Experimental Observations on the Friction of Textile Fibres Relevant to Carbon Fibre Composite Forming

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The friction of fibrous materials is important in several applications including for the manufacturing processes involved in the production of textile fabric products [1]. One application of particular interest occurs in the composites forming industry where friction plays a critical role in the forming of carbon fibre fabric materials. Here, we focus on the dry friction scenario which occurs when the process is carried out with a dry pre-forming stage prior to resin infusion. Currently, forming outcomes can only be determined by expensive trial and error and the forming industry is actively seeking predictive modelling solutions. Such simulations can only make accurate predictions if the frictional effects occurring during forming are well understood. This study focuses on the friction of the carbon fibre tows comprising the fabrics and follows on from a number of recent studies covering aspects of carbon fibre tow friction [2-6].

A fundamental study of the underlying frictional behaviour of carbon fibre tows is carried out for two frictional scenarios prevalent during forming: tow-on-tow and tow-on-tool contact. A new experimental technique is devised to concurrently measure friction force and 'real contact length' in tow-on-tool contact for a range of normal loads. The technique involves in-situ microscope observation of tow contact with a specialised semi-reflective glass coating while simultaneously applying normal or tangential load (Fig. 1). The rig is easily adaptable to the study to tow-on-tow contact (without optical observation of the contact). For the tow-on-tool arrangement, filament contact length was not constant with normal load (as would be expected from an idealised arrangement of parallel touching filaments), but increased in a characteristic manner as the tows were compacted. The friction of the tows followed a power law variation with normal load with exponent in the range 0.7 to 1. Accounting for the evolving contact length in a Hertzian calculation of the real contact area produces a contact area versus load variation which differs only by a constant factor from the measured friction force curves. Thus, the results agree with a 'constant interface strength' model of friction. Tow orientation and sizing are found to have a significant effect on friction by altering the real contact area. Parallel tow-on-tow contact gave higher friction than the corresponding perpendicular arrangement owing to higher 'real contact area' in the 'tow-tow parallel' case as demonstrated by a simple contact model of the tow-tow interaction. Greater sizing amounts on the tows also conferred higher friction - again, this was due to an increased 'real contact area'.

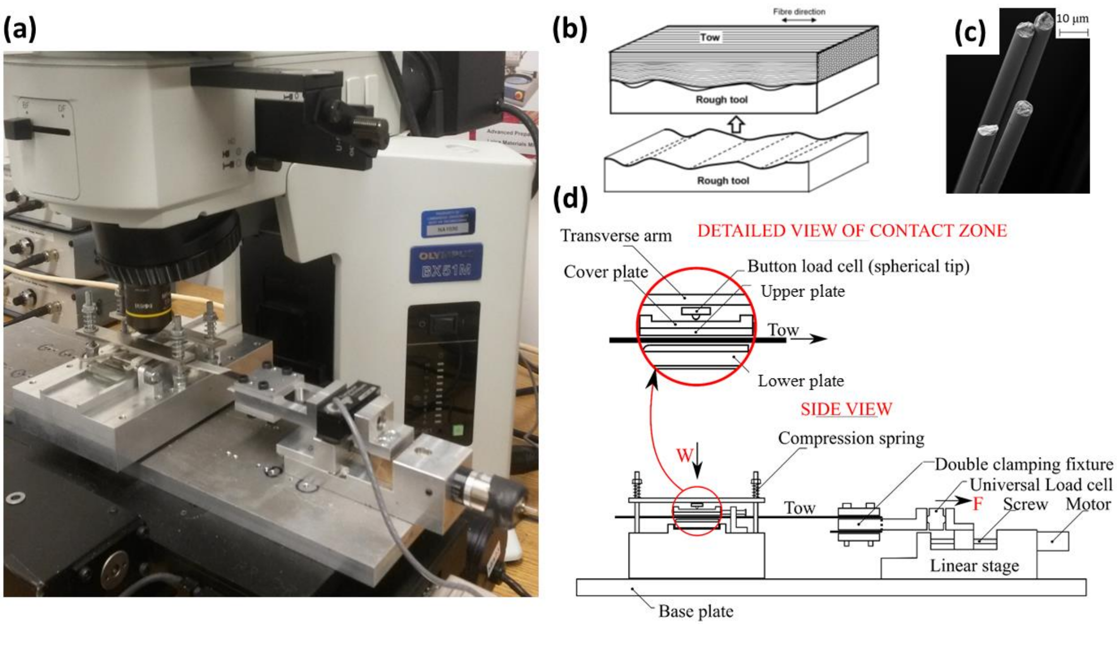

Fig.1: (a) Photo of experimental rig in-situ on microscope stage, (b) schematic of tow-tool contact, (c) SEM micrographs of individual carbon filaments and (d) Schematic side view of experimental rig.

The effect of tool surface roughness topography on tow-on-tool friction was also studied. Friction force *F* versus normal load *W* curves were recorded for carbon fibre tows in contact with counterface surfaces having a wide range of average surface roughness R_a values from 0.005 to 3.2 μm. The slopes of these surfaces, which play the critical important role in the contact behaviour, increased in line with the roughness amplitudes. All *F*-*W* curves obeyed the power law description $F = kW^n$ with the exponent *n* being in the range 0.71 to 0.91 and tending to increase with increasing roughness amplitude and slope. Friction was found to increase rapidly with decreasing surface roughness and slope for surfaces having an R_a less than about 0.1 μm, but was relatively insensitive to roughness for higher R_a values. A finite element based contact modelling approach was used to explain these results in terms of the level of tow conformance with the counterface surfaces. The smoother low-slope surfaces allowed the tows to conform well to the surfaces and, hence, generate a higher real contact area and a friction force more sensitive to changes in roughness, while the rougher high-slope surfaces showed poor conformance allowing the peaks of the roughness profile to dominate the contact causing the real contact area under the fibres (and hence, the friction) to be less sensitive to roughness.

Thus, much as for metals, the friction of carbon fibre tows appears to be largely determined by the behaviour of the 'real contact area'. The results described have important implications for the composite forming industry and will need to be incorporated in predictive models of friction in the dry forming process. The results are also important for fabric manufacturers where friction is a critical parameter in determining the occurrence of filament breakage issues and filament waste build-up since tows are generally run through a complex arrangement of rollers to weave and process the fabrics. There is also a wider applicability to the study beyond the carbon fibre field as some of the fundamental observations will apply to the friction of many types of fibrous tows and textile materials.

References

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