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TITLE: Manufacture and Thermoforming of Carbon Fibre Reinforced Thermoplastics Tapes, using Waste Polymer Blends

AUTHOR(S): M. Pitto[1], O. Gordon[1], P. Hubert[2], R. Radjef[3], B. Eisenbart[3], M. Battley[1], T. Allen[1], C.J.R. Verbeek[1], S. Bickerton[1]

AFFILIATION(S): 1 - Centre for Advanced Materials Manufacturing and Design, The University of Auckland, Auckland, New Zealand

2 - Structures and Composite Materials Laboratory, McGill University, Montreal, Quebec, Canada

3 - Industry 4.0 Testlab on Composite Additive Manufacturing, Swinburne University of Technology, Melbourne, Australia

ABSTRACT: New Zealand sends approximately 380000 tonnes of plastics to landfill every year even though our system for collecting and recycling plastics is improving rapidly. A large transdisciplinary team has been funded for 5 years to address some of the problems in this space, encompassing engineering, supply chains, marketing and design, in order to create a new circular market system for plastics in New Zealand. To upcycle waste plastics that would otherwise go to landfill, low temperature atmospheric pressure plasma jets (APPJ) are being used in this program to treat both fibres and thermoplastic matrices, to create microfibrillar composites (MFC) and short and continuous fibre reinforced thermoplastics. The longer-term goal is to create high value composites using difficult or impossible to separate polymer blends from waste sources. This presentation will summarise efforts to develop carbon fibre reinforced thermoplastic prepreg tapes, utilising blend matrices from waste streams. The modelling and development of a slot channel melt impregnation die is discussed, and the quality and performance of tapes, and composites compression moulded from these tapes is presented. Tapes from a second iteration of the impregnation die have been laid up via Automated Tape Placement (ATP) at Swinburne University of Technology (SUT), for an analysis of panel quality and mechanical properties, and for a subsequent thermoforming demonstration. A model waste blend of PA6/PP was applied in this study, with surface treatment of carbon fibre by APPJ being assessed as a low-cost, sustainable method for enhancing fibre-matrix adhesion. A schematic of the prepreg tape line developed at the University of Auckland (UoA) is presented in Figure 1, demonstrating inline APPJ treatment of the CF tow prior to matrix impregnation.

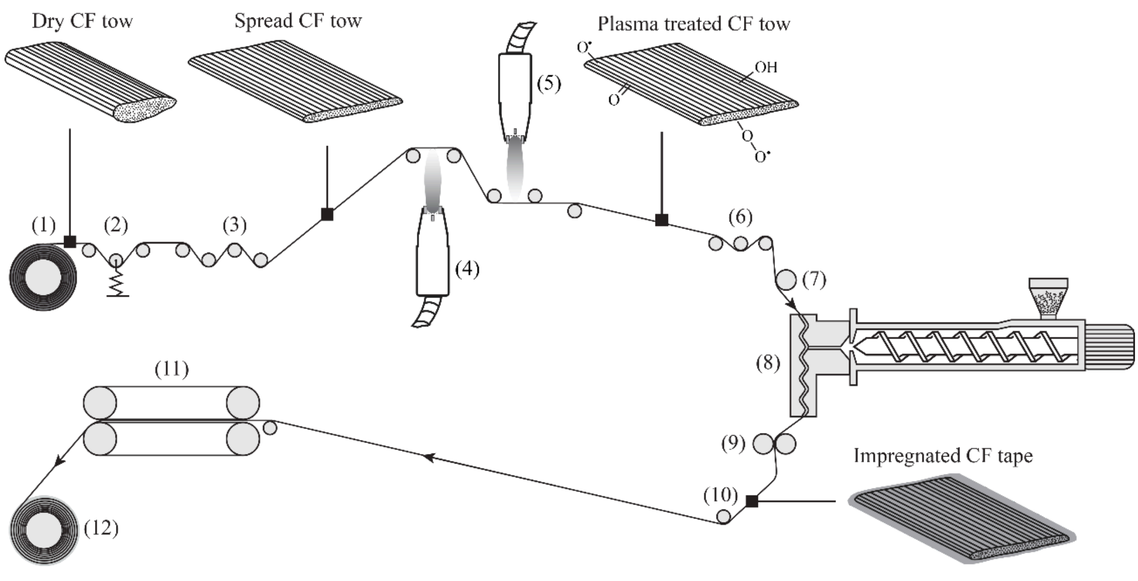

Figure 1: Plasma-enhanced tape manufacturing schematic depicting (1) dry CF tow let-off; (2) pre-tensioning; (3) spreading; (4) plasma surface treatment from below; (5) plasma surface treatment from above; (6) tension measurement; (7) fibre guiding into impregnator; (8) melt impregnation; (9) impregnated tape metering; (10) tape guiding to pulling unit; (11) pulling; (12) take-up.

