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VARIABILITY IN AEROSPACE VARTM PROCESSING

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ABSTRACT: Vacuum-Assisted Resin Transfer Molding (VARTM) is widely used for large-scale composite manufacturing of civil and defense applications. Here, the infusion process reduces part costs due to a decrease in labor, material and equipment expenses compared to other composite manufacturing techniques. However, in order to replace conventional manufacturing methods for aerospace-quality parts such as autoclave processing, the VARTM process repeatability and part quality must be improved. This research is evaluating the influence of incoming material and processing condition on final part quality for three dominant VARTM process variations.

INTRODUCTION

Vacuum-assisted resin transfer molding (VARTM) has the potential advantages of relatively low cost with sufficiently high volume fractions of reinforcement and can be readily applied to large-scale structures. However, for many aircraft applications, VARTM does not currently provide sufficient repeatability or control of variability. In order to routinely produce VARTM parts of aircraft quality, the key factors of variability must be understood. This will enable the long-term objective of repeatable properties (property/weight) that are close to autoclave processed part levels at a lower cost.

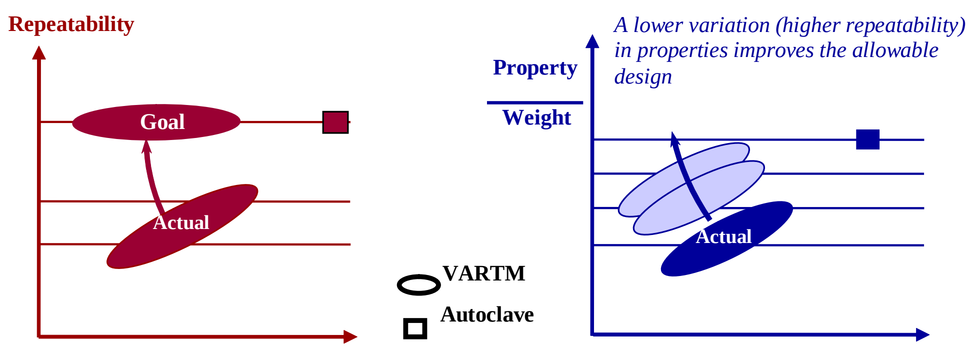

Figure 1: VARTM has the potential to reduce cost with equivalent repeatability compared to autoclave processing

There are many factors that influence the variability of the final part. The factors that play a major role in the cause of this variation need to be identified and the causes and effects of changes in these factors understood. Three main VARTM process variations have been considered: 1) The SCRIMP process [1], patented by TPI Composites is a vacuum infusion process using a high-permeability layer to rapidly distribute the resin on the part surface and then allow through-thickness penetration, 2) The CAPRI process [2], patented by Boeing Co. is a SCRIMP variation where a reduced pressure difference is used to minimize thickness gradients and resin bleeding, 3) The VAP process [3] is another SCRIMP variation, patented by EADS where a air-permeable membrane is used on top of the distribution media to allow continuous and areal venting reducing void content and creating a robust process variant.

VARTM PROCESS COMPARISON

UD-CCM's models [4,5] are used to investigate the effects of processing parameters and different processing scenarios on variation of resin flow, resin pressure and thickness variation of the composite laminate. The important material parameters include the permeability of the preform and distribution media for flow prediction as well as the compaction behavior to characterize dimensional tolerances. A new apparatus has been developed at UD-CCM [6] allowing measurement of the transverse permeability as a function of compaction and debulking cycles using both gaseous and liquid flow. The experimental cell provides insight into the variability of the incoming material and provides the needed understanding of the material changes during debulking to fully understand the CAPRI process. Figure 2 shows a typical compaction and permeability curve for a plain-weave preform subjected to debulking. An 80%-90% reduction in permeability is observed as well as a 4-5% decrease in thickness after 200 debulking cycles increasing significantly the fiber volume fraction in the part.

