

## Will “Spray On” Vacuum Bags Save the Aerospace Industry Millions?

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***Long the Achilles’ heel of the “cure by autoclave world of composites,” vacuum bagging could undergo a revolution that may spread to other composites applications.***

In the early days of the composites industry, most innovations came from aerospace companies, probably because these companies developed composites technologies as part of the WWII effort.

When the war was over, these companies were forced to scramble to find new and viable applications for their technologies. They found some immediate applications in the promising aerospace industry, but the conservative “work inside the box” attitude the industry assumed dictated relatively slow progress in adopting innovative composite applications on a broad scale.

However, the civilian free-market environment in the post war boom was more entrepreneurial and thus open to new materials and applications. The Fiberglass Reinforced Plastics (FRP) industry was born in this environment and the many innovative manufacturing methods and materials that are characteristic of FRP manufacturing were either developed at that time or are direct descendents of those early technologies.

Occasionally a new material or manufacturing method has emerged in the aerospace marketplace and found its place in the civilian marketplace as well. The use of carbon fibers in sports equipment and the process of resin transfer molding (RTM) are two such examples where the high performance side has influenced the FRP side. Such advances in aerospace composites technology continue to be important for FRP manufacturers. Who knows what innovations might significantly change conventional FRP manufacturing methods and provide new materials that could open new markets?

Something new has happened in the aerospace industry in the last two years that is so revolutionary that *Composites Manufacturing Magazine* has devoted two previous articles to its exploration and continues with this article. In October 2004 we reported on "Breakthroughs in Aerospace Composites Manufacturing" and discussed the dramatic changes happening in the aerospace industry because of Boeing's commitment to a real composites commercial airplane for the first time (the 787 Dreamliner). That article also explored the new possibilities of using filament winding to manufacture small aircraft bodies and wings in single pieces. Both of these changes signaled a new culture of vibrancy and innovation in aerospace, a lesson learned from the entrepreneurial survival skills of many FRP businesses.

Then, in our March 2005 issue we explored the world of epoxy resin formulation—an important development that enables new aerospace technologies. These new resin formulations give aerospace manufacturers the freedom to explore the new manufacturing methods that are so important to the widespread adoption of composites in the aircraft of the future.

Now, we will look at a new method that corrects a problem that has plagued aerospace manufacturing for five decades. The problem has cost aerospace companies millions of dollars a year and has, therefore, raised the price of composite parts so much that composites have been difficult to economically justify even for aerospace applications. This problem is unique to aerospace manufacturing and is largely unfamiliar

to FRP manufacturers. The problem is failed vacuum bags. This cost busting deterrent can rightly be considered the Achilles' heel of advanced composite manufacturing.

### **The Use of Vacuum Bags**

When complex composite parts are made, especially in aerospace, performance requirements demand that the directions of the fibers and the amount of resin be carefully controlled. Those requirements are met by using layers of prepreg materials. That is, sheets of fibers and resin in which all fibers either run in the same direction (unidirectional prepreg) or are woven in various patterns in a cloth (fabric prepreg). The application of the resin to the fibers is carefully done so that the resin/fiber ratio, the uniformity of the resin distribution, and full impregnation of the fibers is carefully controlled. Specialty manufacturers, called prepreggers, have developed machines to make the prepreg materials that are then sold in rolls to the molders of aerospace parts.

The molding is done by carefully laying the prepreg sheets, one layer (or ply) at a time, onto the mold either by hand or by special (and expensive) “laydown” machines. The orientation of fibers is carefully controlled so that the eventual accumulated buildup of various layers representing what may be a diverse array of fiber directions is exactly as required by design to achieve maximum strength and other performance qualities. If it is anticipated, for instance, that forces will be exerted on the part in several directions, layers of the fibers are pointed in the direction of the forces. Strength and stiffness requirements, along with other requirements such as achieving a balanced and symmetrical layup, can result in rather complex layered sequences for each part.

The curing of parts made with prepreg materials must be done so that the layers of prepreg bond together into a consolidated unit with no air trapped between the layers. This requires that the parts be cured at high temperatures and pressures (usually in an autoclave) and, simultaneously, with a vacuum system to remove excess air. The vacuum is created by enclosing the uncured part in an air-tight bag in such a way that the vacuum is evenly distributed across the part. The trapped air can now move out of the layers, and the resin can flow across layer boundaries and provide full part consolidation. (See figure 1.)

