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Influence of Wear on the Sizing Layer and Desizing of Single Carbon Fibre-to-Fibre Friction

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ABSTRACT

Carbon fibres are sized for use in the reinforcement of composite materials. The purposes for sizing include improving yarn cohesion, which is necessary for the weaving process, and increasing the adhesion between the fibres and the matrix. Nevertheless, during weaving, some fibrillation can occur, and that has detrimental effects on the weaving productivity and on the composite's properties. The purposes of this research were: (a) to determine whether abrasive wear between sliding fibres would modify the sizing and (b) to study the influence of sizing on the friction between fibres. The same type of carbon fibre was subjected to different desizing processes. The coefficient of friction between single fibres was obtained before and after desizing. The effects of sizing and sliding distance on frictional behaviour were investigated, and are related to the observed the wear of sizing layer. In fact, it increased with sliding distance and induced a decrease in the coefficient of friction. Moreover, an efficient desizing process induced a decrease of the coefficient of friction.

1. Introduction

In the field of composite materials, the significant role of sizing on the carbon fibre–matrix adhesion, and thus on the mechanical properties of composite materials, is very well known. In fact, carbon is extremely inert and, naturally, the adhesion of carbon fibres with polymer matrices is relatively low. In order to improve the adhesion between the carbon fibres and the polymer matrix, different surface treatments of carbon fibres can be done, such as plasma treatment or surface oxidation; the most common is the use of polymer sizing [1–5]. In that case, the sizing must be compatible with the matrix [6–10]. Moreover, the mechanical behaviour of the sizing has an influence on the mechanical properties of the final composite in terms of fatigue performance [11], flexural strength and fracture toughness [12].

The role of sizing is important for the interfacial properties between fibre and matrix, but also for tow or yarn cohesion. In fact, sizing is necessary for reinforcement manufacturing processes, such as during weaving, braiding or knitting processes. When yarn or tow cohesion decreases, fibrillation occurs and increases after several machine cycles, forming free fibres and fibril clusters, which can continue until the fibre breaks [13,14], inducing degradation of the composite's properties [15,16].

In another way, friction between yarns or tows influences the mechanical behaviour of plies during extension, shear [17] or compaction [18], and forming [19–21]. In these studies, the coefficient of friction between carbon fibres is arbitrarily chosen.

Cornelissen et al. showed an influence of sizing or desizing on the coefficient of friction (COF) between tows by the use of the capstan method [22]. Moreover, relative humidity has a great influence on the tow–tow COF with sizing, but not without sizing. Sizing has also been shown to have an influence on the creep compaction behaviour of dry fabric when the temperature varies (25 and 160 °C), while the behaviour of unsized fabric does not change [23].

The influence of the stages of production of a carbon fibre on the friction between single fibres and stainless steel has been studied by Kafi et al. using the capstan method [24]. The results obtained show a higher COF for sized carbon fibres than for oxidised and unoxidised ones. To the best of our knowledge, there are no other studies regarding the influence of sizing on the friction between two single fibres. However, Roselman and Tabor studied the influence of an oxidation treat-

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Table 1
Different desizing processes used.

Name of the process	Acetone	THF-5	THF-10
Solvent	Acetone	Tetrahydrofuran	Tetrahydrofuran
Boiling temperature	56 °C	65 °C	65 °C
Number of times siphoned	10	5	10

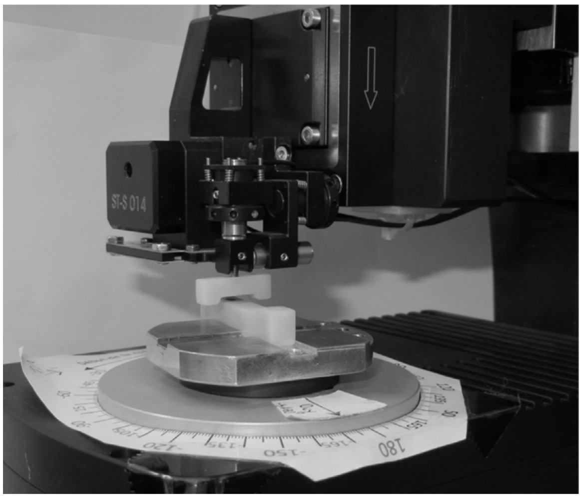

Fig. 1. Picture of the nanotribometer in the specific fibre carrier developed in the laboratory.

