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Characterisation of random carbon fibre composites from a directed fibre preforming process: Analysis of microstructural parameters

L.T. Harper [a,*], T.A. Turner [a], N.A. Warrior [a], J.S. Dahl [b], C.D. Rudd [a]

[a] School of Mechanical, Materials and Manufacturing Engineering, University of Nottingham, The ITRC Building, University Park, Nottingham NG7 2RD, United Kingdom
[b] Ford Motor Company, Scientific Research Laboratory, P.O. Box 2053, MD 3135 SRL, Dearborn, MI 48121-2053, United States

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Abstract

This paper seeks to quantify the influence of microstructural parameters on the mechanical and physical properties of carbon fibre laminates produced by automated directed fibre preforming. The main objective was to establish whether a correlation exists between local areal density variation and mechanical performance. The parameters studied were fibre length, tow filament count and laminate thickness. A statistical process simulation was developed to predict preform density variation and the results were compared with experimental tensile properties.

In general, consistent preforms with low areal density variations exhibit higher mechanical properties. There was a notable reduction in areal density variation and consequently an increase in tensile properties with shorter fibres (75–25 mm) and thicker laminates (1.5–4 mm for a constant volume fraction). The effect of filament count was less clear. Simulations indicated that filament count was the most significant parameter in terms of areal density variation; with low filament counts improving density variation by up to 50% (6 K compared with 24 K). However, no variation in tensile properties was observed because of a secondary filamentisation effect caused by the fibre surface treatment.

Keywords: A. Carbon fibre; A. Discontinuous reinforcement; E. Preform; A. Tow

1. Introduction

Directed fibre preforming (DFP) is an established process [1] in which chopped glass fibre and an emulsified binder are manually sprayed onto a tool face. The elimination of intermediate fibre conversion reduces costs compared with engineered fabrics, but historically, DFP laminates suffer low fibre volume fractions and poor part consistency compared with competing preforming processes. Automated variants now exist for the production of net shape preforms of higher volume fraction, which address some of the historical limitations. Industrial implementation [2–4] commonly consists of four main stages; deposition, consolidation, stabilisation and extraction (see Fig. 1). A robot-mounted mechanical chopper head sprays fibres and a polymeric, powdered binder onto a perforated tool. Air is evacuated from the underside of the tool and the resulting pressure differential holds the deposited fibres in place. When material deposition is complete, a matched perforated tool is lowered to compress the preform to control the preform thickness. Hot air is cycled through the perforations to consolidate the binder and subsequently ambient air is cycled to stabilise the preform. Finally, the preform is extracted from the preforming station and

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* Corresponding author. Tel.: +44 115 9513823; fax: +44 115 9513800.
E-mail address: lee.harper@nottingham.ac.uk (L.T. Harper).

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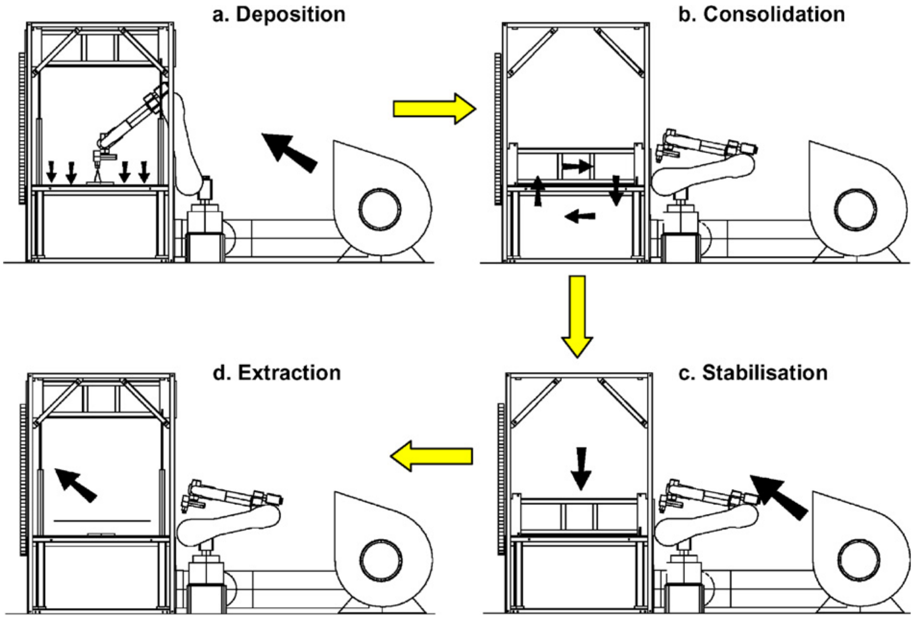

Fig. 1. Directed fibre preforming process schematic.

transferred to a separate moulding station for the injection of liquid resin via conventional means.

Typical processes dispense low-cost fibre (as roving) and with little wastage (<3% by mass). The process is generally automated, has potential for low cycle times (~5 min) and allows the production of complex shapes with reported mass variations of only 2% between preforms [5]. This technology has been further developed within the automotive industry and is currently in use in low-volume applications using glass fibre [6].

Mass reduction potential is limited to 20–30% over steel pressings for typical automotive applications. The substitution of carbon fibre potentially offers 40–60% weight reduction, with significant cost savings over alternative carbon fibre processing technologies [7]. The introduction of low-cost, large tows (>24 K) offers further cost reductions.

The potential of directed carbon fibre preforming (DCFP) for structural applications has been investigated within the aerospace industry [8,9] and in large wind turbine applications [10]. Various mechanisms have been explored to orientate the chopped tows to improve the mechanical properties and to increase fibre volume fractions. However, most result in substantially longer cycle times [11], rendering the methods unsuitable for high throughput applications. Industrial development continues [12–16], but the use of carbon rather than glass reinforcement presents a challenge both from a processing perspective and in terms of mechanical performance. The higher strength and lower failure strain relative to glass fibre increases problems with fibre handling and cutting. Tow damage prior to chopping may lead to fibre blockages and increase machine down-time and material wastage. The low density of carbon fibre creates difficulties in placement, as the transporting air stream tends to disrupt previously deposited fibres, particularly from vertical tool faces.

Local variation in areal density yields inconsistent volume fractions across the laminate and in turn, variation in mechanical properties. Areal density variation is generally mapped by manually cutting and weighing contiguous coupons from the preform, or, as in [17], by measuring light transmission through the preform using image analysis software. Clearly a principal goal in optimisation of the process involves minimising errors associated with uniformity of carbon coverage and improving preform consistency. However, the aspect ratio of larger tows makes it increasingly difficult to achieve uniform coverage for thin laminates. In the present work, a process simulation has been developed to predict the effects of material and process parameters on local areal density variation.

This work aims to quantify the influence of microstructural parameters on the mechanical and physical properties of DCFP composites and to establish whether a correlation exists between local areal density variation and mechanical performance. Experimental results from a state-of-the-art preformer are compared with predictions of coverage from a process model. Structural properties from DCFP laminates are compared with rule of mixtures (ROM) and classical laminate theory (CLT) type predictions.

2. Effects of process variables

A Taguchi orthogonal array was formed to investigate the effect of fibre length, filament count and global areal density (laminate thickness) on the local density variation using a statistical process model outlined below. Five repeat preforms were simulated for each scenario outlined in Table 1. Minitab® v.14 was used to analyse the Taguchi array by performing a general linear analysis of variance (ANOVA) to determine the significance of each variable. A full factorial experimental design was subsequently