INVESTIGATION OF THE FRICTION BEHAVIOUR OF SPREAD CARBON FIBRE TOWS WITH REACTIVE BINDER

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ABSTRACT

This paper deals with spread carbon fibre tows with epoxy-based thermoplastic binder that can be used in two-dimensional dry fibre placement (DFP) layups, which show freely selectable fibre orientation of each tow and layer structure. In a second step the DFP preforms can be draped into a three-dimensional preform, here the friction has a significant influence on the forming behaviour. Especially in the case of the mentioned DFP preforms, where the forming mechanisms are not dominated by a stitching or weaving pattern. To build a mesoscopic draping simulation of the DFP preforms, detailed knowledge of the friction behaviour is necessary. A special test set-up for the friction characterization of bindered spread tows and experimental results are presented. As the friction behaviour is dominated by the epoxy-based thermoplastic binder, the investigations focus on the temperature dependent friction characteristics. A significant increase of the friction coefficient above the reversible forming temperature of the bindered spread tows is visible. In addition to the variation of the temperature, the normal pressure, relative velocity as well as the fibre angle are investigated.

Keywords: Friction; Dry Fibre Placement; Automated Fibre Placement; Preforming; Draping

1. INTRODUCTION

A common way to manufacture flat and moderately curved composite parts is done by forming two-dimensional semi-finished products into the final three-dimensional form, regardless of the use of prepreg or bindered dry material. When using dry material several options of textile products are available. One opportunity is the use of spread carbon fibre tows, which are used in a dry fibre placement (DFP) process to generate two-dimensional layups. Benefits of this manufacturing process are high reproducibility as well as flexibility in fibre orientation while causing low waste by near-net-shaping [5]. During the following forming of these DFP preforms mainly inter-ply and intra-ply tow movement occur, unlike woven fabrics or non-crimp-fabrics, whose forming mechanism is primarily shearing [8]. Tow movements in the forming process are basically dominated by friction, where a distinction has to be made between inter-tow friction and tow to tool surface friction [2]. Some work was already done to understand friction in dry textiles [1,6,7] and dry carbon tows [2]. To improve the quality of the forming process with DFP preforms and to detailed understand the tow movement, mesoscopic forming simulations are established, which need basic information about the friction behaviour. Hence, this paper deals with the determination of the friction characteristics of a bindered spread carbon tow with focus on influence of temperature and relative fibre angle.

2. EXPERIMENTATION

2.1 Materials

The examined material, M&A Dieterle FixedTow, is a spread carbon tow with an average width of 20 ± 0.5 mm [9]. The used basic tow is SIGRAFIL®C T24-5.0/270-E100, a 24k roving from SGL Carbon, which has been bindered on one side for fixation and improved processability in later steps like DFP (s. Figure 1). As binder Hexion Epikote™ Resin TRAC 06720 was used during the production of the FixedTows with an average binder amount of 8 wt.% or equivalent 9 g/m². This reactive epoxy-based binder has reversible forming behaviour in the temperature range of 80-90°C and is well suited for further use in the forming process. [10]

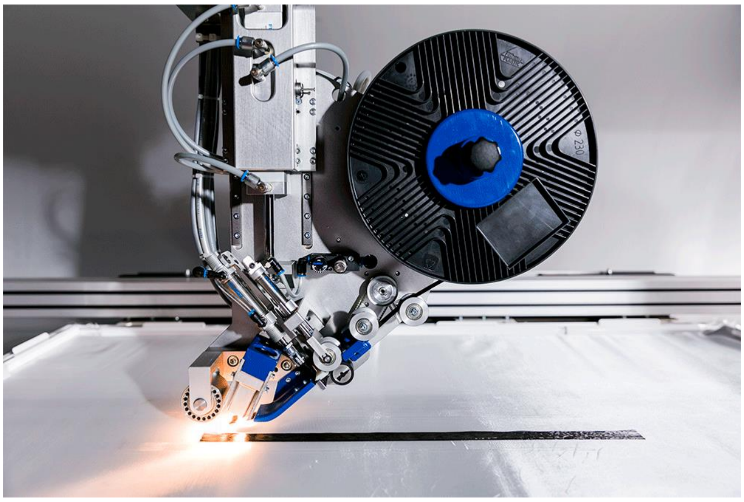

Figure 1: M&A Dieterle Crosslayer laying head

In order to be able to determine the friction behaviour of the spread carbon tows as realistically as possible, the FixedTows will be laid down individually on the Crosslayer (see Figure 1) with a length of 30 cm before the actual friction measurement. As the binder will be briefly heated in the Crosslayer during the DFP, this circumstance has to be considered when determining the friction behaviour of the FixedTows for the following forming process.

