

**A Fully Contained Resin Infusion Process for
Fiber-Reinforced Polymer Composite
Fabrication and Repair**

by Larry R. Holmes, Jr.

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14. ABSTRACT In laboratory or manufacturing conditions, the Vacuum-Assisted Resin Transfer Molding (VARTM) process is applicable for fiber-reinforced polymer (FRP) composite fabrication and repair. However, VARTM is not optimal for in-field processing or repair due to the precision required in measuring and mixing, and the need to remain contaminate free. Current repair constraints require damaged FRP composites to be returned to repair depots resulting in excessive cost. One solution to this costly scenario is a fully enclosed VARTM system that limits the need for laboratory or manufacturing equipment. The Bladder-Bag VARTM (BBVARTM) technique provides the in-field user a fully contained FRP composite processing method which uses premeasured resin stored in portable bladder. The resin bladder has an internal bag containing the curing agent, which is ruptured and kneaded in order to mix the resin and curing agent. The bladder bag is placed under vacuum with the fabric to be infiltrated, and ruptures under mechanical means. The matrix material penetrates the fabric, which will then cure into the desired FRP composite structure. This technique has direct soldier impact as it allows for the fabrication of resin-infused parts in non-laboratory locations and is a fully enclosed and safe process for in-field composite repair.					
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1. Introduction

The Vacuum-Assisted Resin Transfer Molding (VARTM) process is an out-of-autoclave fiber-reinforced polymer (FRP) composite fabrication method, which is advantageous due to its relatively low cost and ease of use. VARTM is applicable for manufacturing large-scale FRP composites of military, marine and other commercial uses (1–8). The cost advantages are due to decrease in labor, material, and equipment expense as compared to other techniques. The most common variation of the VARTM process was developed by Seemann Composites, Inc., (Gulfport, MS) and is called the Seemann Composite Resin Infusion Molding Process (SCRIMP). Other variations of VARTM include the Controlled Atmospheric Pressure Resin Infusion (CAPRI) process, and the Vacuum-Assisted process (VAP) (9–11). U.S. Army Research Laboratory (ARL) resin-infused composites are typically fabricated using a modified SCRIMP method with the addition of a redundant second vacuum bag, which is added in order to ensure processing performance and repeatability. Figures 1 and 2 illustrate the VARTM process.

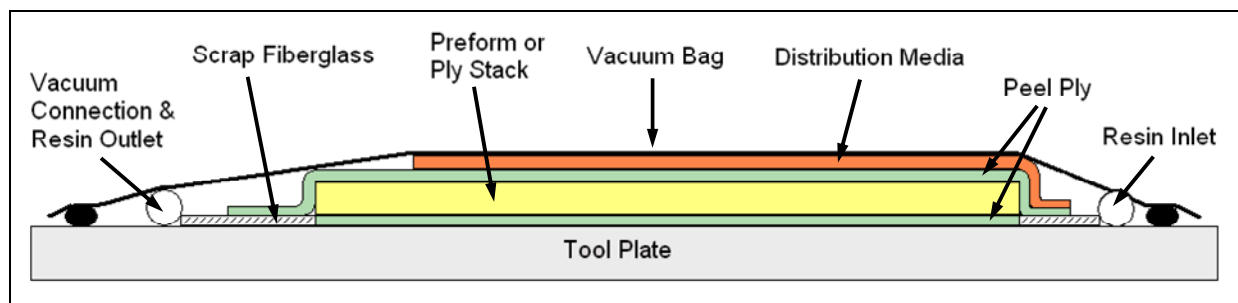


Figure 1. Schematic showing the side view of a composite plate being fabricated by the VARTM process with a single bag.

VARTM processing of FRP composites has two significant limitations: the first is that the process requires a high level of accuracy in the mixing of the resin, and second, the process requires that the resin system be kept free from dust and debris during mixing, infusion, and curing. In a laboratory or manufacturing environment, these two issues are easily managed. However, these issues are difficult to control in an in-field environment.

In this study, a solution to the difficulties of in-field VARTM composite processing is addressed by the development of the Bladder-Bag VARTM (BBVARTM) technique. The fabrication of FRP composite specimens, and repair of a composite structure, are shown as a proof-of-concept for the BBVARTM technique.

