EXPERIMENTAL INVESTIGATION OF NCF-ON-TOOL CONTACT

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ABSTRACT

The true fibre contact length for NCF-on-tool contact was measured for an area of 8.29 mm × 11.54 mm over a range of normal pressures using microscopy. Contact length was approximately 67% lower than for unidirectional tow-on-tool contact at the same nominal pressure (240 kPa). This is because NCF stitching and gaps between tows significantly reduce fibre contact length compared to tow-on-tool fibre contact measurements. A Hertzian approach was used to estimate contact area from contact length.

1 INTRODUCTION

The use of carbon fibre reinforced plastics (CFRP) is growing in the automotive industry, meeting the need to produce lightweight and complex parts in a cost-effective manner [1]. A variety of forming techniques can be used to produce these parts from either dry fibre preforms or prepregs. Non-crimp fabric (NCF) composites are reinforced with layers of straight (non-crimped) fibres held together by stitching [2]. Compared to woven fabric, NCF could offer better mechanical properties and fatigue performance, ease of handling, shorter process cycles with lower resin consumption and thus reduced manufacturing costs. During the dry forming process (prior to the resin infusion stage), an accurate description of the fabric forces such as normal pressure, fibre-tool and fibre-fibre friction in the system is required to predict deformations, wrinkling and buckling behaviour. To better comprehend friction forces, first it is important to understand the true fibre-tool and fibre-fibre contact. This paper uses an experimental technique devised by our group [3] to measure true NCF-on-tool contact length over a range of normal loads.

2 PROCEDURE

The method uses an experimental loading rig in which fabric is compressed by a glass slide while under a microscope, thus allowing visualization of the true contact area between the fabric and a flat tool surface (Figure 1). A key feature of the rig is the use of a special semi-reflective coating on the glass plate (tool) [4], which enhances the contrast of the contacting fibres.

The biaxial NCF used (FCIM591) is made from 12K tows, weighs 300 grams per square metre. This fabric contains two tow layers orientated at -45°/+45° and is tricot stitched.

In each test, a layer of a carbon NCF material was clamped between a platform and the glass plate. A range of normal loads (W) was applied and measured by two button load cells. Five tests were carried out in total and each consisted of 14 normal loading steps. The applied normal load was converted to a nominal pressure (p) using the nominal contact area of 25 mm × 25 mm. At each normal load step, a representative rectangular micro-scale scan area of 8.29 mm × 11.54 mm was imaged covering an area of 1.5 tricot stitching units. In these images, the fibres appear as distinctive bright strands. An image analysis algorithm, implemented using Matlab [4], was used to detect and calculate the filament contact length. Although the image resolution is insufficient to evaluate the width of each of the fibre contacts, this was estimated with reasonable confidence (for the circular-cross-section fibres used in this study) using a Hertzian contact analysis [3].