2.2 Methods

The special test setup to determine the friction properties of the FixedTow is based on the pull-out principle, where FixedTows are clamped between the desired friction counterpart and pulled out during the measurement. Combinations of FixedTow to the metal surface of the friction test setup (aluminium alloy AA7075) as well as FixedTow to FixedTow will be examined. For the first combination, a distinction has to be made between dry and bindered tow side to metal. The FixedTow is only bindered on one side, but both sides are in contact with the metal tool surface or the blankholders during the forming process. As the layup of the carbon tows in the automated fibre placement is fixed, only contact between a dry tow side and a bindered tow side will be investigated in the case of FixedTow to FixedTow friction.

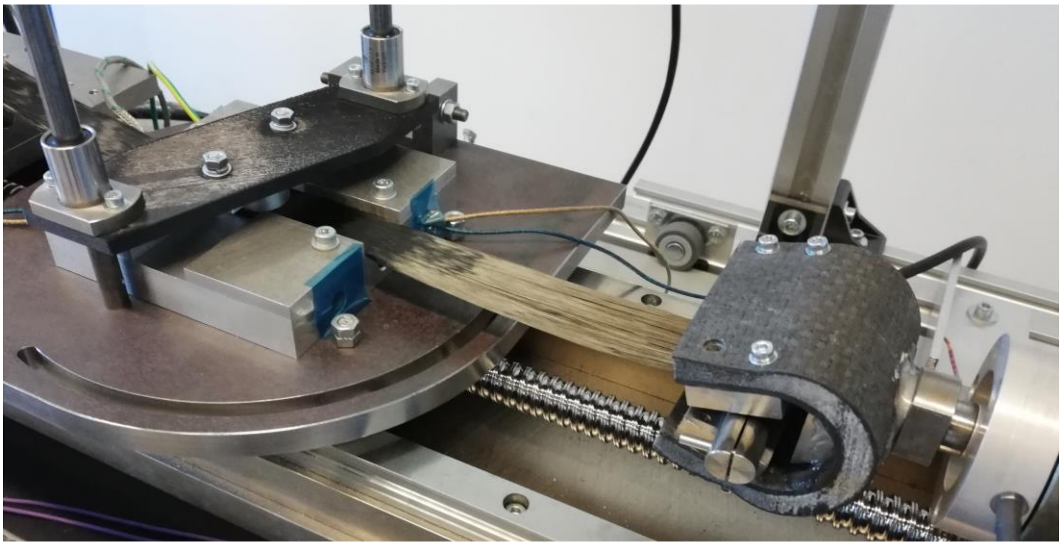

Figure 2: Test setup for friction measurement

The experimental setup for FixedTow/Metal combination is shown in Figure 2. The 30 cm FixedTow is connected via a clamp to a load cell, which is attached to a linear guided carriage driven by a spindle. The pull-out velocities of the tests will vary between 1 and 5 mm/s. The test assembly for FixedTow/Metal basically consists of the baseplate and the normal force stamp. The FixedTow will be positioned between them and pulled-out to determine the friction force. The baseplate will be heated up to 120°C controlled via two heating cartridges and a type K thermocouple. The normal force stamp is guided by two linear ball bearings and will be equipped with masses for establishing the desired normal force or respectively the normal pressure. To prevent the FixedTow from slipping sideways, guidance plates are mounted on the baseplate. Two FixedTows are always clamped at the same time in order to be able to realise the contact between dry or bindered tow side to the top and bottom metal surfaces. To examine the friction behaviour of FixedTow/FixedTow, an additional carbon tow will be attached to the main FixedTow with variable fibre orientation of 0 - 90°, with suitable guidance plates for 0°, 45° as well as 90°. The additional FixedTow will be pretensioned to avoid slipping sideways.

