representative volume elements, are currently being performed to test this hypothesis.

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