Exploring dry and lubricated sliding friction behaviour of carbon fibre tows: Discrete Element Method simulations and mixed lubrication model

Olga Smerdova*[1] and Noël Brunetiere[2]

[1]Institut Pprime – CNRS-Université de Poitiers - ENSMA, CNRS - Université de Poitiers - ENSMA, CNRS, Université de Poitiers, ENSMA, CNRS, Universite de Poitiers, ENSMA – France

[2]Institut Pprime – CNRS-Université de Poitiers - ENSMA, CNRS - Université de Poitiers - ENSMA, CNRS, Université de Poitiers, ENSMA, CNRS, Universite de Poitiers, ENSMA – France

Abstract

Understanding the sliding behaviour of fibrous materials presents a significant challenge that must be addressed to improve the manufacturing processes of fibrous composite materials and reduce defects in composite parts. In many processes, friction plays a crucial role: it can help keep fibres in place to prevent unwanted sliding, which may lead to the formation of matrix-rich zones in a composite. Conversely, friction can also promote sliding between tows, facilitating shear deformation of a fabric and helping to avoid out-of-plane defects in dry preforms. Moreover, the friction between fabric and tool is an inevitable aspect of all manufacturing processes. However, the sliding behaviour of fibres, tows and fabrics remains poorly understood due to the multiscale nature of these materials, which consist of numerous individual fibres with varying degrees of mobility.

This aim of our research is to contribute to the understanding of the sliding friction of fabrics through a detailed study of the sliding behaviour at a scale of a single tow in both dry and lubricated by liquid resin states. Two distinct approaches, both combining numerical models and experiments, have been employed in this work. A tow consisting of 12,000 carbon fibres (ref. T700SC-12k-60E) with a nominal width of approximately 10 mm and a fibre diameter of around 7 μm, was used for the sliding experiments. In all experiments, the tow was clamped at both ends and slid against a smooth glass plate in a direction transverse to the fibre orientation. To investigate lubrication, a liquid epoxy resin without hardener was introduced into the contact area between a tow wound onto an aluminium cylinder and the rotating glass disk. For the dry friction study, the glass plate was slid over the flat tow. The axial tension of the tow was controlled in both experiments by suspending weights.

To explain the results of the lubricated sliding experiment, a numerical lubrication model for a rough, tow-like elastic surface was developed (1). The model considers the tow as an elastic foundation under sliding with and without lubrication by a non-Newtonian liquid. The lubrication behaviour of this surface was investigated by varying the normal load and sliding speed. In the mixed lubrication regime, it was found that friction depends on the local arrangement of the fibers. This dependence disappears in the hydrodynamic regime; however, this regime is only achieved at high sliding speeds (several meters per second). Therefore, the mixed lubrication regime is the most probable scenario during common composite forming processes.

*Speaker

In the sliding friction experiments conducted on a dry flat tow, the friction force, displacement and transverse strain of the tow were continuously measured during sliding. Several repetitions of this experiment on different pieces of tow cut from the same spool revealed considerable variability in these three parameters. To understand the origins of this behaviour, a two-dimensional Discrete Element model representing the tow's cross-section was developed. The advantage of this method is that is allows for rapid numerical analysis of large movements involving a high number of particles (3,000 in our model), while considering frictional contact between all particles. The bending and torsional stiffness of the fibres were represented by linear and rotational springs attached to each fibre. The model was used to explore the effects of compression load, the number of fibres in a tow, and the local friction coefficients between the fibres and between the fibres and the glass plate. A simulation of repeated cyclic sliding was also performed to study the accommodation of sliding. This parametric study revealed the crucial significance of the bending and torsional stiffness of the fibres on the overall sliding behaviour of the tow. These parameters, in turn, depend on the axial tension in each fibre, which can vary among the thousands of fibres in a tow.

1. N. Brunetière, K. Bhantrakuppe Narayanappa, O. Smerdova. From mixed to hydrodynamic regime in lubricated sliding of carbon fiber tows. Composites: Part A 180 (2024) 108088 https://doi.org/10.1016/j.compositesa.2024.108088.