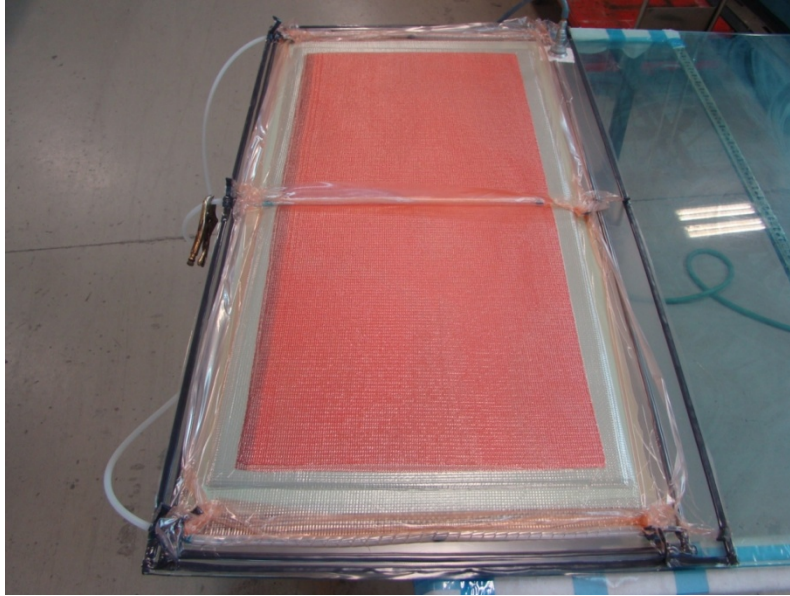


Figure 2. Image of fiberglass composite being fabricated using VARTM processing.

2. Experimental

2.1 Composite Laminate Fabrication

Multiple 6 inch square 8-ply panels of 831 g/m² 240 style 5 × 5 plain weave, S-2 fiberglass (BGF, Greensboro, NC) were infused with the SC-15 epoxy (Applied Poleramic Inc., Benicia, CA) resin system. The SC-15 was prepared by mixing according to the manufacturers' standards and then degassed in a vacuum oven at ~28 in mercury (Hg) for 30 min. The resin was then transferred into vacuum sealable FoodSaver® storage bags (Sunbeam Products, Inc., Boca Raton, FL). The bags were then sealed and all air was evacuated from the bag to prevent the introduction of air into the resin infusion process. The resin was then heat sealed in the minimum amount of bag possible to prevent having excess resin bag material within the consolidation vacuum bag. A storage bag and vacuum can be seen in figure 3.

* FoodSaver is a registered trademark of Jarden Direct, Inc.



Figure 3. (Left to right) Vacuum storage bag and vacuum sealer.

The 6 inch square panels were then laid up in the same fashion as a typical double-bagged VARTM lay-up, with the only exception that the resin inlet tube was replaced with the bladder bag containing resin. Samples being fabricated can be seen in figure 4a and 4b. The bladder bag was placed in contact with the distribution media of the part in order to assure resin infiltration of the dry fabric. The lay-ups are placed under vacuum at ~28 in Hg and checked for leaks.

Upon testing of this system, it was determined that there was a need for a device inside of the consolidation vacuum bag that would burst the bladder bag of resin. A piece of polycarbonate was laser cut to create a serrated edge, and placed directly on top of the bladder bag in the lay-up process. The serrated polycarbonate can then be pressed through the bladder bag to begin resin infusion. The rupture device can be seen in figure 5a and 5b.