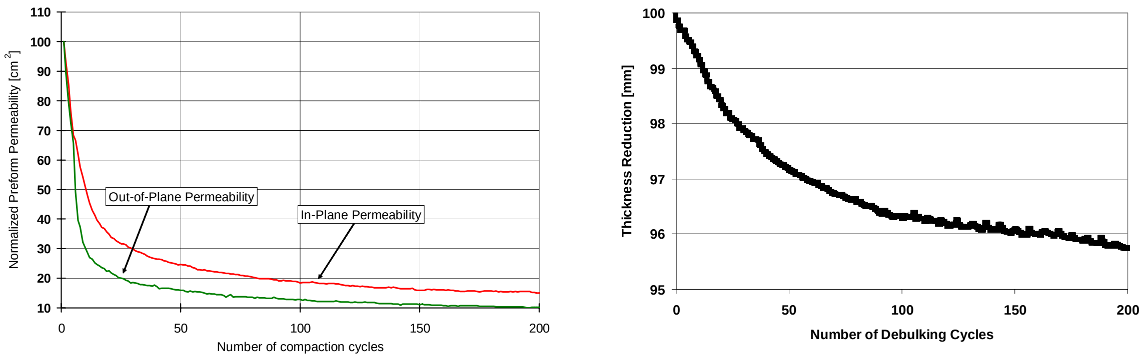

Figure 2: Debulking alters the thickness and permeability of the incoming reinforcement

All VARTM processes apply vacuum across the infusion and vent gates allowing resin flow into the reinforcement and compaction of the preform. The resulting pressure gradient during injection reduces the compaction pressure near the injection line and increases the thickness of the preform and reduces fiber volume fraction. After full infusion the pressure and thickness gradient can be reduced during a subsequent resin bleeding step. Models have been developed to predict the dimensional tolerances as a function of material parameters and process setup and can be used to optimize the CAPRI pressure during infusion and the required gel time and/or vacuum pressure during resin bleeding to minimize the final part thickness variation. Figure 3 shows the benefit and disadvantage of the CAPRI setup compared to conventional VARTM processing. The final cured part thickness is greatly reduced due to the vacuum debulking of the preform while the gradient is minimized with the application of partial vacuum in the infusion bucket. Nevertheless, a potential disadvantage is the increase in infusion time due to the reduced pressure gradient and reduced permeability of the fabric.

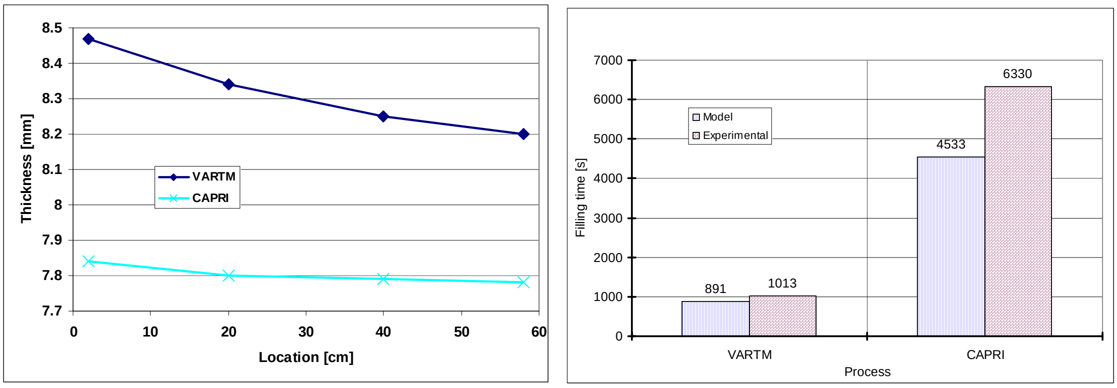

Figure 3: The CAPRI process improves fiber volume fraction and dimensional tolerances while increasing processing time

The VAP process provides an alternative approach to reduce variability. The air-permeable, resin-proof membrane allows application of continuous vacuum compaction on the complete surface even during infusion reducing the thickness gradient. The membrane also enables a more robust VARTM process that minimizes/eliminates the potential for dry spot formation and lowers void content due to continuous degassing of the resin during impregnation. Here, volatiles generated during processing can escape through the membrane layer and reduce the void content well below 1% for typical epoxy resin systems. Research has shown, however, that this innovative solution works only when the resin and membrane are compatible. For example, current membrane material supplied by W. L. Gore & Associates GmbH is effective with epoxy resin systems but inadequate for vinyl-ester systems, which have high styrene content. To fully control the membrane-based process and extend its use to a wider range of resins, a fundamental understanding of compatibility issues is currently developed.