The composite layers shown in figure 1 are of the several prepreg layers described above. In a typical layup, these materials are laid against the tool with normal release compound applied to the tool to ensure easy removal after the heat/pressure cycle in the autoclave. The tool, which is usually made of metal, determines the final shape of the part. A perforated fluorocarbon sheet, or release film, is placed on top of the composite layers to allow air to escape and excess resin, if any, to move through the prepreg layers and achieve good consolidation. The excess resin is absorbed by a layer of absorbent material (called the bleeder layer) that is placed on top of the release film. Some molders use prepreg that has so little excess resin that the bleeder layer is unnecessary. In some cases, especially when there is a large amount of excess resin, a solid layer of release film is placed on top of the bleeder layer and sealed, thus forming an inner bag that controls resin flow. To ensure that air can move freely within the entire vacuum bag assembly, a layer of porous material, called the breather layer, is placed on top of the layers already described. In some cases, especially when excess resin is scant, the bleeder and breather layers can be the same material. This is the case represented in figure 1. Sometimes thick fiberglass is folded (called belly bands) and laid around the perimeter to enhance vacuum

and to ensure the part is secured to the tool. Finally, the vacuum bag is applied over the entire assembly and sealed with “tacky tape” to the tool. The vacuum bag is shaped and occasionally filler material is added to accommodate heavily contoured areas to prevent bridging conditions, described below. Some tools have vacuum ports already installed. If they do not, independent valves are placed around the tool, the bases underneath the vacuum bag material, and the stems on top.

All in all, vacuum bagging can be the most cumbersome and precarious part of the layup process. Vacuum bagging in many aerospace companies is often considered an art form, more than a simple technique, and with production parts assuming more and more complex shapes, special training is required to gain this skill.

### **What Can Go Wrong?**

The greatest difficulty arises when the tool and layup have complex contours, which many aerospace parts that make up various assemblies and sub-assemblies do.

In the heavily contoured areas or areas with a variety of degrees of radii, ones that protrude outward or concave inward, the vacuum bag must, when vacuum is drawn, conform to the lines of the contour. If it doesn't, in a radius that concaves inward for instance, what is called a bridge may occur, when the bag does not completely seat to the tool, when there is nothing but air underneath the part of the bag that is bridged. Imagine stretching a balloon over the top of a coffee cup. When pressure is applied in the autoclave, this bridged part of the vacuum bag, with nothing underneath to support it, can rupture, causing a condition known as backpressure. If the rupture occurs after the temperature has reached a certain level and the resin has begun to flow, the part will be lost and the process must be started over. Heavily contoured parts create many more opportunities for bags to break in process. Labor and material costs must be written off in the red. Entire production lines could be stalled.

Without special techniques such as pleats, the vacuum bag also could wrinkle and cause an impression on the part called mark-off that would subsequently cause the part to fail inspection. For example, think of a typical computer mouse with its rounded contours. How would one wrap it using a flat sheet of paper (which is like bagging film) and not have wrinkles in the surface of the wrapping? This is precisely the kind of challenges those in aerospace and other industries who use high performance composites are faced with. It's important since highly trained technicians spend days or weeks carefully preparing vacuum bags to make parts that must meet strict quality requirements.

Another time-consuming part of the process is that of sealing edges and seams in the vacuum bag. It is critical that the bag is airtight or the part may be destroyed completely, in a scenario similar to the bag rupturing during process.

In fact, industry leaders say that failure in pre-production stages typically runs at 25-30 percent on parts of moderate to high complexity. In full production, 3-5 percent of parts typically fail due to problems related to the vacuum bag. Failures that occur during the last stages of part production happen exactly when part loss is most catastrophic. The cost of these failures can run in the millions of dollars a year. Equally devastating is the time lost in the preparation of the parts and the resultant changes in production schedule that must occur or, at the alternate, the warehousing of finished parts to be held in store for production requirements. Either way, costs skyrocket.

