EXPERIMENTAL VALIDATION OF PROCESS SIMULATIONS FOR VACUUM-BAG-ONLY PREPREGS IN THICK-SECTION STRUCTURES

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Introduction

Manufacturing thick-section structures from thermoset-based composites can be challenging due to the exothermic curing reaction. With a low thermal conductivity through the thickness, thermal gradients can develop within the thick structure, leading to processing defects such as warpage. Previous work has focused on developing process models for thick-section composite manufacturing using low-exotherm epoxy powders [1, 2]. These powders are combined with a reinforcing fabric to form a low-cost vacuum-bag-only (VBO) prepreg which contains little or no volatiles, can achieve low viscosities, and has a long out-life (> 4 months) [3]. The challenge of these materials is that powder introduces bulk initially and a thick laminate undergoes significant thickness reduction during processing. Consequently, heat transfer and thickness change are coupled in the process models. To ensure that the models are accurate and that they can be used to help manufacture thick-section components, it is necessary to validate the models against controlled experiments.

Experimental methods

An experimental apparatus, shown in Figure 1, was designed and built to validate an existing process model for one-dimensional (1D) heat transfer and resin flow. The temperature is measured at several locations both in-plane and out-of-plane (i.e. through the thickness) using K-type thermocouples. The thickness change due to powder compaction and resin flow is measured using a linear variable differential transformer (LVDT). Two types of material arrangement were tested: Test 1, 48 plies of stitched uni-directional glass-fibre (GF) with epoxy powder manually dispersed between each ply; Test 2, 44 plies of triaxial GF semi-preg (a stitched fabric that is partially impregnated with epoxy powder).

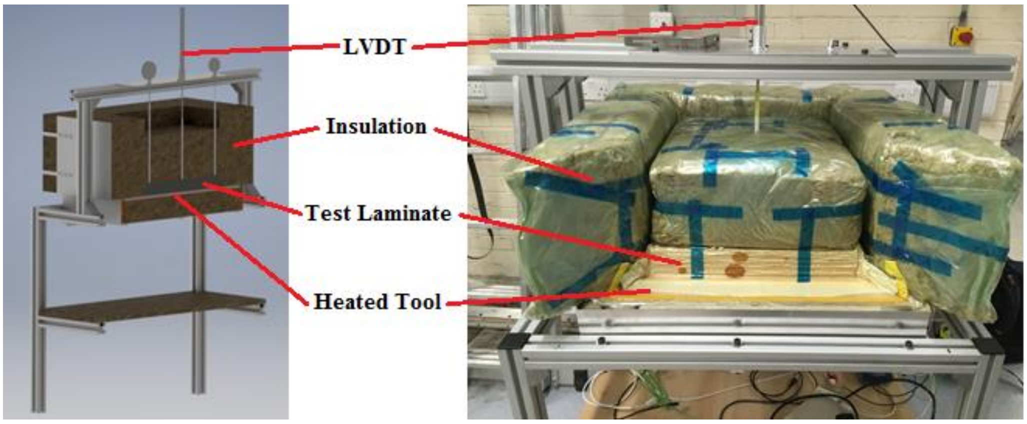

Figure 1: *(L) A 3D rendered illustration showing a cross-section of the experimental apparatus. (R) The experimental apparatus after manufacturing a 58 mm thick laminate (Test 2).*

Results

The experiments were successful in measuring both the thickness change and the temperature through the thickness of the laminate. For test 1 a significant thickness change was measured due to the melting of the powder, whereas the powder was pre-melted for test 2. At elevated temperatures

temperatures (above 55°C), both test laminates showed similar behaviour with a steady decrease in thickness as resin flowed into the fibre bundles. It was found that the in-plane temperature gradient was negligible and the boundary conditions of the experiment could be assumed to match those of the 1D process simulations. As shown in Figure 2, close agreement between the simulations and experimental data was achieved for test laminate 1 (analysis of test 2 is ongoing). For powder compaction, a basic statistical model for powder melting was implemented [4] and worked well as a first approximation. Both the tests and the simulations show little or no temperature overshoot due to the exothermic reaction, however, through-thickness gradients persist due to the insulating properties of the material.

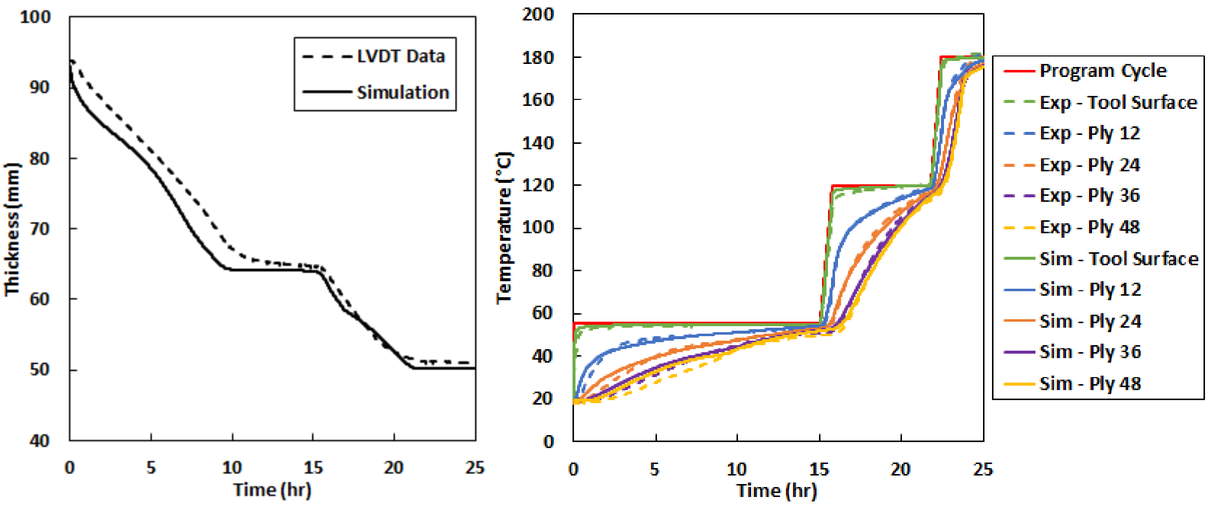

Figure 2: *Comparison of experimental results and simulation data for test laminate 1: (L) The thickness of the laminate changes as the powder melts, compacts, and then flows into the fibre tows. (R) Heat transfer through the powder is particularly slow, but becomes faster as the thickness reduces and cure initiates (generating a small exotherm).*

Conclusions

The experimental apparatus was successful in validating the existing process models to the extent that the manufacture of a thick-section laminate could be described with relatively good accuracy. The results show that there is significant thickness reduction in terms of powder compaction (test laminate 1) and resin flow (test laminates 1 and 2). Heat transfer through the thickness is slow and large temperature gradients can be developed. The process models will help to determine conditions under which those gradients can be reduced.

Further work is required to develop an accurate model for powder compaction, and the resin flow model should be augmented to account for the pressure sharing effect of the fibre bed at high degrees of impregnation [5]. In addition, the effects of large temperature gradients would be better understood with the implementation of a model for residual stresses due to cure shrinkage and thermal expansion.

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