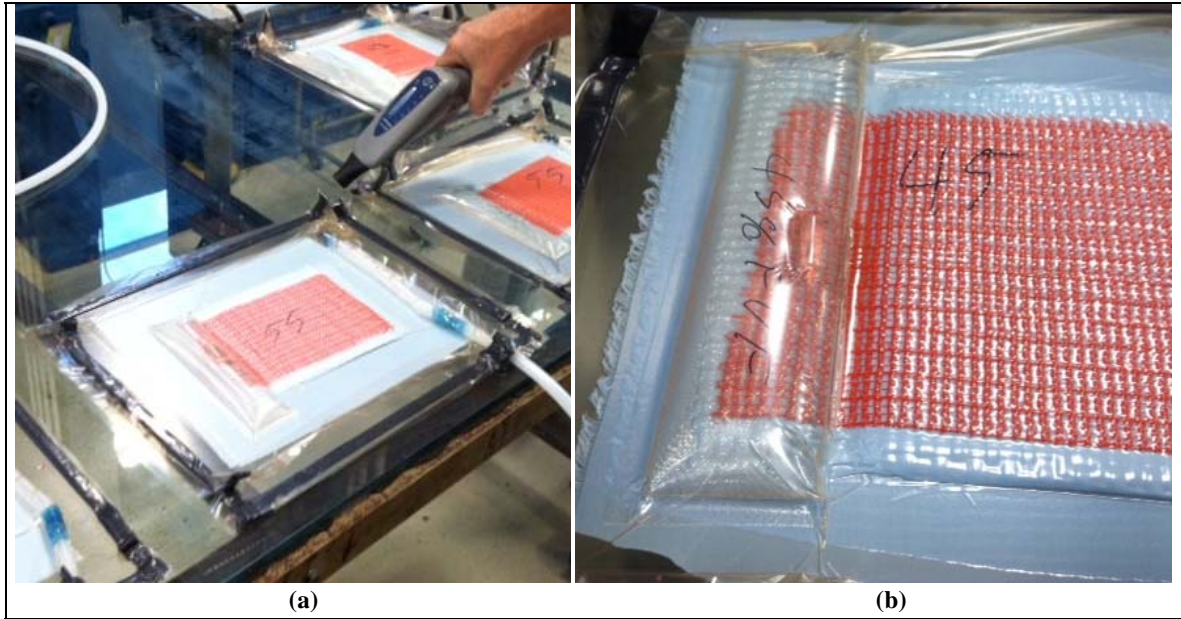


Figure 4. (Left) a and b leak check of BBVARTM lay-ups. (Right) resin in bladder bag before infusion of the dry fabric.

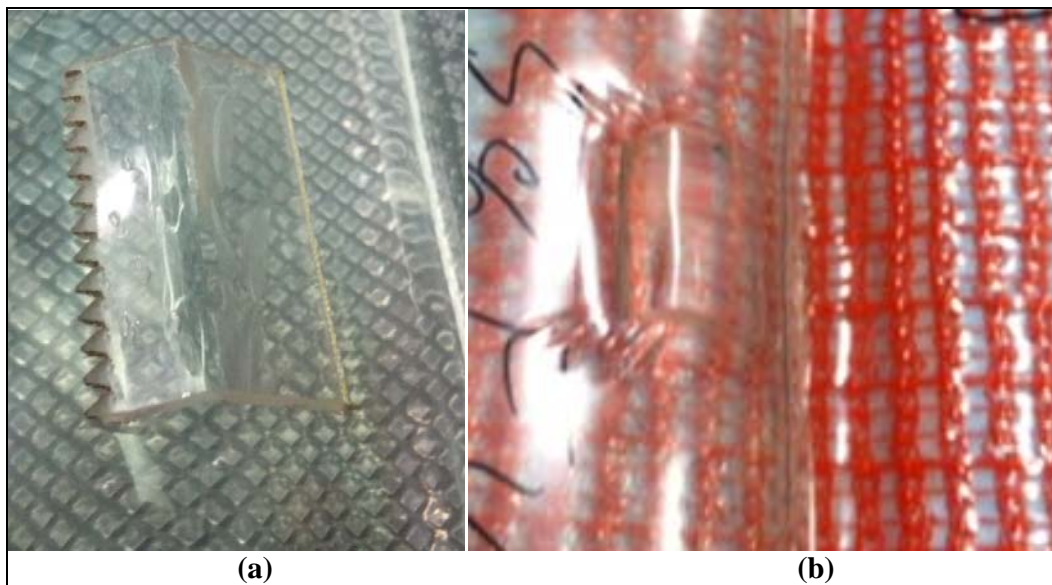


Figure 5. (Left) (a) and (b) bladder-bag rupture device after machining and (right) before infusion.

Once under vacuum, infusion is initiated by lightly pressing down on the rupture device.

