Army Research Laboratory

Research Update for: A Method for Out-of-autoclave Fabrication of High Fiber Volume Fraction Fiber Reinforced Polymer Composites (ARL-TR-6057)

by Larry R. Holmes, Jr.

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14. ABSTRACT
In an update to previous research, we have been increasing the fiber-volume fraction by Vacuum Assisted Resin Transfer Molding (VARTM) in order to produce composite structures with aerospace grade qualities. Of specific focus is the control of processing parameters during resin infusion to obtain fiber-volume fractions like those of autoclave processed composites. Using a combination of viscosity control, U.S. Army Research Laboratory (ARL) based VARTM techniques, and a pressure control system, we have shown an increase in fiber-volume content from 50% (ARL's normal processing range for a particular material system and VARTM process) to over 60%. Future work will focus on continued processing improvements in order to achieve 65% fiber-volume fraction with this material system. It is shown that the increase in fiber-volume fraction provides for higher strength to weight ratios in composite parts while cutting the cost of fabrication. Processing characteristics will be presented, and evaluations will be discussed.

15. SUBJECT TERMS
composite processing, composite fabrication, microcomposite, rapid prototyping

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1. Review of Previous Work

It was shown in technical report ARL-TR-6057 titled *A Method for Out-of-autoclave Fabrication of High Fiber Volume Fraction Fiber Reinforced Polymer Composites*, that a method for producing thick cross-section fiber reinforced polymer (FRP) composites with a fiber volume percentage of above 60% can be accomplished with an out-of-autoclave technique. The U.S. Army Research Laboratory's (ARL) standard processing method for 813 g/m^2 (24 oz/yd^2) 5 × 5 plain weave S2 fiberglass with SC-15 epoxy resin allowed for the fabrication of thick cross-section composites with an approximately 50/50 fiber to resin ratio. This is accomplished with an infusion time of 30 min for a 61 × 61 × 1.3 cm (24 × 24 × 0.5 in) laminate after a 12 h debulk cycle under 95 kPa (14 psi) vacuum. Using a hydraulic press, the 12 h debulk cycle is replaced with a 241 kPa (35 psi) compaction of the preform that is accomplished in less than 10 min. The press is heated, and in turn the preform is heated, to a temperature allowing for viscosity control of the resin, and optimal infusion. The resin is heated to the same temperature to ensure infusion time is completely optimized. For this system, the optimum infusion temperature was determined to be 48.9 °C (120 °F). Once compaction of the preform and infusion dynamics were optimized, the resulting thick cross-section composite laminates had an average fiber volume percentage of 60.4%. This represents a 20.6% increase in fiber volume fraction (FVF) over our current state-of-the-art processing techniques for this material system. The average infusion time increases by 2 min, as compared to the control, but the overall processing time is decreased by the elimination of a long debulk under vacuum.

FVF data was collected from at least three sample sets for each of the processing parameters described in the previous work can be seen in figure 1. It is shown that Sample Set 4 provided for a high FVF composite that was fabricated while maintaining low void content. Also, the low standard deviation suggests a high level of repeatability.[1]

[1]Holmes, Jr., L. R.; Wolbert, J.; Gardner, J. *A Method for Out-of-Autoclave Fabrication of High Fiber Volume Fraction Fiber Reinforced Polymer Composites*; ARL-TR-6057; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, June 2012.