The impregnation die was designed based on the concept presented by Zhang et al., where melt impregnation is facilitated by pressure gradients at crests, analogous to pin-driven melt impregnation. A semi-analytical model was developed to predict the tape degree of impregnation (DoI) and guide detailed die design. The model framework is depicted in Figure 2. In a cross-head slot channel, polymer melt is driven from the gate to the die exit by a static pressure gradient and drag at the fibre-tow interface. A process model was developed that combines static pressure in the melt, wedge-driven pressure between crests, and crest pressure where fibres mechanically contact the die. This was accomplished by analytically modelling the wedge and crest pressure, while numerically modelling static pressure. Initial tape manufacturing trials were carried out to validate the model, predictions of DoI being presented in Figure 3. Good agreement was found, utilising either of the permeability models proposed by Bruschke and Advani, and Kozeny-Carman.

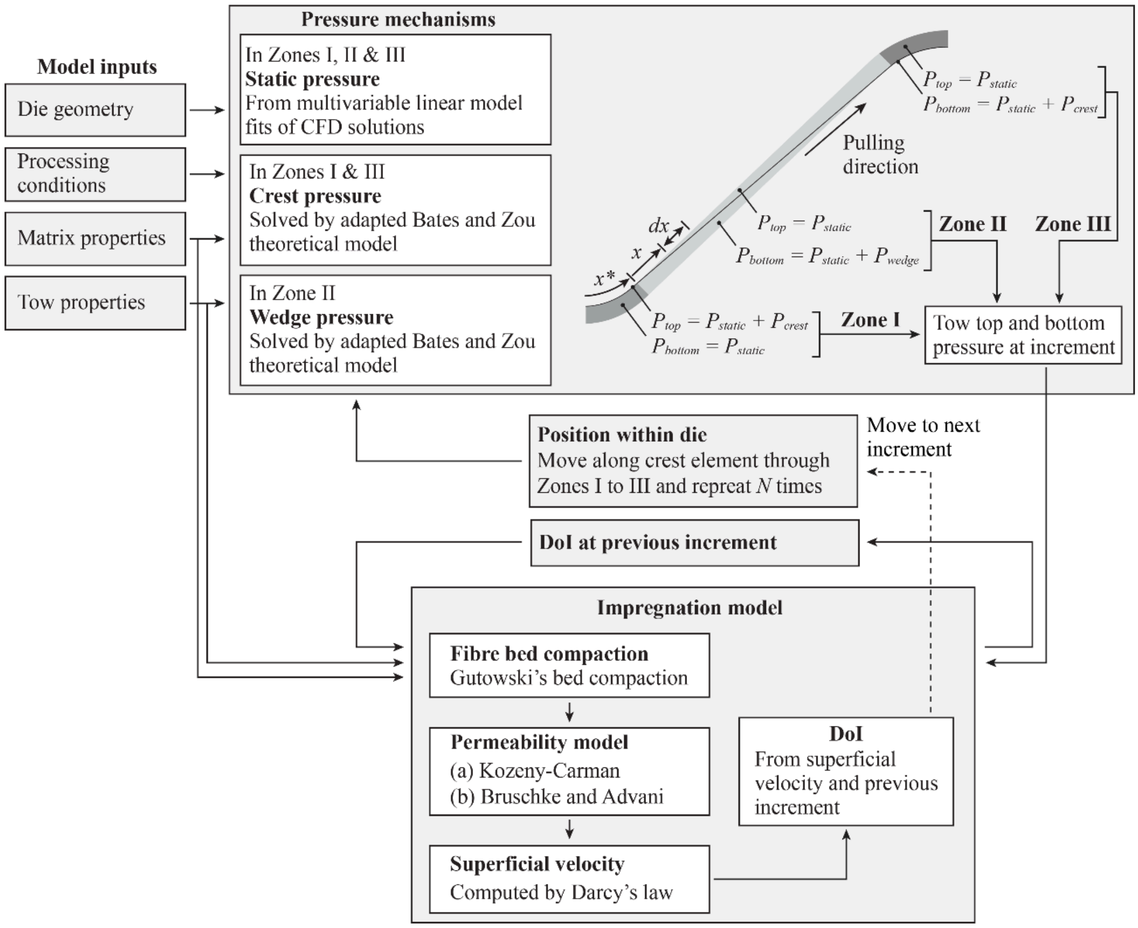

Figure 2: Schematic illustrating the modelling framework used to compute the DoI throughout the repeating slot channel crest where static, wedge, and crest pressure drive polymer into the tow.

Unidirectional composite bars have been produced by compression moulding, utilising PA6, and a PA6/PP (50:50 wt.%) blend as the matrices. At a fibre volume fraction of ~0.3, increases in composite short beam strength of 45% and 90 % were found for PA6 and PA6/PP respectively, as a result of APPJ treatment of the CF tow.

