LIQUID COMPOSITE MOULDING FLOW FRONT CHARACTERISATION BY MICRO-CT

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Introduction

Liquid composite moulding (LCM) is an increasingly common technique used to manufacture large scale composite structures in multiple transport industries. The vacuum assisted resin infusion (VARI) process is especially popular due to the reduced tooling costs; however the increased variability of LCM processes over other composite manufacturing techniques can result in reductions in part quality. A number of causes are known to produce and manipulate void volumes during the LCM, one of the critical parameters involved is the dual scale permeability of the fibres. Resin flow into dry fibres during LCM of large structures is highly non-uniform due to the isotropic nature of composite materials and strongly influences part quality. A number of point and distributed monitoring techniques exist to identify and record the resin flow front: thermocouples, dielectric, ultrasonic, fibre optics, pressure transducers, thermal imaging, SMARTweave and linear variable differential transformers [1]. However a fully three dimensional technique is required to carry out a full characterisation of the advancing flow front to aid infusion strategies and to validate the increasing number of computational flow models. An experimental investigation was performed using an X-ray microtomography (μ-CT) scanner to provide a three dimensional characterisation of the advancing flow front, void production/distribution and progression.

Background

For decades yacht manufacturers have utilized the advantages of the VARI process to improve working conditions, composite quality, repeatability and reliability over the traditional manufacturing processed. However due to the limited driving force and high parametric and environment variance between infusions, structural and surface quality variations are common [2]. More recently significant effort has been placed on computationally modelling to improve part quality; however there is still a need to provide three dimensional characterisation of the impregnation process. The accuracy of the commutation models are directly linked to the accuracy of the input data obtained through experimental tests, or CFD simulations which equally require experimental validation.

μ-CT is an experimental technique used to obtain three dimensional information of a material utilising a series of X-ray radiographs taken through a 360^0 rotation. X-rays radiate through the sample, attenuate proportionately to the material density creating a shadow projection of the microstructural information [3]. The μ-Ct technique can be used to capture the resin impregnation of the dry fibres during an LCM infusion.

Methodology

Non-crimp glass fibres and polyesters resin used in the marine industry were investigated through partial processing of the infusion to a known flow front locations. A 60mm diameter mould was used so that a 1:1 depth/breadth aspect ratio was achieved to reduce scan times for a monolithic laminate with a length of 450mm and a perceived infusion width of 160mm. To freeze the flow front the resin inlet and vacuum were closed for a period of 20 minutes whilst the scans were carried out. A heat shrink tube was used to replace the vacuum bag, whilst heat shrink tape was used to constrict the expansion of the preform during the scan period where any leaks would result in changes in preform thickness. The μ-CT scanner field of view was restricted to 100mm which was fixed whilst the flow location was scanned at 20mm intervals to obtain three dimensional microstructural data of the advancing flow front and associated voids. This data was used to investigate the initial microstructure of the fibres and measure impregnation at each processing stage and the evolution of macro voids within the laminate. Volume separation was achieved though segmentation of the grey scale histogram allowing for the identification of the resin, gas and fibre volumes.

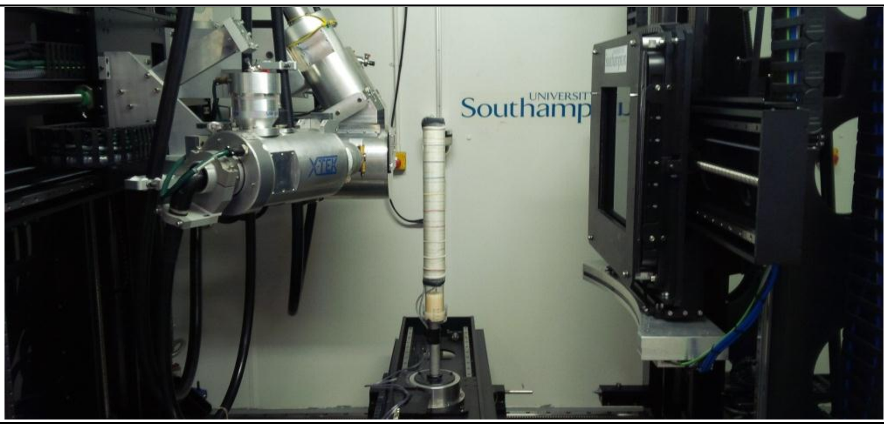

Figure 1: μ-CT in-situ LCM experiment.

Results

The extracted resin volumes highlighted the high level of non-uniformity of the resin progression through the preform. The results clearly illustrate the dual scale fingering effects of the advancing flow front at non-optimal modified capillary numbers as well as the effects of converging flow fronts on fibre impregnation. A large variation between the location of the surface flow front and the sub surface flow was also identified questioning the reliability of the commonly used technique of flow strategy implementation through flow front visual detection, highlighting the need for embedded sensors.

Conclusions

A methodology has been devised to carry out a three dimensional resin infusion characterisation using a μ-CT scanner. The results highlight the risks associated with a non-optimal resin velocity causing micro voids as a result of the dual scale flow effects.

References

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