2.2 Composite Repair

Since resin infusion and part fabrication using BBVARTM were proven achievable, the technology was tested for use as a composite repair technique. Here, a light-weight structural composite part was evaluated. The part was originally fabricated out of 240 style 5×5 plain

weave prepreg S-2 fiberglass fabric and a honeycomb core cured in an autoclave, much like the composite parts fielded in vehicle systems. The original part can be seen in figure 6.

The part underwent simulated tool-drop damage, which caused matrix fracture and debonding of the matrix and fiber. The resulting damage can be seen in figure 7a and b.

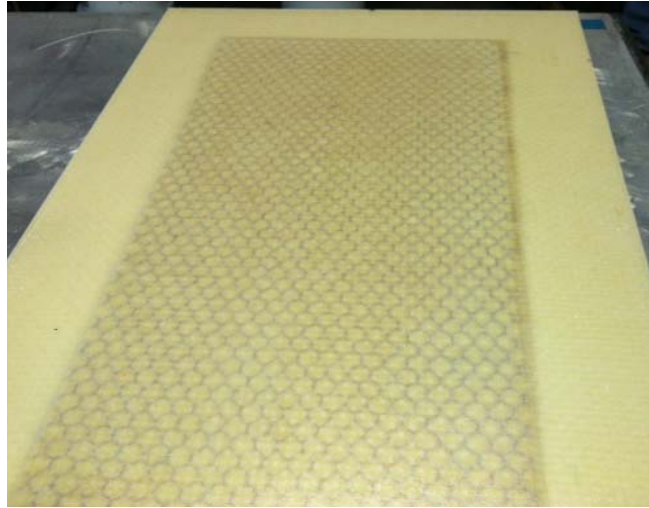


Figure 6. Autoclave fabricated composite part with honeycomb core.

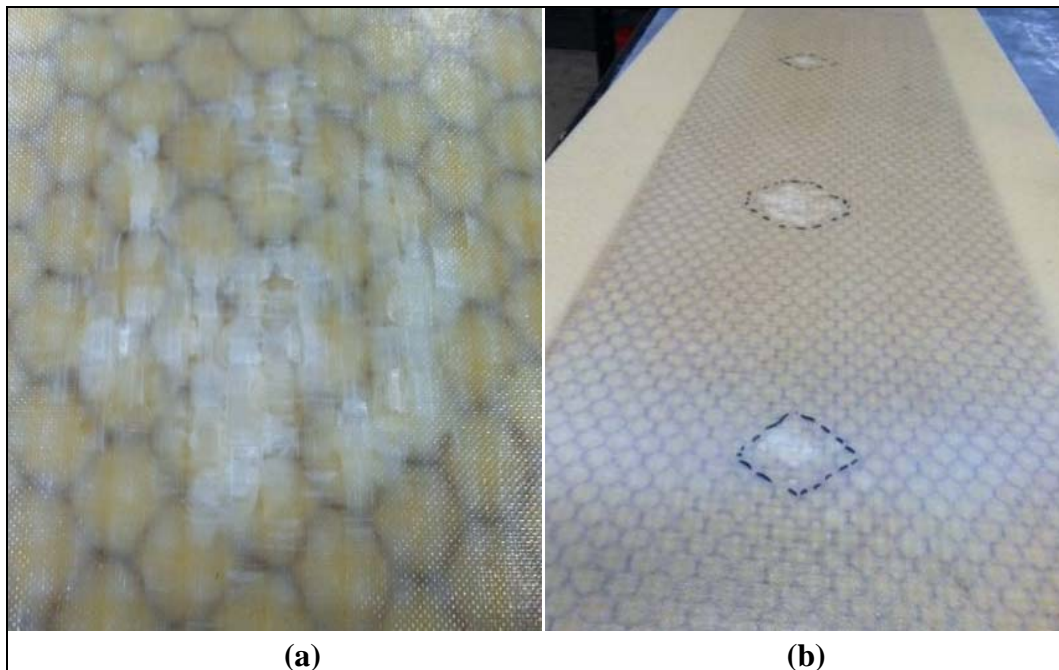


Figure 7. (Left) a and b damage from simulated tool drop. (Right) damage locations.