A second version of the impregnation die has been developed to improve the manufacturing resilience. Specifically, die interfaces where fibres could be trapped and break were machined from a solid block. This increased the die complexity but eliminated occasional tow failure experienced by the initial design. Utilising this die, approximately 2000 m of tape with a PA6/PP (50:50 wt.%) blend matrix has been produced for layup and forming trials at SUT. Tape width was maintained between 5 and 6 mm, resulting thickness and fibre volume fraction were ~ 0.3 mm and ~0.3 respectively. Layup was completed on a FILL Multilayer ATP system, with a number of modifications to the tape gripping and guiding mechanisms being required to work with relatively narrow tape. 6 and 12 layer unidirectional stacks, and quasi-isotropic blanks with 0°+45°/90°/-45°/90°/+45°/0° stacking sequences have been assembled, utilising tape with and without plasma treatment of the CF. These blanks were trimmed, and then consolidated to 1 and 2 mm thick panels in a mould heated to 240 °C with a pre-heating, consolidation 1, consolidation 2, and cooling time of 10, 10, 20, and 5 min, respectively. The compaction pressures were 30 and 170 kN. A study of panel quality and mechanical properties will be presented, along with the results of initial thermoforming trials of a 2 mm thick 0°/90° panel. Figure 4 depicts modifications to the ATP equipment, and examples of an as-laid blank, a consolidated panel, and thermoformed part.

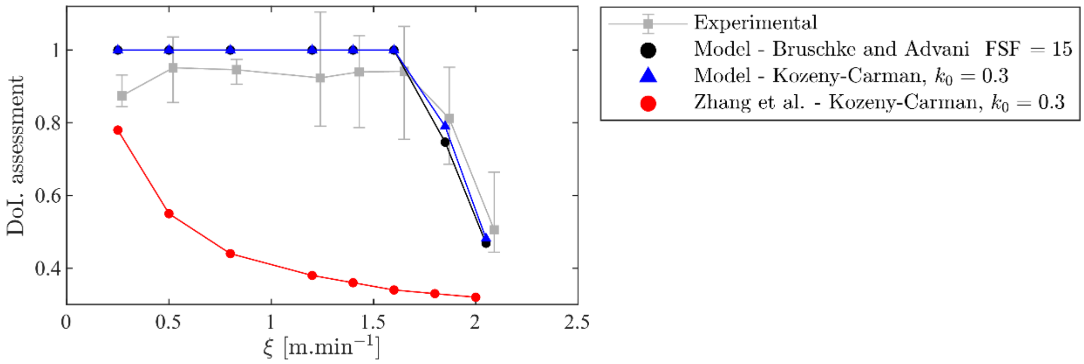

Figure 3: Experimentally determined DoI assessment number for PA6 tapes impregnated at pulling speeds between 0.27 and 2.09 m.min^{-1}.

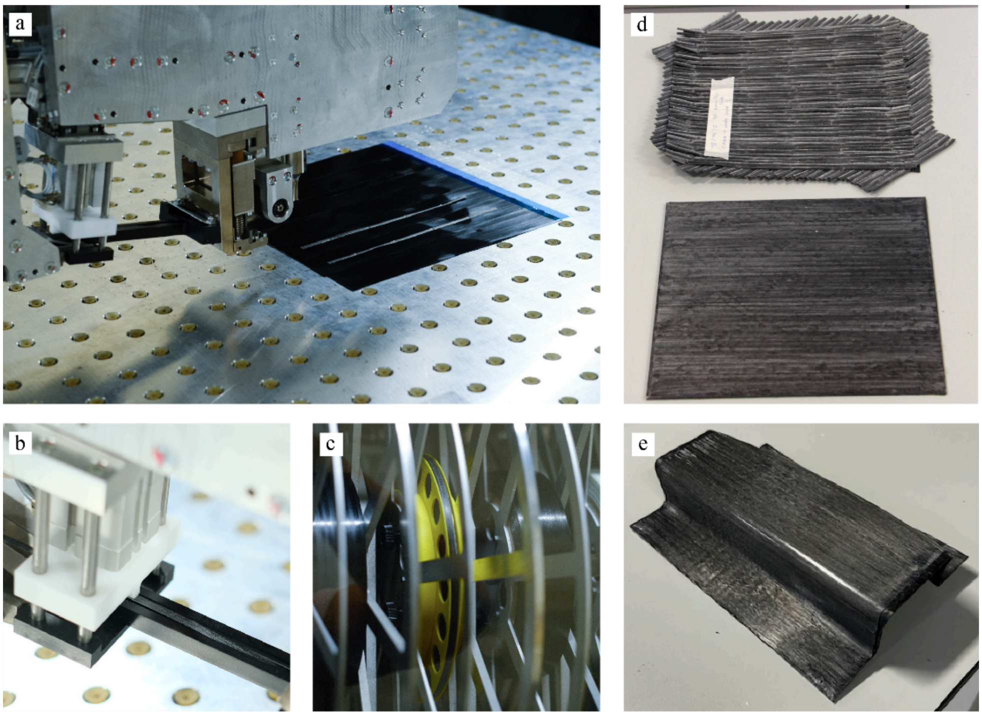

Figure 4: The laying head adapted for 6 mm wide tapes is depicted in subfigure (a) hovering over the GF/PP base layer. A detailed view of the narrow tape gripping and guiding mechanism is illustrated in subfigure (b). 3D printed spools, shown in subfigure (c), were loaded to feed the narrow tape into the gripping mechanism. (d) Example of an as-laid blank and consolidated panel, and (e) a thermoformed demonstrator part.