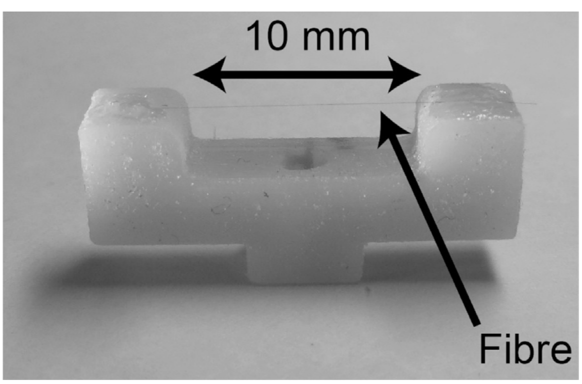

Fig. 2. Fibre sample on the specific sample carrier.

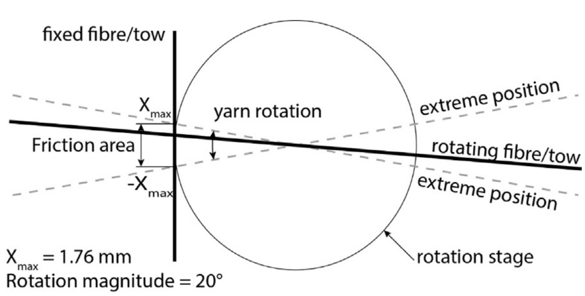

Fig. 3. Schematic of friction experiment.

ment on the friction between single fibres [25]. In that experiment, the lower fibre was clamped by its two ends and the upper fibre was clamped at one extremity, and free at the other. In this old but very interesting paper, the normal load applied on the fibre was not measured, but was calculated from the fibre's mechanical properties and its deformation in the normal contact plane, and the friction force was measured from the deformation of the upper clamped-free fibre. Therefore, the results depended on the Young modulus of the fibre, in both its axis and transversal directions. The results obtained by this method showed that non-oxidised carbon fibres had a slightly lower coefficient than the oxidised ones.

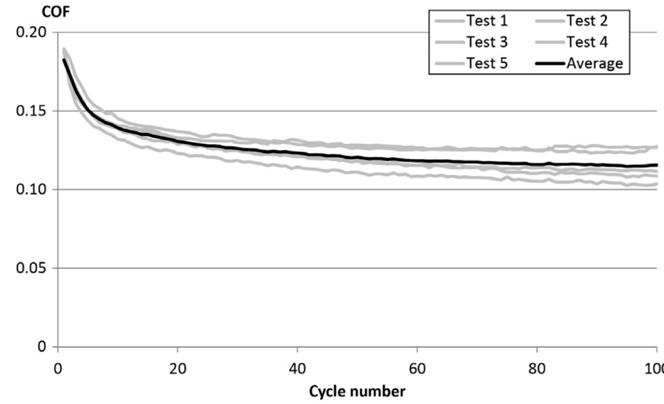

Fig. 4. Repeatability of the measurement of coefficient of friction relative to the number of friction cycles for carbon fibres sized.

As is mentioned in the literature, yarn cohesion due to sizing is very important during the reinforcement manufacturing process, for example, during weaving. A failure of the sizing film induces a defibrillation of the yarn and the formation of fibril clusters. It can be supposed if interaction and friction between fibres increase because of sizing damage, the defibrillation is enhanced and the damage will propagate. The purpose of the present study was to determine whether the friction between fibres that occurs during weaving modifies the sizing due to the wear phenomenon, and whether it influences the friction value between fibres. In the present study, the influence of different types of sizing was not considered, but the difference between fibres with sizing and fibres subjected to different desizing processes were studied.

2. Experiments

2.1. Investigation of carbon fibre

The carbon fibre was extracted from a 12 K type HTS40 tow provided by Toho Tenax. A single fibre is very fine with 7 µm in diameter. The sizing was based on polyurethane.

2.2. Desizing processes

The fibres are generally sized with high molecular weight polymers, which can be removed by extraction with hot solvent. The best means of extraction is the Kumagawa extractor, which consists of a bulb equipped with a siphon. The fibres were placed carefully in the bulb. The bulb was put into a round-bottomed flask. The solvent in the flask was heated gently and evaporated in a reflux condenser. The hot solvent dripped slowly into the bulb, falling onto the fibres, until it was siphoned off. The fibres were rinsed in hot pure solvent each time the bulb was siphoned. Two solvents were tested experimentally: acetone and tetrahydrofuran (THF). Filling and emptying the bulb took about 4 minutes for acetone and 5 minutes for THF, as they have different boiling temperatures of 56 and 65 °C, respectively. Table 1 shows the different conditions of extraction tested experimentally on the carbon fibres.