The damaged surface of the composite was removed at the location of the damage with a rotary grinder. Precision machining could be used for the removal of the damaged surface; however, the goal was to represent in-field repair, therefore, a tool that would commonly be used in-field was chosen. The repair location was taper sanded to ensure that each ply of the laminate was exposed for maximum bonding of the repair material. This technique is commonly called scarf repair, and it is a common composite repair technique used in the aerospace industry (12–14). The part is shown in figure 8 after the damaged surface has been removed.

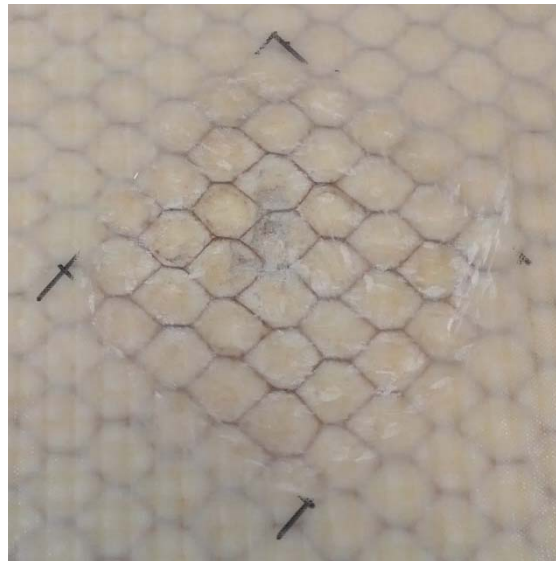


Figure 8. Damaged surface of composite part removed, honeycomb visible.

The part was then cleaned and prepped for repair using BBVARTM. 831 g/m² 240 style 5 × 5 plain weave S-2 fiberglass is cut to the shape of the damaged area and placed in the void left from the removal of the damage. Smaller plies are laid closer to the honeycomb, and successively larger plies are stacked on top in order to accommodate the gradual widening of the tapered void. The dry repair fabric can be seen in figure 9. Peel ply, distribution media, and a bladder of resin were then placed over the dry fabric. Vacuum is drawn on the system, the bladder bag is ruptured, and the repair part is infiltrated with resin. This process is depicted in figures 10 and 11.

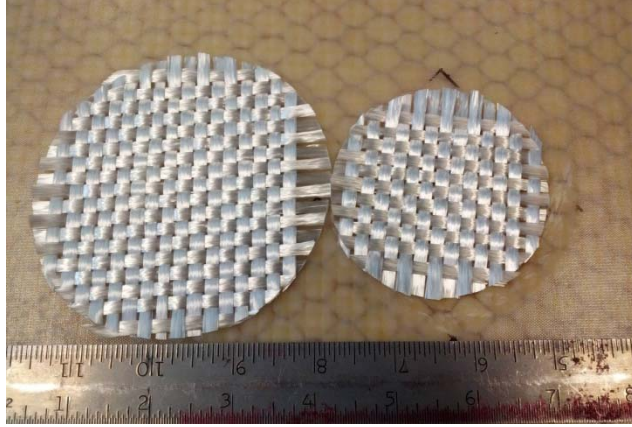


Figure 9. S-2 fiberglass fabric cut and ready to be used for repair.



Figure 10. BBVARTM lay-up under vacuum, ready for infusion. Bladder bag of resin with rupture device before infusion is circled in the image.



Figure 11. BBVARTM lay-up after infusion of resin. The circled section of the image shows the ruptured bladder bag, which was emptied of resin and infused into the fiberglass.

After the infusion was completed, and the resin had cured, the bagging and infusion materials were removed, and the surface is sanded lightly to remove any excess resin. An image of the resulting repair can be seen in figure 12.



Figure 12. BBVARTM repair completed.