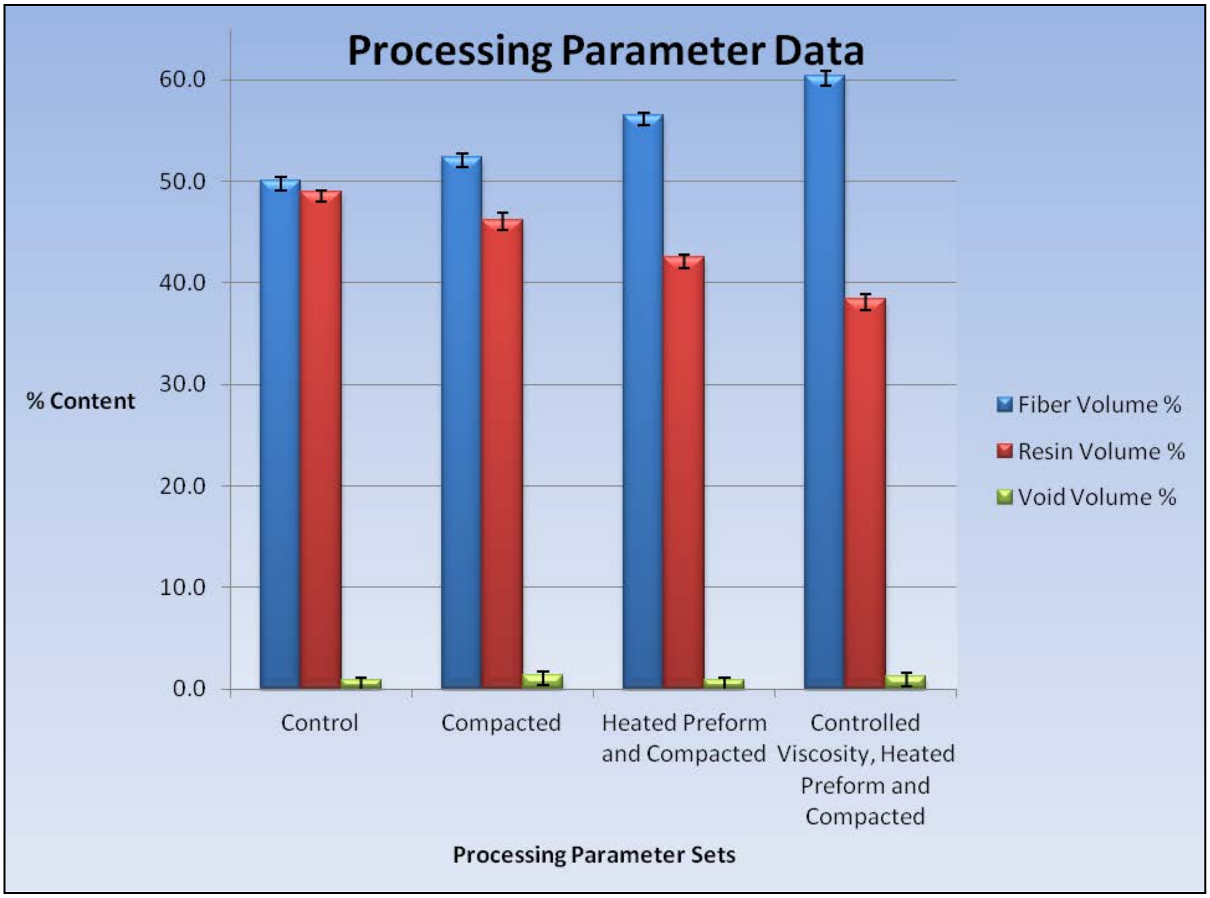

Figure 1. Percent fiber, resin and void content of experimental sets based on their respective processing parameters, including standard deviation.

2. Update of Mechanical Testing

Mechanical evaluations were carried out according to the American Society for Testing and Materials (ASTM) standards D 3039 (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials), and D 790 (Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials).[2,3] Stiffness measurements are shown in figure 2. This figure compares the tensile modulus of the control

[2]ASTM D 3039. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. *Amer. Soc. for Testing and Mater*. **2008**.

[3]ASTM D 790. Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. *Amer. Soc. for Testing and Mater.* **2010**.

specimens versus the high FVF specimens with controlled viscosity, heated preform, and forced compaction. The figure also compares specimens sectioned from the flow side of the infused composite panel versus the vacuum side of the composite panel. It can be seen from the graph that the high FVF specimens have an increased tensile modulus as compared to the control specimens. The maximum increase is observed by comparison between the samples from the vacuum side of each sample set, where the high FVF samples have an increased tensile modulus of approximately 23.5%. The mean increase in tensile modulus is approximately 10.0%.

