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Compaction and bending variability measurements of a novel geometry 3D woven layer to layer interlock composite textile around a 90° curve plate 3.2 mm radius

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ABSTRACT

The aim of this investigation is to measure compaction and bending variability of a novel composite 3D woven textile layer-to-layer interlock around a 90° curve plate geometry. To that, end with the use of an empirical power law the compaction behaviour of the novel weave geometry textile fitted. This way it is possible to evaluate the max shear stress at 90° during bending. The preform thickness variation along the bending was measured with the use of a Coordinate Measurement Machine. The overall methodology and data variability measurements are useful for the manufacturing process of composites at macro-scale level as predictive data in Resin Transfer Moulding flow analysis for a complex composite node with 90° bend moulder geometry.

1. Introduction

Compaction behaviour inside the mould cavity and corresponding V_f determines the local fabric permeability and so is directly related to race-tracking and preform variability. In order to address preform compaction a number of models by Chen et al. [1] have been proposed.

Robitaille and Gauvin [2–4] published studies of the compaction of textile reinforcements for composites manufacturing. The power law Eq. (1), has been used as the base for unsaturated and saturated empirical compaction models by Govignon et al. [5] in simulation of the reinforcement compaction and resin flow during the complete resin transferred moulding infusion process, and also by Bickerton and Buntain [6], Correia [7], Endruweit and Long [8], Summerscales and Searle [9].

$$\mathrm{V_f} = \alpha_c P^{\beta} \tag{1}$$

In Eq. (1) V_f is the fibre volume fraction, P is the pressure, $\alpha_c$and β are empirical material constants. The Eq. (1) implies that the fibre volume fraction is zero when the pressure is zero the equation may work if a limited range of $\mathrm{V_f}$ are considered. A more appropriate model is given by Toll and Manson [10] for elastic compression of a disperse planer fiber network

$$P = \frac{512}{5\pi^4} E f^4 (V_f - V_{f0}) \tag{2}$$

Where P is the applied pressure, E is the young's modulus of the fiber orientation distribution as defined by Toll, V_f is the fiber volume fraction, f^{4} is an empirical carbon fiber material characteristic. The second term V_{f0} is a parameter that needs adjustment but tends to be negligible at realistic fibre volume fractions. So if V_{f0} is is zero when the pressure is zero the Eq. (2) will become (2.1)

$$P = \frac{512}{5\pi^4} E f^4 V_f \tag{2.1}$$

and so with organization of the V_f against the Pressure will be the (2.2)

$$V_f = \frac{1}{E f^4} P^{\frac{5\pi^4}{512}} \tag{2.2}$$

which becames the Eq. (1).

2. Methodology and materials

Composite processing and modelling requires effective materials characterisation. Testing environments need to be representative of the manufacturing method since the results will used in simulation tools. In this way, it is necessary to understand the main factors affecting the material property and design a test routine that considers these factors. Compaction characterisation for this study was conducted in a similar fashion by Correia [7]. A purpose build machined test rig, (see Fig. 1a) consisted of a matched top moving part and a lower fixed 50 mm internal diameter circular fitting, which were fixed to a dual-column, Instron 5969 tester. For consistency and reflect to previous findings on