3. Conclusions

It has been shown that BBVARTM can be used for the fabrication and repair of resin-infused FRP composites for in-field applications. This method is currently being adapted and included in a repair kit containing all the necessary materials for in-field use called the Composite Resin Infusion kit (CRIKit). The kit includes: plies of fabric, a handheld vacuum pump, release ply, and vacuum bagging materials. CRIKit also includes resin systems for multiple applications. The resin systems are contained in bladder bags that keep parts A and B separate with a bag-inside-a-bag, in which the innermost bag contains the curing agent, and the encompassing bag contains the resin. The inner bag is ruptured by mechanical means, and the resulting combination is kneaded to ensure proper mixing immediately before the time of use. The characterization of repair patches and composite laminates fabricated by BBVARTM will follow. The process will also be evaluated for use in the fabrication of FRP composites with fiber volume fraction by design. Since this method is fully enclosed, it is theorized that specific amounts of resin could be infused in order to create composites with a desired amount of resin. Fiber volume fraction could then be decided by the user, thereby controlling mechanical properties of the laminate for specific applications.

4. References

1. Lazarus, P. Resin Infusion of Marine Composites. *In: 41st International SAMPE Symposium*, 1996; pp. 1447–1458.
2. Nguyen, L. B.; Juska, T.; Mayes, J. S. Evaluation of Low Cost Manufacturing Technologies for Large Scale Composite Ship Structures. *Collection of Technical Papers – AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics & Materials Conference*, 1997; Vol. 2, April 7–10; pp 992–1001.
3. Cairns, D. S.; Skramstad, J. D. Evaluation of Hand Lay-up and Resin Transfer Molding in Composite Wind Turbine Blade Structures. *International SAMPE Symposium and Exhibition*, 2000; 45 (1), pp. 967–980.
4. Chajes, M. J.; Gillespie J. W. Jr.; Mertz, D. R.; Shenton III, H. W.; Eckel II, D. A. Delaware’s First All-Composite Bridge. *In: ASCE Conference*, Philadelphia, PA, 2000.
5. Lewit, S. M.; Jakubowski, J. C. Low Cost VARTM Process for Commercial and Military Applications. *In: 42nd International SAMPE Symposium*, 1997; pp. 1173–1187.
6. Pike, T.; McArthur, M.; Schade, D. Vacuum Assisted Resin Transfer Molding of a Layered Structural Laminate for Application on Ground Combat Vehicles. *In: International SAMPE Technical Conference*, 1996; Vol. 28, November 4–7, pp 374–380.
7. Wienhold, P. D.; Wozniak, J. J. Application of SCRIMP VARTM Fabrication Technology to the Compressed Natural Gas Integrated Storage System. *In: International SAMPE Technical Conference*, Vol. 29, October 28–November 1, pp. 67–76.
8. Beckwith, S. W.; Hyland, C. R. Resin Transfer Molding: A Decade of Technology Advances. *SAMPE Journal* **1998**, 34 (6), 7–19.
9. Seemann et al. W. H. Plastic Transfer Molding Techniques for the Production of Fiber Reinforced. U.S. patent 4,902,215.
10. Woods, J.; Modin, A. E.; Hawkins, R. D.; Hanks, D. J. Controlled Atmospheric Pressure Infusion Process. International Patent WO 03/101708 A1.
11. Filsinger, J.; Lorenz, T.; Stadler, F.; Utecht, S. Method and Device for Producing Fiber-Reinforced Components Using an Injection Method. German Patent WO 01/68353 A1, 2001.
12. Baker, A. Repair Techniques for Composite Structures, Middleton, D. H., Ed. *Composite Materials in Aircraft Structures*, Longman Scientific and Technical, pp. 207–227, 1990.

13. Robson, J. E.; Mathews, F. L.; Kinloch, A. J. The Strength of Composite Repair Patches: A Laminate Analysis Approach. *J. Reinforced Plastics & Composites* **1992**, *11*, 729–742.
14. Armstrong, K. B. British Airways Experience with Composite Repairs. Middleton, D. H., Ed., *Composite Materials in Aircraft Structures*, Longman Scientific and Technical, pp. 368–378, 1990.

List of Symbols, Abbreviations, and Acronyms

ARL	U.S. Army Research Laboratory
BBVARTM	Bladder-Bag Vacuum-Assisted Resin Transfer Molding
CARPI	Controlled Atmospheric Pressure Resin Infusion
CRKit	Composite Resin Infusion Kit
FRP	fiber-reinforced polymer
SCRIMP	Seemann Composite Resin Infusion Molding Process
VAP	Vacuum-Assisted process
VARTM	Vacuum-Assisted Resin Transfer Molding

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