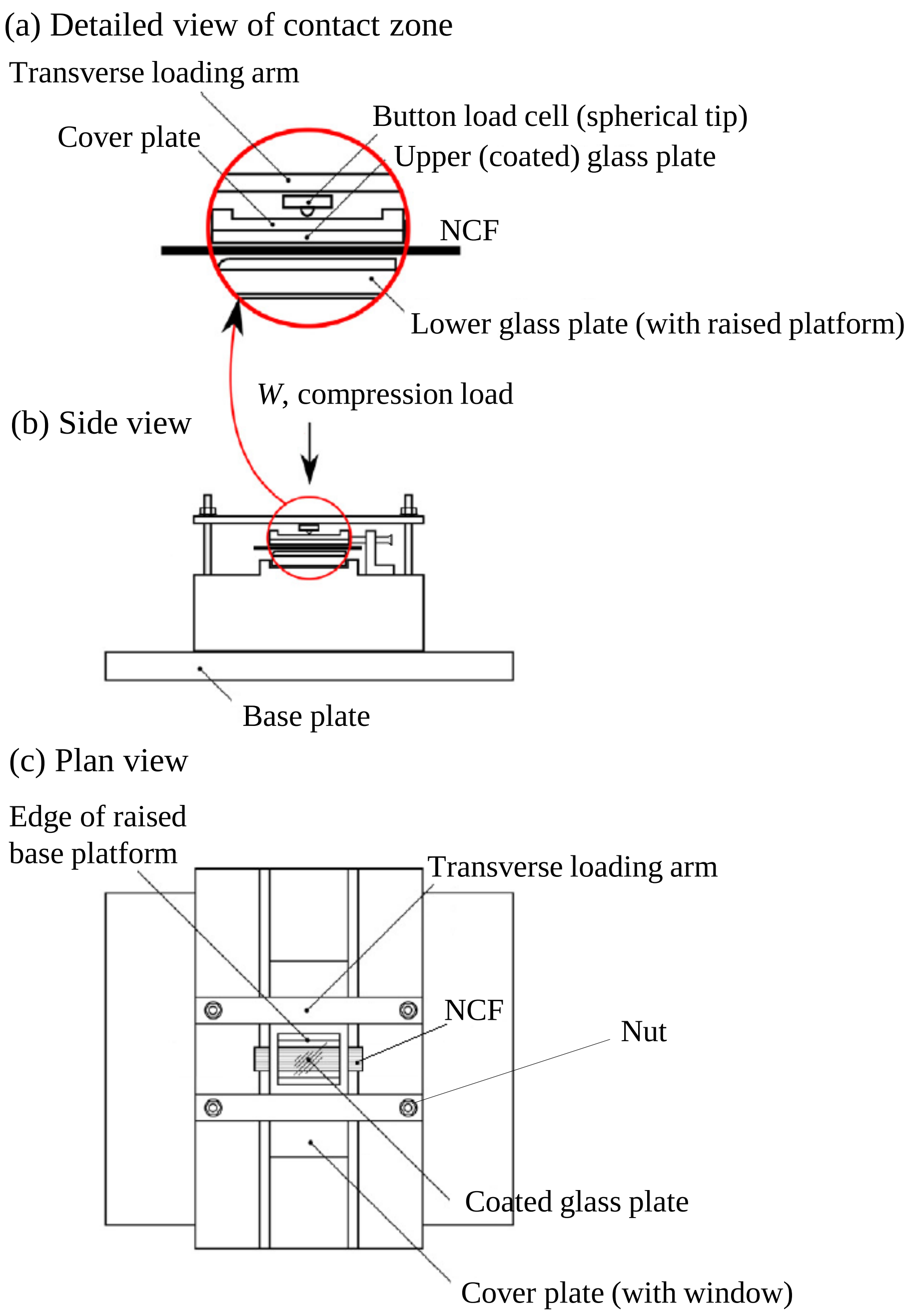

Figure 1: Schematic drawing of the experimental rig for NCF-on-tool testing.

3 RESULTS

3.1 Contact length

Figure 2 shows the increase in true fibre contact length (L) with nominal normal pressure (p) for the five tests carried out. The true contact length is given as a percentage of the idealised contact length (L_{max}) associated with the limiting case when all the fibres contacting the tool are parallel and touching each other. The average contact length varied from 1.5% at 6.4 kPa to 11% at 320 kPa. As with previous measurements on other fabrics [3, 5], this value is significantly below 100%, confirming that the contact geometry is far from the idealised case of parallel touching fibres. Compared to tow-on-tool tests of the same fabric [3], these NCF-on-tool results showed a 67% reduction of true fibre contact length on the tool surface at a normal contact pressure of 240 kPa.

This reduction in NCF contact, as compared with tow contact, is due to the presence of contact-free areas that are developed around the stitching of the NCF layers and between the tows. To visualise these factors, Figure 3a shows a representative micrograph of the entire scanned area at a normal pressure of 320 kPa, while Figure 3b is an annotated subsection of Figure 3a. Figure 3b illustrates the influence of the stitching and gaps between the tows on the true contact regions (identified in red). Figure 3b shows that in the regions around the stitching (highlighted in green), the surrounding fibres lose contact with the tool as they lie below the contacting stitching threads. Additionally, gaps between the tows reduce the true fibre contact length by creating areas with minimal fibre contact (white hatched regions between tows outlined in black in Figure 3b).

