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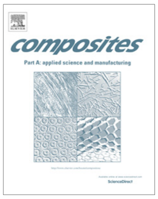

Characterization of the dynamic friction of woven fabrics: Experimental methods and benchmark results

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ABSTRACT

A benchmark exercise was conducted to compare various friction test set-ups with respect to the measured coefficients of friction. The friction was determined between Twintex®PP, a fabric of commingled yarns of glass and polypropylene filaments, and a metal surface. The same material was supplied to all benchmark participants and the test conditions were prescribed, making the used set-up the most important variable among the laboratories. Tests at ambient temperature as well as tests above the melting point of polypropylene are part of the benchmark, in order to determine both the dry and hydrodynamic friction characteristics. The dependency on sliding velocity, average pressure and temperature was investigated. Systematic differences are observed between the measurements obtained by the different set-ups, which are discussed and related to design characteristics of the devices. The values obtained in this benchmark are comparable and may serve as a reference to evaluate other friction set-ups. The paper concludes with guidelines for the design of a friction tester.

1. Introduction

Continuous fiber reinforced thermoplastic polymers provide advantageous properties, like a higher stiffness to weight ratio, compared to often used metals for structural applications. Comparing with their thermoset counterparts, they provide a better fracture toughness and infinite shelf live. Their ability to melt can also be exploited for automated forming and joining processes with relatively short cycle times, in the order of a few minutes.

An example of such a process is sheet forming of thermoplastic composites in a hot press. The process of forming a flat laminate to a 3D shape induces a number of different deformation mechanisms in the laminate. These can be classified by the length scale in which they occur [1,2]. The microscopic deformation mechanisms are the shear strain and elongation strain of each constituent (resin and fiber) and the contact mechanism between them. On a mesoscopic level the deformation may be perceived as fiber bending, resin percolation and transverse fiber flow. As the fiber redistribution and the change of the ply thickness is of less importance to describe the global deformation, we can turn to a macroscopic description of the deformation mechanisms in terms of ply bending, in-plane and inter-ply shear. These are the most common descriptions in literature, but other or additional definitions for the macroscopic mechanisms may be used, for example intra-ply extension or inter-ply rotation [1]. A delicate balance between the resistances to these deformation mechanisms determines the forming behavior of the laminate [3]. A precise characterization of these deformation mechanisms is necessary to accurately describe the composite forming process, to truly design for manufacturing in thermoplastic composites and to deploy their full potential. As a

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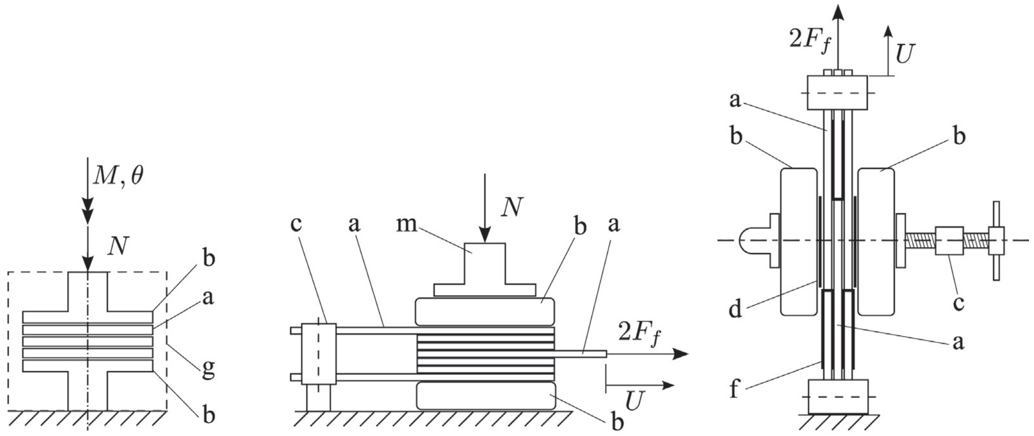
result, inter-ply shear or friction between the laminate and the tools is an often investigated mechanism and has led to numerous different testing devices and testing methods [4–9].

