CONSIDERATIONS FOR LAYER-BY-LAYER MANUFACTURING WITH SNAP-CURE THERMOSET PREPREGS

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Abstract

Purpose of the research

Layer-by-layer manufacturing is an automated additive technique combining the three usual processing steps (deposition, consolidation and curing) into one. This in-situ consolidation method is already common for thermoplastics but is not applied to thermosets, due to the challenges of obtaining suitable heating conditions, currently too long for dynamic processes. Snap-cure thermoset prepreg materials may provide a way forward but need extensive characterisation to assess their suitability to situations where the material is heated and compacted during lay-up.

The experimental investigation on snap-cure prepreg compaction presented here was done to understand the behaviour in various processing conditions. Numerical simulations were also performed, to predict the consolidation of the samples during compaction as well as the evolution of the viscosity, degree of cure and cured ply thickness. Another focus of the study was the analysis of the process-induced defects. X-ray Computed Tomography (CT) was used to evaluate the levels of porosity. It was necessary to assess the density and distribution of voids after the experiments, to ultimately be able to define guidelines to optimize the manufacturing method and control the parameters better.

Indeed, recent studies using both the layer-by-layer (LBL) curing technique and snap-cure material point to the necessity to optimize the process variables to achieve better laminate quality [1]. The use of the simulation model is expected to help reduce the need for time-consuming characterization tests, while offering a reliable estimation of the final thicknesses.

Methodology

The manufacturing considerations of an automated deposition system (heat application, roller pressure and deposition speed) were replicated by a setup of heating plates installed on an universal Instron machine. Two types of samples were prepared, all with a 0/90° cross ply configuration: the 'Bulk' samples, with all plies laid before the tests, and the 'Ply-by-ply' samples, where a new ply was added to the stack after each cycle. In both cases, specimens of 5 plies and 10 plies were made and tested at temperatures ranging from 100 to 160 °C. X-ray CT scans were performed on the compaction area, at a resolution of 25 microns, for porosity analysis. Microscope images were also taken, for microstructure analysis.

The simulation model used has been previously described in [2]. To track the evolution of the ply thickness, the model takes into account the processing parameters (pressure, time and temperature) and the uncured material's characteristics (sample's dimensions and volume fraction). Then, the material is defined by its viscosity, cure rate and degree of cure and processed through the fully coupled cure and compaction simulation. The model tracks the evolution of the ply thickness throughout the compaction cycle and determines the final thickness of the sample.

Main findings and conclusions

The temperature had noticeable influence on the samples' thickness, width and porosity evolution (Fig.1, left). The CT scans reveal evidence of both resin squeezing and bleeding. Their respective effects are believed to be controlled by the increasing temperature and resulting changes of viscosity. The consolidation process was facilitated by the compaction, but hindered by the evolving degree of cure. At 100°C, the resin had time to flow long and across the fibres, leading to a thin (2.90 mm) barrelled sample, with low porosity (0.52%). At 160C (Fig.1, centre and right), the curing happened faster than the resin could flow, leading to a thick (3.97 mm) but straight sample, with high porosity (4.34%) and surface defects. Thickness is also mainly related to the presence of voids. This suggests not using high processing temperatures despite the appeal of fast production rates. Furthermore, as depicted in Fig. 2, there seems to be a good agreement between the material's experimental behaviour and the simulations results. The dashed line shows the linear evolution that would have occurred if each ply attained the theoretical cured ply thickness, but both the experiments and simulations show a stack thinning behaviour that can be linked to the substrate's compliance.

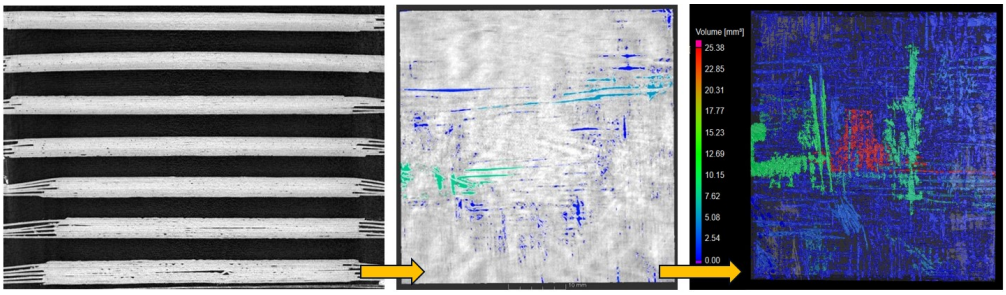

Figure 1 : X-ray CT scan of ply-by-ply compacted samples and observation of process-induced defects – (Left) Samples thickness and width evolution - Side view, (Centre) 160°C sample - Top surface view, (Right) Through thickness view of defects, with void volume highlight

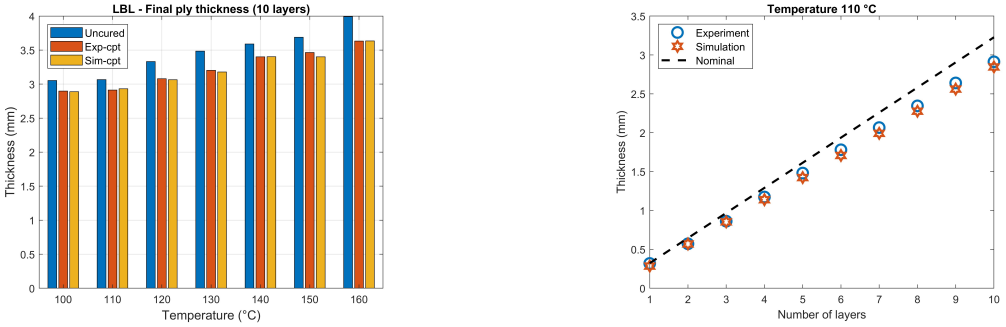

Figure 2 : Experiment vs. Simulation Model output - (Left) Sample thickness at temperatures ranging from 100 to 160°C for uncured (blue), experimental (red) and simulation cured ply thicknesses (yellow), (Right) Cured ply thickness at 110°C for different number of plies

The analysed snap-cure thermoset prepreg appears to be reactive enough for the desired one-step process. A correct control of the process parameters is however still vital to guarantee laminate quality and the model's output provides a detailed depiction of the ply thickness evolution, offering valuable insights into the material's behaviour under various processing conditions.

References

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