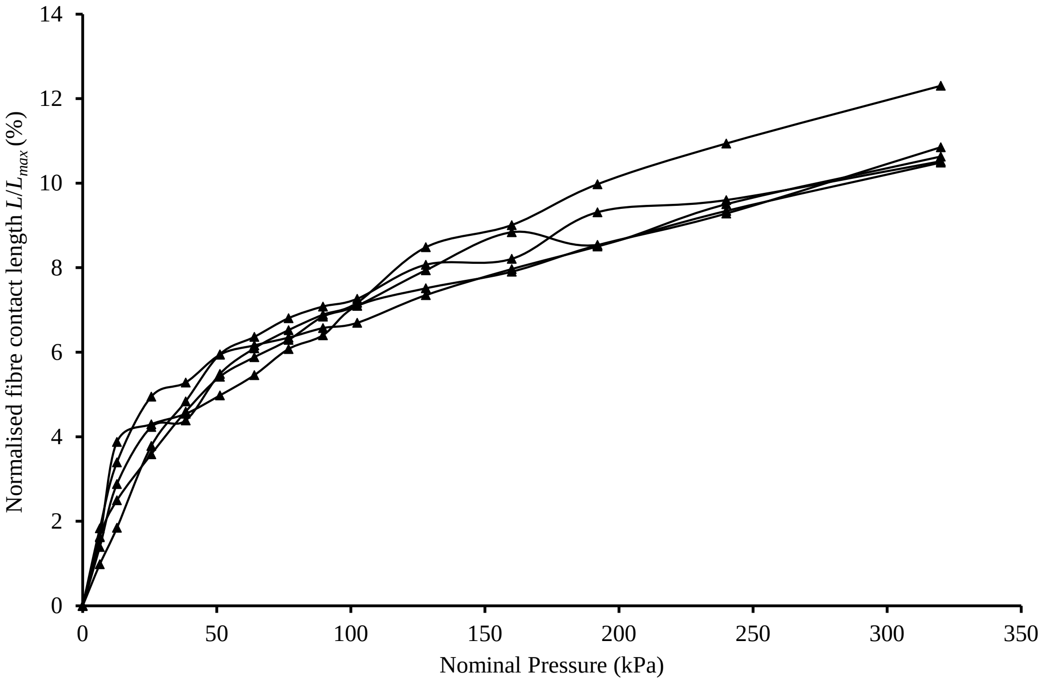

Figure 2: Effect of nominal normal pressure (p) on true fibre contact length (L) for NCF-on-tool contact, expressed as a percentage of the idealized contact length (L_{max}) for parallel touching fibres.

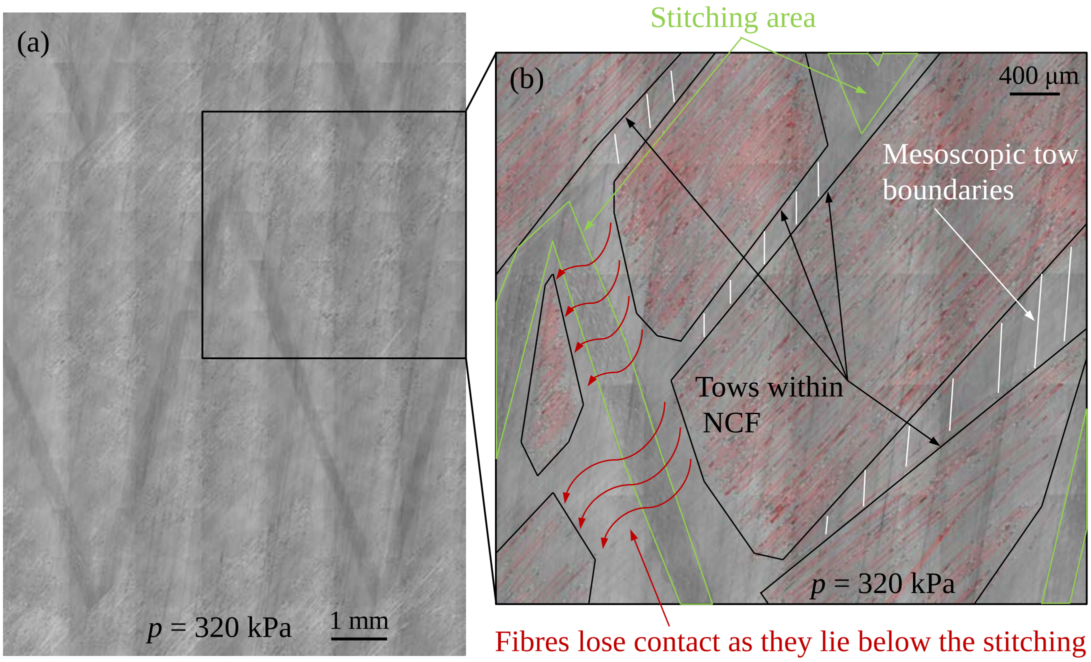

Figure 3: (a) Raw image from the microscope of the total scanned area. (b) Part of the post-processed image which detects the fibres in contact with the coated glass plate (in red). Fibres lose contact with the tool as they pass below the stitching filaments (in green). Contacting tows within NCF are identified and drawn as black polygons. White lines define gap regions between tows where almost no fibre contact was observed. Nominal normal pressure p = 320 kPa.