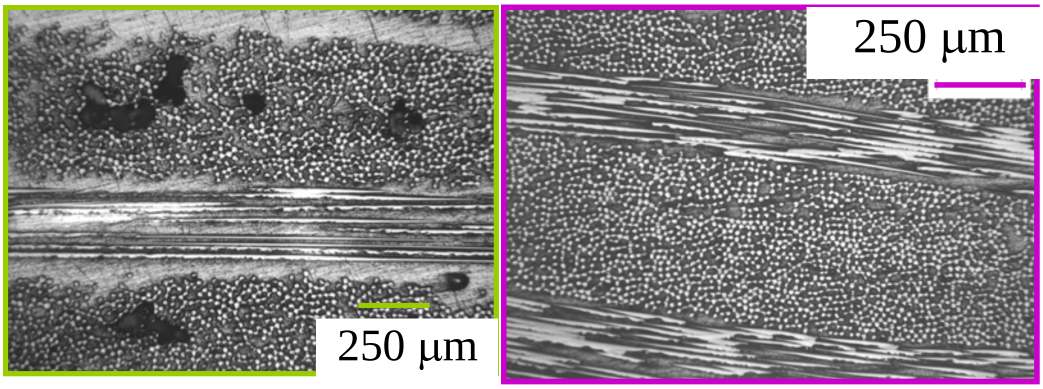

Figure 4: Vinyl ester part on the left shows high void content versus below 1% for the epoxy part

Automation is also key to improve repeatability of the VARTM process [7]. UD-CCM has developed the SMARTMolding Intelligent Process Control (IPC) system which has been implemented at various companies for production of VARTM components. This approach enables material, process, and part traceability along with semi-automated material lay-up, automated debulking and resin mixing, and resin infusion and control of dwell times and cure cycles. The automation capabilities enable monitoring of cycle times for all processing steps, sensing of the important process parameters through embedded sensors and QA/QC of the complete process.

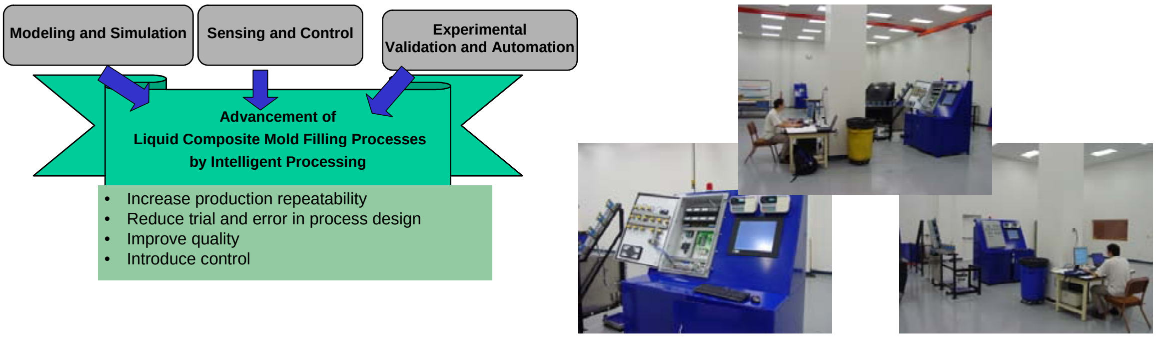

Figure 5: Industrial hardened automation is available to provide QA/QC of the VARTM process

SUMMARY

The VARTM process is poised to penetrate the aerospace market. New process developments and a better fundamental understanding of the process allow part fabrication with improved dimensional tolerances and good mechanical properties at reduced total fabrication cost. Typical fiber volume fraction of above 55% with below 1% void content can be repeatable achieved bringing it close to autoclave properties. In addition, the material suppliers have commercialized new toughened resin systems and non-crimp fabric materials. Automation is also available to reduce the expert's input currently required to fabricate components. Still, continued research is on-going to allow for a better understanding of the infusion process in particular when the system is scaled up to large and complex geometry components.

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