## A New Fix?

Recently, a new patent pending technology was introduced that promises to make drastic reductions in the time it takes to bag parts and to reduce the rate of failed bags. Whereas a conventional vacuum bag is a flat film, the new technology involves spraying a tough pliable heat-resistant coating on top of the breather to form the vacuum bag. Those familiar with conventional bags might ask how the sprayed coating is kept from penetrating the breather material. That is done by laying an inexpensive film such as polyethylene with good elasticity over the breather material. The edges of this film are sealed and vacuum is drawn so that the film conforms to the contours of the part without wrinkles. The new coating is then sprayed over the drawn film. The elastic film may melt in the autoclave, but that is of no concern since it has already served its purpose and will not interfere with curing of the part. Those familiar with the conventional bagging process will recognize the time savings in such a procedure. Bagging procedures that previously took days or weeks may now be reduced to minutes or hours. The new procedure has numerous advantages over conventional bagging. It is much faster, inherently conforms to part contours, cures in seconds, has no solvents to evaporate, seals edges quickly and effectively, and reduces failure rates. The cost savings of this new technology become obvious when compared to conventional bagging procedures.

The inventors of this system have also found that if the spray material is applied to the top of a conventional vacuum bagging film, the failure rate of the bagging system is dramatically reduced and much time and cost are saved. Therefore, the new spray bagging system can be used either by itself or in combination with traditional bagging.

The performance improvements of the new bagging technology were initially demonstrated in laboratory tests. These tests compared the performance of the sprayed bagging system (alone and in combination with conventional bagging) with conventional bagging alone in conditions in which the vacuum bag would be greatly extended, as it would in making a part with a deep profile. A new test procedure was devised and the fixture for these tests is pictured in figure 2. The diameter of the tool is 2.5 inches and the depth is 3 inches with walls that taper in at 15°.

In the test procedure a film specimen is laid across the top of the tool and clamped tightly in place with a gasket forming an airtight seal. Air pressure is then introduced above the test specimen causing it to stretch and conform down into the tool. Shims were made that create a floor in the tool at varying depths in 1/4-inch graduations starting at one inch down. In order to determine where the film contacted the tool, a marking compound was printed on the test specimen in a grid pattern so that the contact area would be evident after the specimen was removed. This makes it easy to see how well the specimen conformed to the tool during the test. Tests were performed at room temperature (70°F) which is the critical temperature at which vacuum is applied. The results are given in Table 1. Additional tests conducted at 250°F have confirmed that the spray material is not degraded and is even more compliant. Tests at 350°F are underway.

The data in Table 1 indicates that the failures of the bags increase as the depth of the tool increases, as expected. It can be noted that the consistent failure point for the conventional bag is at 1.5 inches depth (at room temperature) whereas the new sprayed bag will survive to 2.0 inches. The combination of the bags fails most of the time at 1.75 inches. Testing at 250°F follows the same trend but failures occur at greater depths. Therefore, it can be concluded that the sprayed bag performance exceeds the traditional

bag and that the combination of the traditional bag with the sprayed material on top is intermediate in performance, thus suggesting a linear relationship in the bags' performances. The data also show that the failures of the sprayed bag are more predictable, that is, the failure point is better defined. This feature will, of course, reduce the number of unexpected failures.

To confirm this performance on an actual tool, the tool shown in figure 3 was bagged with a traditional system and then over sprayed with the new material. Part consolidation was shown to be good and bag integrity was excellent.

The reasons for the improvement in performance for the sprayed bag are, perhaps, attributable to the improved conformance of the new material and its higher elongation. Apparently, then, parts with highly complex shapes, especially when the part is highly contoured so that a high strain on the vacuum bag occurs, will be easier to cure. If new aircraft are to be largely composites, as is anticipated with the 7E7, complex composite parts will be much more common and so this improvement of bagging performance will be ever more important.

Industries that have aggressive production schedules with high performance composite products have shown a great deal of interest in this new technology as it promises significant savings and increased revenues by speeding production and reducing failures. Other cost savings are possible, for instance, as composite tool life can be extended by using the new material to seal leaks that have developed from extended use.

Environmental concerns over disposal are minimal with this sprayed coating. The new material is 100 percent solids so there are little or no VOCs to recover when sprayed. If desired, the material can be applied by painting, rolling or any other method for liquid materials. Also, the coating itself is inert after spraying so disposal is not difficult.