3.2 Contact area

The true fibre contact area was not directly measured as the image resolution was not sufficient to evaluate the width of contact between each of the fibres and the glass plate. Thus, an estimation of the true fibre contact area can be made based on a Hertzian contact analysis. According to the Hertzian analysis, the contact half-width a of a cylinder (the fibre) on a flat plane (the glass tool) is given by:

$$a = \sqrt{\frac{2Wd}{\pi E' L}} \tag{1}$$

where W is the total normal load on the contact patch, d is the fibre diameter (equal to 7 µm), E' is the effective elastic modulus and L is the total true fibre contact length. The effective elastic modulus is given as follows:

$$\frac{1}{E'} = \frac{1-\nu_{glass}^2}{E_{glass}} + \frac{1-\nu_{CF}^2}{E_{CF}} \tag{2}$$

where E_{glass} and E_{CF} are the Young's moduli of the glass plate (tool) and carbon fibre, respectively. The quantities ν_{glass} and ν_{CF} are the Poisson's ratios of the glass plate (tool) and carbon fibre, respectively. The values of E_{glass} and E_{CF} (transverse direction) were taken equal to 69 GPa and 16.5 GPa, respectively [6, 7]. The values of ν_{glass} and ν_{CF} were taken equal to 0.24 and 0.31, respectively [6, 7]. The true contact area A is given by:

$$A = 2aL \tag{3}$$

Figure 4 plots the normal load against true fibre contact area A obtained from the measured contact lengths via equation 3 for each of the five tests. This contact area A is inferred for the entire NCF contact area over which the load W was applied (25 mm × 25 mm) by scaling the contact measurements from the smaller imaged area (8.29 mm × 11.54 mm). For the average contact area results (the orange curve on the graph), a power-law fit to the data was found with an exponent n equal to 0.69 and a factor k equal to 0.0392. Figure 6 includes the theoretical variation of contact area with normal load for the ideal case of parallel touching filaments (n = 0.5 and k = 0.326).

4 CONCLUSIONS

An experimental investigation to measure true NCF-on-tool fibre contact length over a range of normal loads has been carried out. The average contact length, expressed as a percentage of the idealised contact length, varied from 1.5% at 6.4 kPa to 11% at 320 kPa. The presence of stitching in NCFs reduces the true contact length of the fibres within the fabric for 67% comparing to tow-on-tool tests. A Hertzian cylinder-on-flat analysis was used to estimate true fibre contact area. The results showed that the true fibre contact area A could be described by a power law relationship with respect to normal load W with an exponent of n equal to 0.69.

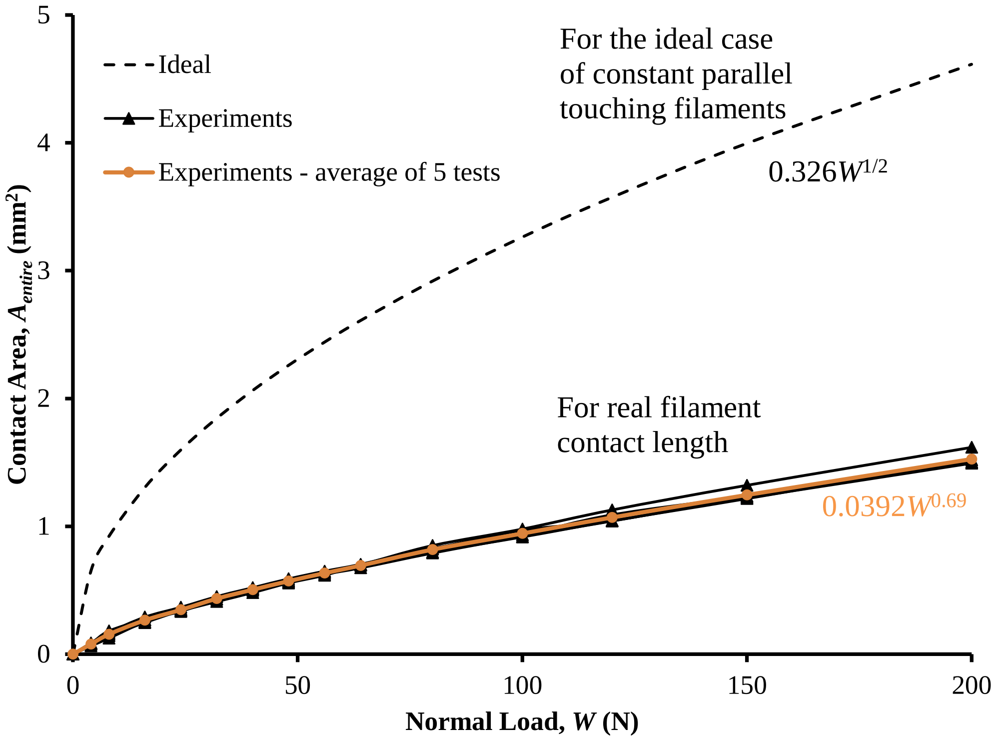

Figure 4: True fibre contact area (A) against normal load for a 25 mm × 25 mm NCF calculated from the true fibre contact length using Hertzian contact analysis for the cylinder-on-flat scenario.

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