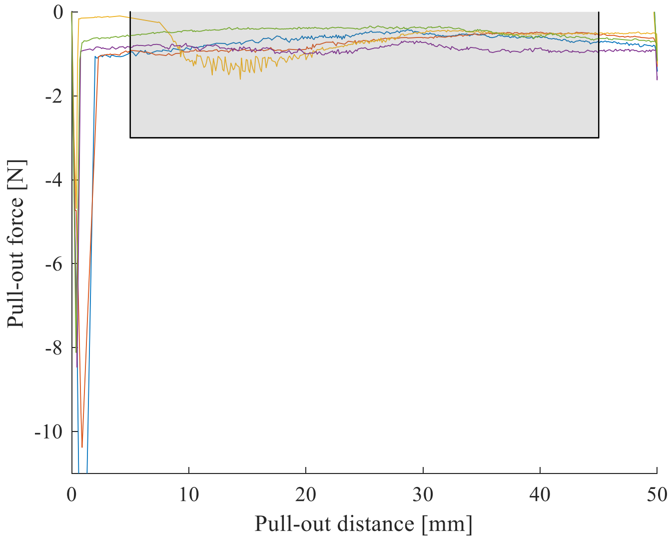

Figure 3: Force curves at 80 °C, normal pressure of 0.006 MPa and pull-out velocity of 1 mm/s for bindered-tow to metal contact

At a relative fibre angle of 0° no pretension is necessary, thus the additional FixedTow will be simply aligned parallel to the main FixedTow.

To receive the friction characteristics, the FixedTow will be pulled-out over a distance of 50 mm. As only the dynamic friction will be determined, the force measurement will be evaluated between 5 and 45 mm pull-out distance, shown as grey area in Figure 3. Each test will be performed at least 5 times to obtain reliable results of the average value. Using Coulomb's law, the friction coefficient µ will be calculated by equation (1) with F_N as normal force and F_R as average value of the friction force [3].

$$\mu = \frac{F_R}{2 \cdot F_N} \tag{1}$$

3. RESULTS

The following diagrams show the mean value of the friction coefficients dependent on the chosen test parameters. The standard deviations are displayed as error bars.

3.1 Normal pressure

To investigate the influence of the normal pressure on the friction behaviour tests at four different pressure levels from 0.004 MPa to 0.01 MPa were carried out. Temperature has been set to constant 80 °C and the FixedTow was pulled out at 1 mm/s. Figure 4 shows the corresponding friction coefficients for FixedTow to metal contact. Over the various pressure levels no significant change of the friction coefficient is visible regardless the orientation of the tow to the metal surface. In the case of the bindered tow side contacting the metal higher standard deviations occur compared to the contact of the dry tow side to metal.

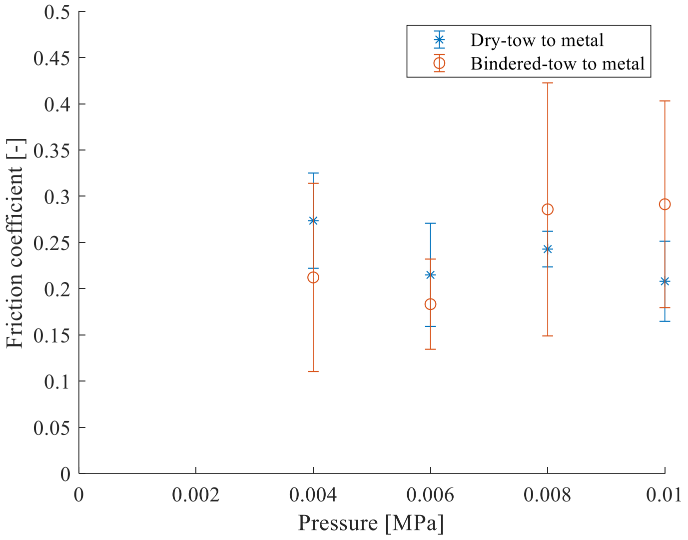

Figure 4: Friction coefficients at 80 °C and 1 mm/s pull-out velocity

As there is no major change of the friction coefficient over the investigated pressure levels, the use of Coulomb's law is justified for the parameters 80 °C and 1 mm/s. To ensure comparable results, all friction coefficients in this paper will be determined by Coulomb's law.