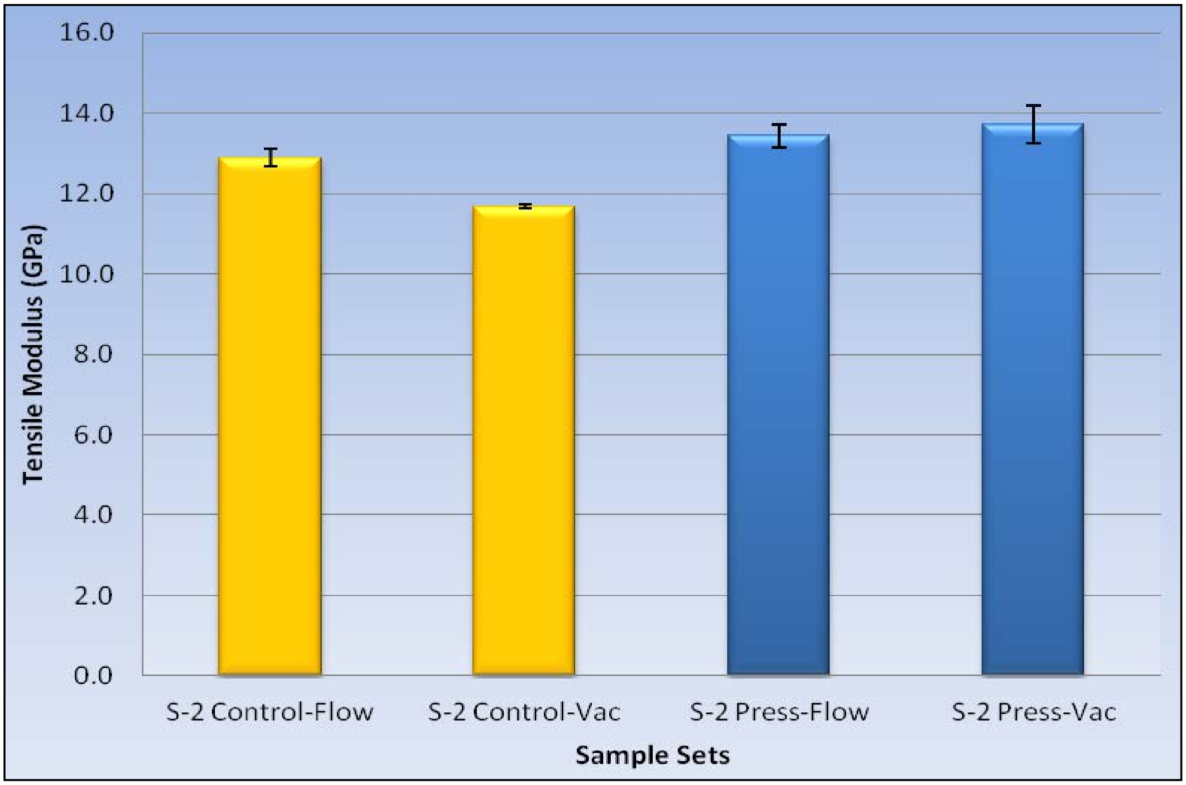

Figure 2. Tensile modulus of samples evaluated using ASTM D 3039.

The tendency for the materials to bend was also evaluated during flexural deformation, which can be seen in figure 3. As seen in this figure, the flexural modulus of the high FVF specimens is greater than that of the control samples. The maximum increase in flexural modulus is approximately 40.0%, and the mean increase is approximately 19.2%. There was a greater standard deviation of the high FVF samples in the flexural testing as compared to the control. However, even with the standard deviation taken into account, the Press Vacuum Assisted Resin Transfer Molding (VARTM) samples had a minimum increase in flexural modulus of approximately 8.1%.