Literature that deals with inter-ply shear of composite sheets primarily focuses on wet friction, i.e. matrix in a molten state, while literature on dry friction of composite sheets, i.e. matrix in a solid state, is scarce. A short review of test methods of wet friction with controversial issues is presented next.

Groves began investigating inter-ply shear using a Rheometrics Dynamic Spectrometer [4]. A stack of several plies was placed between two parallel disk platens and subsequently subjected to an oscillatory torsional deformation (Fig. 1a), maintaining a constant temperature above the melting point of the polymeric resin. The resistance against shear can be calculated in terms of a dynamic viscosity from the measured torque and the rotation angle. Groves was able to relate the dynamic viscosity to the steady shear viscosity by describing the fluid behavior with a Maxwell model. His experiments also indicated that the shear deformation was not only restricted to inter-ply resin rich layers, but was also accompanied with intra-ply shear. Typically, for this type of composites the transverse shear stress increases with the shear velocity. Influences of the temperature or normal pressure were not considered, yet.

Scherer and Friedrich [5] determined the inter- and intra-ply shear by drawing a single ply out of a stack of plies (Fig. 1b), maintaining a constant slip velocity. A hot platen press was used to keep the temperature constant and above melt temperature throughout the slip process. Only slight pressure was applied to ensure contact of the heating platens with the specimen. Also here the shear stress increased with higher slip velocity. While Groves could not find large differences between cross-ply and parallel ply configurations, the experiments of Scherer et al. did show a large influence of the lay-up of the composite. These experiments captured also the transient starting effects, showing a gradual increase of the shear stresses, until a steady state situation was reached.

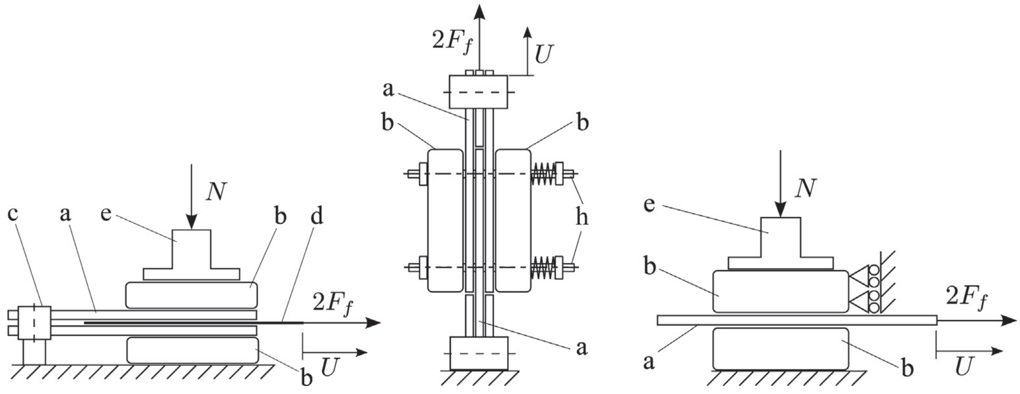
Morris and Sun [6] prepared specimens consisting of two outer sublaminates and a central sublaminate. The specimen was clamped between two heated platens, by means of a clamp. The applied pressure was determined by strain gauges attached to the clamp and only acted on the overlap of the sublaminates (Fig. 1c). The central sublaminate was pulled out during the test. These experiments led to an initial peak force which exceeds the later steady state value, which was not observed in [5]. Both peak and steady state stresses showed an exponential increase for increasing sliding velocities, while they were considerably decreasing when increasing the temperature from below the melt temperature to



(a) Groves [4], material: UD carbon PEEK and UD glass PEEK.

(b) Scherer *et al.* [5], material: UD carbon PP.

(c) Morris and Sun [6], material: UD AS4/PEEK.



(d) Murtagh *et al.* [7], material: UD AS4/PEEK

(e) Lebrun [8], material: 2/2 twill glass/PP (Twintex)

(f) Gorczyca-Cole *et al.* [9], material: 2/2 twill glass/PP (Twintex)

Legend:
a: composite specimen b: plate/ heated plate c: clamp d: steel foil
e: press f: release film g: climate chamber h: axis of springs

Fig. 1. Friction test set-ups in the literature.