3.2 Pull-out velocity

While setting the temperature to constant 80 °C and the normal pressure to 0.006 MPa, several tests with various pull-out velocities were done. As Figure 5 shows, there are no clear deviations in the pull-out velocities from 1 mm/s to 5 mm/s. Again, the standard deviations of the bindered tow side are increased in comparison to the dry tow side, indicating the complex friction behaviour of the reactive binder system.

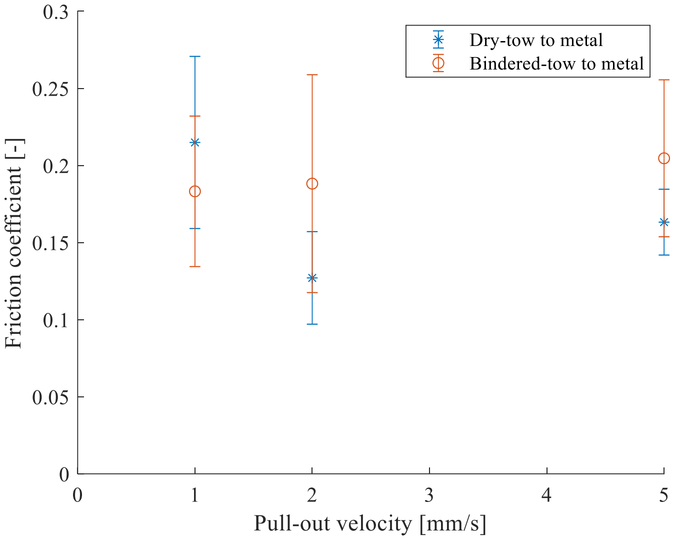

Figure 5: Friction coeff. at 80 °C and normal pressure of 0.006 MPa

3.3 Temperature

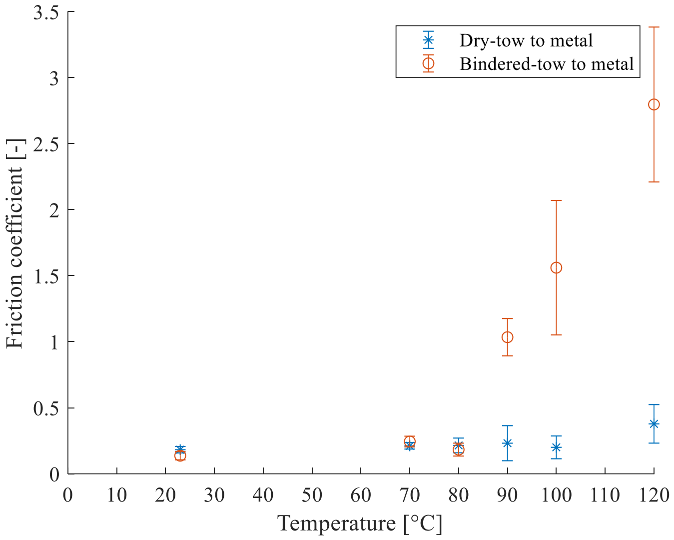

Figure 6: Friction coefficients at normal pressure of 0.006 MPa and 1 mm/s pull-out velocity

As this paper deals with epoxy-bases thermoplastic bindered spread carbon tows a major focus lies on the friction behaviour during the variation of temperature. Therefore, several tests in the temperature range from room temperature (23 °C) to 120 °C haven been realized. The maximum temperature of 120 °C was chosen close based on the curing temperature of the reactive binder in the forming process. Figure 6 shows the friction coefficients for the combination of FixedTow to metal surface with a constant normal pressure of 0.006 MPa and pull-out velocity of 1 mm/s. The figure can be separated into two different areas of friction behaviour. Between room temperature and 80 °C no significant influence of the temperature on the friction characteristics is visible, either for the bindered or dry tow side. With then increasing temperature, starting at 90 °C the two different tow sides reveal divergent trends. In the case where the dry tow side is in contact with the metal surface, no clear dependency of the friction coefficient to the increasing temperature is apparent. Whereas a strong rise of the friction coefficient occurs, if the binder side of the tow is in contact to the metal. At the maximum investigated temperature of 120 °C the friction coefficient of the bindered carbon tow side is approx. seven times higher than the friction coefficient of the dry tow side.