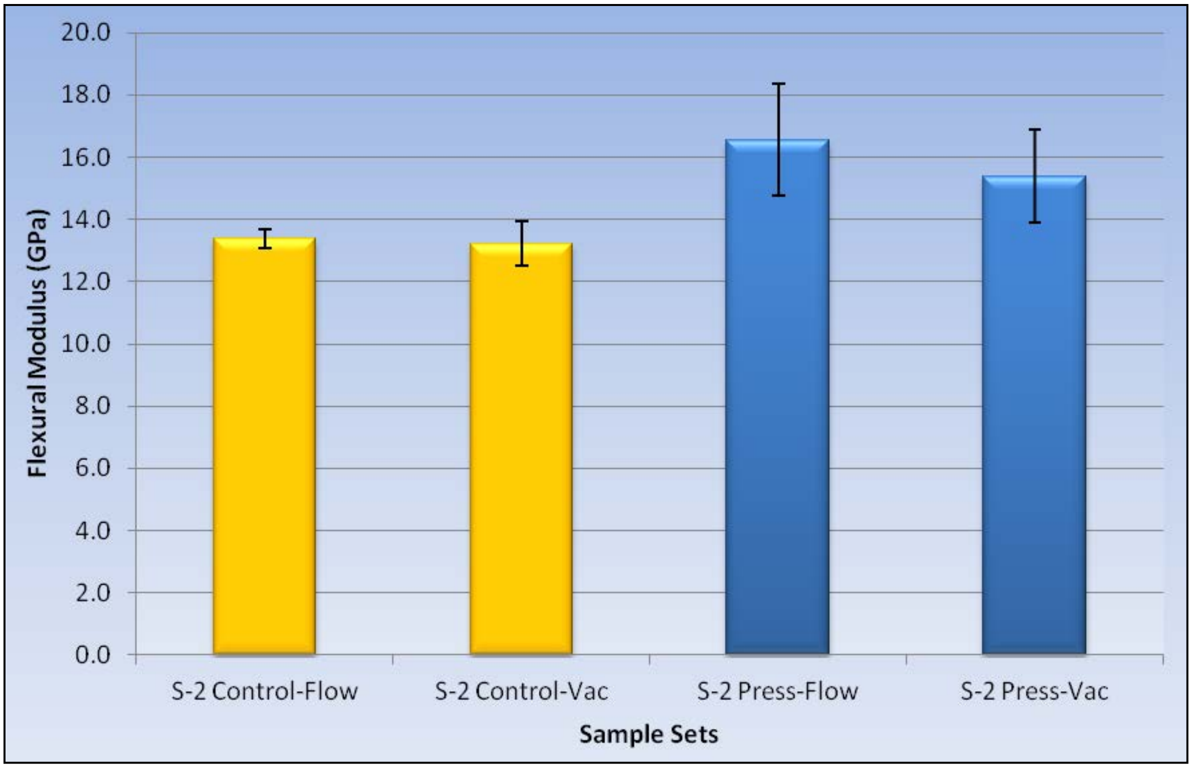

Figure 3. Flexural modulus of samples evaluated using ASTM D 790.

3. Conclusions

It has been shown that the high FVF composite samples exhibit increased mechanical performance over the current processing standard (control). An increase in tensile modulus of approximately 23.5%, and an increase in flexural modulus of approximately 40.0% have been recorded. Standard deviation of the evaluated samples is minimal, which suggests high repeatability. The high FVF samples also showed little variation in tensile modulus across the composite plate, from flow side to vacuum side. However, there was a significant drop in tensile modulus of the control samples on the vacuum side versus the flow side of the composite. This trend did not follow in the flexural modulus tests.

From these mechanical evaluations, it appears that the forced nesting of the compaction process did not induce degradation or fiber breakage and was not detrimental to the composite. The void content was increased from 0.9 % in the control samples to 1.2 % in the high FVF samples, but no negative impact was determined through quasi static mechanical evaluation. It has been shown that there are significant mechanical performance increases with the higher FVF samples. Further mechanical evaluation will study the ultimate strength of the high FVF composite samples as compared to the current processing standard samples. The structural integrity of the fiber before and after nesting will be analyzed. Impact experiments will also be conducted, and experimentation will continue in order to determine the optimum FVF attainable using this technique for this material system. Validation of experimentation will be conducted and tested for other material systems.

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