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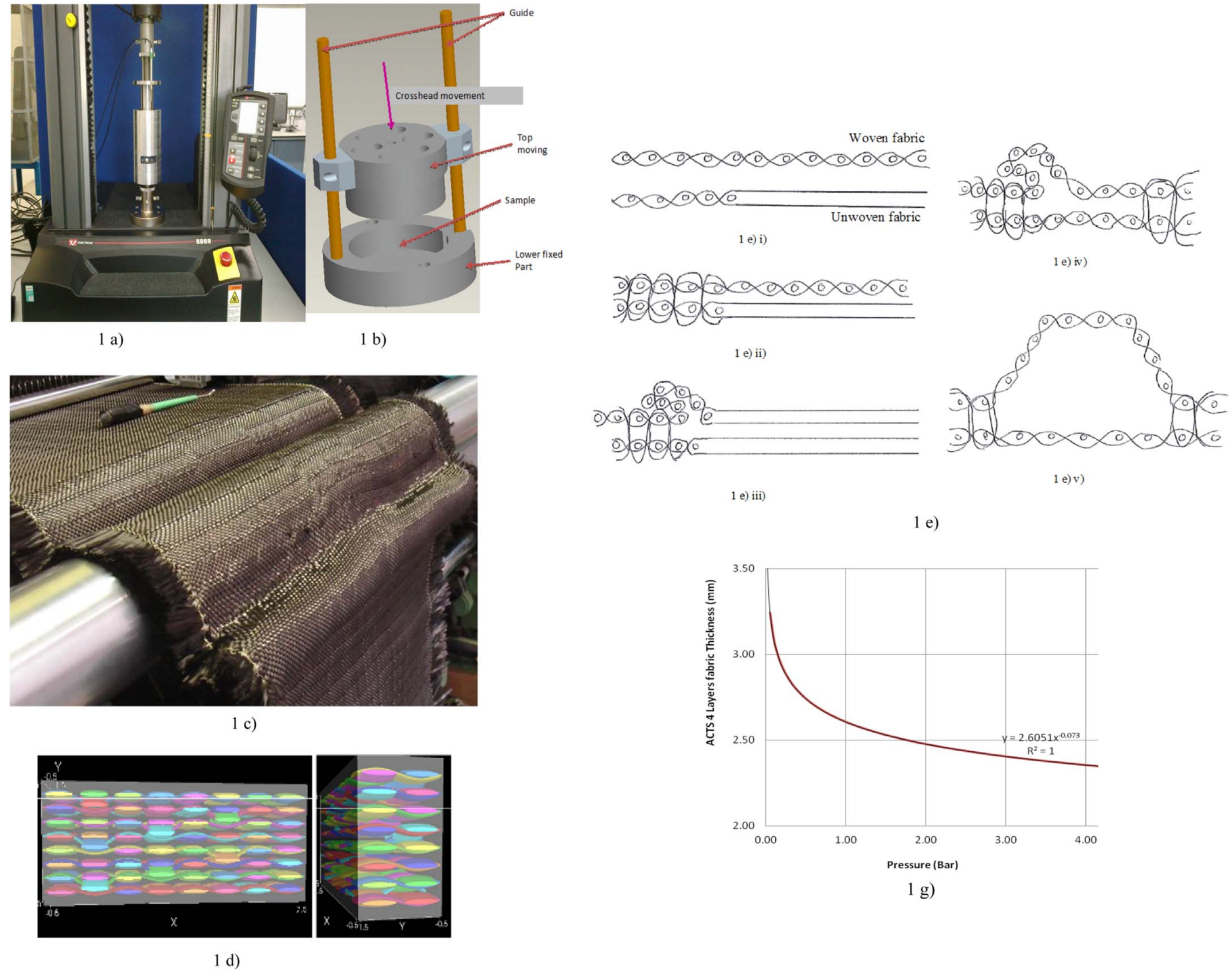

Fig. 1. a) Instron 5969 model compaction testing rig, 1 b) Schematic of fabric compression test, 1 c) Reinforcement used for compaction tests 3D woven made off HTS40 F13, 1 d): Design of the Sigmatex textile used for textile used for compaction and bending measurements. Image generated using Tex-Gen software. X-axis coincides with the weft direction and Y-axes coincide with the warp direction of the fabric, 1 e) i) Shows a fabric which is woven and a fabric which is unwoven, 1 e) ii) Shows a fabric which has 2 layers with the upper portion woven and lower portion unwoven, 1 e) iii) Shows the bound fabric where the upper portion is folded over to form a loop during the weaving process, 1 e) iv) Shows how the material appears after weaving has recommenced with the upper portion longer in length than the lower portion 1 e) v) Shows how the structure could be formed to create a defined cross Section, 1 g) Compaction and fitting equation of the 3D woven layer to layer interlock textile.

layer effects, reinforcement samples were press-cut into 50 mm discs and loaded into the lower fixed plate sample fitting cavity, see Fig. 1a). Dry samples of the novel architecture 3D woven fabric were compacted at a rate of 1 kN/s, from zero to 10 kN static load capacity. An auto-ranging load cell used to measure force as shows Fig. 1b).

To enable the determination of absolute distance (specimen height *H*) between the upper moving plate and the lower fixed plate cavity of the rig during testing, a linear displacement transducer was used in order to calculate the fibre volume fraction at each state of compression according to Eq. (3) Endruweit **[8]**.

$$V_f = \frac{m}{\rho A H} \tag{3}$$

where *m* is the specimen mass, *A* is the specimen area, and ρ is the density of the carbon fibres. The Eq. (3) is an adaptation of the more complete Eq. (3.1) in CRAG method 1000 for the measurement of the engineering properties of fibre reinforced plastics, royal aerospace establishment technical report 88012, February 1988 as presented by Curtis [11].

$$V_f = \frac{n A_F}{\rho H} \tag{3.1}$$

Where n is the number of layers, A_F the aerial weight of the fabric, ρ is the density of the carbon fibres, H the thickness of the laminate.

With the combination of (1) and (3):

$$H_{fabricthickness} = \alpha P^{-\beta} \tag{4}$$

In Eq. (4) the preform thickness *H* is related to a given compaction pressure *P*, where $\alpha = \frac{m}{\rho A}\frac{1}{\alpha_c}$and β are empirical material constants. The instrumentation and materials tested presented in Fig. 1 the material properties in Table 1a) and b).

3D woven HTS40 F13 (Fig. 1c) made from carbon fibres known as Toxo Tenax® HTS40 F13. These are commercial high strength aerospace grade carbon fibres 12k for yarn in warp, weft and binder as shows Fig. 1d). The textile is one layer composed of eight weft yarns with measured thickness of (5.85 ± 0.05) mm made of HTS40 F13 carbon fibres with carbon fibres density ρ = 1760 kg/m³. The aerial mass was calculated as the ratio of mass density, *m*, over surface area, *A*, and it