Between room temperature and the melting point of the epoxy-based thermoplastic binder both sides of the spread FixedTow show similar friction behaviour due to the fact that the binder particles are solid and evenly distributed. Above a temperature of 80 °C the binder particles start to melt, increase their surface area and smear over and into the tow [4]. Hence the friction coefficient is rising due to the increased contact area between melted binder and metal surface. A lubricating effect of the viscous binder cannot be noticed. In the case of dry tow friction potentially the sizing leads to complex friction behaviour at high temperatures [4].

3.4 Relative Fibre Angle

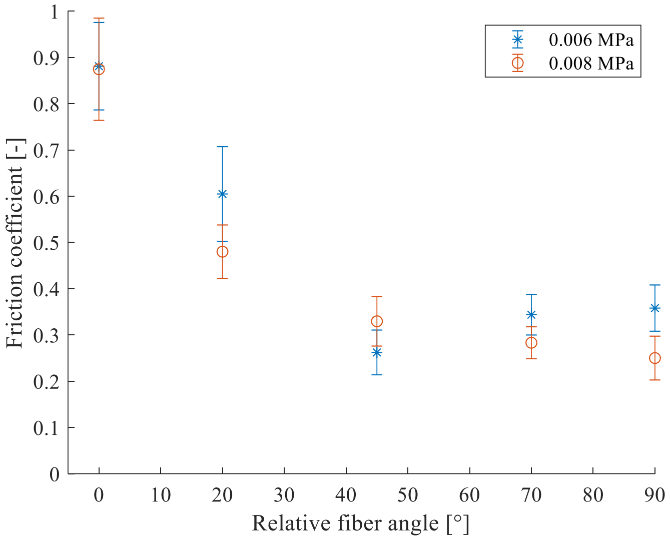

Figure 7: Friction coefficients at 80 °C and 1 mm/s pull-out velocity for two normal pressure levels

If two carbon tows are in contact the friction behaviour additionally is dependent on the relative angle between the fibre orientation of these tows. Results of the frictions measurements, displayed in Figure 7, show a unique dependency of the friction behaviour to the relative fibre angle. At relative angles of 45°, 70° and an orthogonal orientation of the tows no clear trend of the friction behaviour is visible for both pressure levels of 0.006 MPa and 0.008 MPa. With decreasing relative fibre angle a significant increase of the friction coefficient comes along, regardless the normal pressure. At parallel tow alignment the friction coefficient is increased by approx. 2.5 times (0.006 MPa) and 3.5 times (0.008 MPa) compared to the orthogonal orientation of the FixedTows.

With increasing parallel alignment of the spread carbon tows the interlocking of the fibres comes along, where the filaments are embedded into the opposite spread tow [2]. The consequently increase of the contact area leads to the determined rise of the friction coefficient irrespectively of the normal pressure level.

4. CONCLUSIONS

The presented method to determine the friction coefficient is based on the later forming process, hence the focus is on change of temperature and fibre angle. Orientation-dependent friction behaviour occurs at tow to metal surface contact during the variation of temperature due to the fact, that the M&A Dieterle FixedTow is bindered one-sided. A significant increase in friction is observed, if the bindered tow side is contacting the metal and temperature exceeds 90°C, the reversible forming temperature of the binder. Furthermore, low relative angles between two spread tows lead on to rising friction values as the contact area between the individual filaments is increasing. The gained knowledge of the FixedTow’s friction behaviour will be further used for creating improved simulation models of the forming process.

5. ACKNOWLEDGEMENT

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