### **Closed Mold Applications For FRP?**

Liquid (usually sprayed) vacuum bagging has the potential to make composite manufacturing more economical and add to the bottom line of those industries that take advantage of it. Clearly the initial application will be in aerospace. However, those who traditionally do layup might find the new technique highly profitable to assist in curing. They could, for instance, reduce the amount of material used if prepregs were used instead of wet layup. The directionality would be superior and, of course, the amount of resin would be optimized. If prepreg are used, the need for vacuum bagging is present.

Those who currently use RTM (or one of its derivative methods) might find that this new bagging method will greatly simplify use of soft tooling techniques. Spraying a large boat to effect a cure would certainly be easier than trying to cover the entire structure with bagging film. Even those who use spray-up techniques may find that converting to soft tooling that can be sprayed onto the part will find better productivity rates and, of course, lower tooling costs.

Just as in the past, developments in aerospace may spill over into the FRP market. This newest development might just be one of those.

For further information about liquid (sprayed) vacuum bagging contact Mike Kipp [mdkipp@americanctr.com](mailto:mdkipp@americanctr.com) or call 775/781-7612.

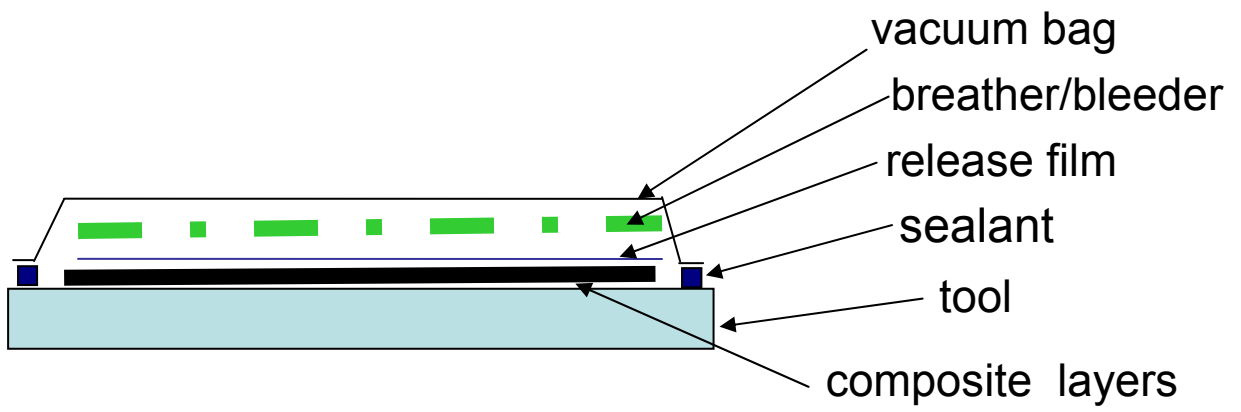


Figure 1. Schematic Layup Diagram of a Vacuum Bagging System



Figure 2 Test fixture for bag failure testing



Figure 3 Parts with reasonably deep draws showing a conventional vacuum bag assembly and the bare tool

Table 1 Experimental data for conformance testing of vacuum bags

**Conventional bag material .002-.003 inch thick**

Tool Depth (inches)	70°F	250°F
1	Pass 3 of 3	Pass 3 of 3
1.25	Pass 2 of 3	Pass 3 of 3
1.5	Fail 3 of 3	Pass 3 of 3
1.75		Pass 3 of 3
2.0		Pass 2 of 4
2.25		Pass 2 of 4
2.5		Fail 3 of 3

**Sprayed bag material alone**

Tool depth (inches)	70°F	250°F
1	Pass 3 of 3	
1.25	Pass 3 of 3	
1.5	Pass 2 of 3	Pass 3 of 3
1.75	Pass 3 of 3	Pass 3 of 3
2	Fail 3 of 3	Pass 3 of 3
2.25		Pass 3 of 3
2.5		Fail 2 of 2

**Sprayed material over conventional bag**

Tool depth (inches)	70°F	250°F
1	Pass 3 of 3	
1.25	Pass 3 of 3	
1.5	Pass 3 of 3	Pass 3 of 3
1.75	Fail 4 of 6	Pass 4 of 5
2		Fail 5 of 5