# Composite fabrication via the VARTM process

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## 1) Material System

North Carolina A&T State University has worked and conducted research in the area of composite materials over the last 20 years. It has worked extensively with the Department of Defense (DoD), NASA, NAV/AIR (Naval Air Force), Federal Aviation Administration (FAA), Air Force Research Laboratories/Materials Directorate (AFRL/ML), Army Research Laboratories (ARL), Clarkson Aerospace, Boeing and Lockheed, the NAVY and the ARMY. The research ranged from composites materials manufactured from carbon, fiberglass and carbon-carbon reinforcements with epoxy and vinyl-ester resins. NCA&TSU has the ability to manufacture composites using RTM (Resin Transfer Molding), VARTM(Vacuum Assisted Resin Transfer Molding), HVARTM( Heated Vacuum Assisted Resin Transfer Molding) and the Autoclave process. NCA&TSU also has the ability to develop a molding process to custom fit a material system and/or resin system through it manufacturing and processing experience. A&T has worked with Fiber Glass Industries ( FGI, Inc.) and Hexcel Corporation in developing the methodology of improving coating of resins onto the sizing provided by these two companies. A working relationship with the manufacturer's research laboratories, A&T and Triangle Polymer Technologies will strengthen the development process in this endeavor to supply the best product possible. The first phase will involve the use of woven roving and stitched bonded S2 fiberglass reinforcement. These materials are currently being used by A&T in several research areas along with the VARTM and HVARTM processing methods.

## 2) Fiber reinforcement

A planar structure produced by interlacing two or more sets of yarns, fibers, rovings, or filaments, where the elements pass each other essentially at right angles and one set of elements is parallel to the fabric axis, is referred to as a woven structure. A roving is a collection of glass filaments put together with as little twist as possible. Thus a woven structure composed of rovings is known as a woven roving structure. Figure 4.2 shows the woven roving fabric FGI 1854 that was used in this study. A structure produced by mechanically combining the warp (0°) and weft (90°) rovings is a stitch-bonded fabric. The resulting product is a non-crimp fabric. The advantage with stitch-bonded fabrics is that a single layer of fabric can be made multidirectional by orienting the rovings at any angle between 0° and 90° and using polyester thread to stitch them together. Figure 4.3 shows the stitch-bonded fabric FGI 1800 A2 that was used in this study. Figure 4.4 shows the stitch-bonded carbon fabric Devold AMT AS's LT 650-C12 that was used in this study also.

Composite structures, fabricated using these fabrics in conjunction with vinyl ester resin by the vacuum assisted resin transfer molding process, are now being considered for use in various structural applications as a cheaper alternative to conventional materials without compromising the mechanical properties.

## 3) Applications

The VARTM (vacuum assisted resin transfer molding) process though a relatively low cost process can be used to fabricate composite parts of very high quality. The following section discusses

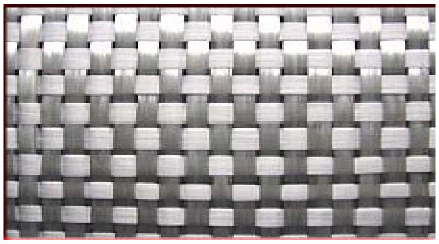


**Figure 1.1 Woven Roving E-Glass Fabric - FGI 1854**

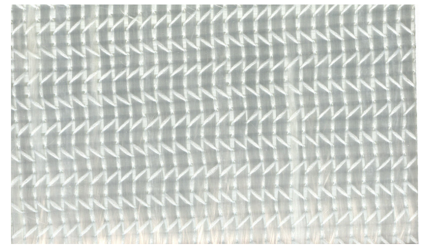
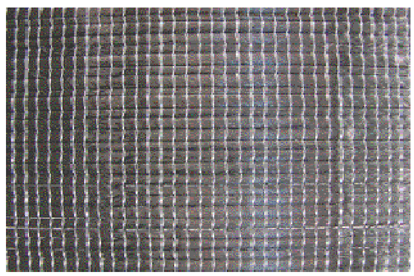
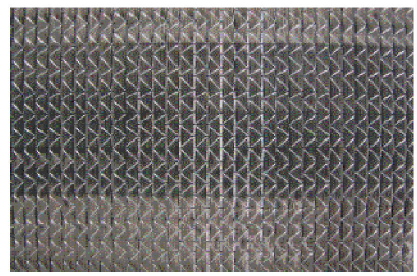


**Figure 1.2 Stitch Bonded E-Glass Fabric - FGI 1800 A2**



**(a)**



**(b)**

**Figure 1.3 Stitch Bonded Devold AMT AS's LT 650-C12 carbon Fabric**
**i. Front View; (b) Rear View;**

in detail the use of this process to manufacture glass and carbon composites. Years of research have been done in the development of the VARTM process so that a method of fabrication can be developed to result in consistent mechanical properties for all the panels fabricated using this process. In this process a dry preform is placed on the mold plate and vacuum bagged in conjunction with the resin injection and resin ejection or vacuum lines. A low viscosity resin is drawn into the preform with the aid of vacuum. Spicola et al. [1] have investigated the details of application of this process to large structures. The effects of increasing the fracture toughness of glass fabric laminates and development of process modifications allowing the manufacture of large structures in one stage have been discussed in his work. Heider et al.[2] have come up with a new vacuum controlled work cell which is able to adjust the vacuum levels at several vent locations and thus control the process to a greater extent. Vacuum sensors are used to measure the in-situ vacuum levels at different locations in the system and then the resin flow is adjusted accordingly to have an even flow front. Sun et al.[3] have performed a detailed analysis of the SCRIMP process. They have developed several computational models to predict the flow patterns and the fill time. A heat transfer model combined with the kinetic model has been developed to simulate the cure behavior of this process.

The VARTM process has been used in many applications because of its time-saving and cost-effective characteristics. This process is being currently used in many of the applications in the defense sector. It is being used in composite integral armors which are defense structures requiring ballistic protection. VARTM has been used in marine applications to build the outer bodies of ships. The composite layer offers protection from rust and mechanical damage. The strength to weight ratio of the composite is greater than that for metals. Hence they are being used in the defense industry for building sophisticated structures. Nguyen et al.[4] has described the application of VARTM in the naval industry.

## 4 Steps in the VARTM Fabrication Process

The low cost VARTM process involves performing the following steps:

1. Mold preparation and fabric lay-up.
2. Sealing the mold and creating a vacuum.
3. Resin preparation and degassing.
4. Resin impregnation.
5. Cure of fabricated panels.

## 5 Mold preparation and fabric lay-up (Figure 2 and 3)

### 5.1 Mold Surface:

The mold used for the fabrication of the composite panel is either a metal plate or wooden plate that is laminated with vinyl. The metal plate (usually aluminum) has a provision of heating while the fabrication is in progress.

### 5.2 Mold Surface Protection:

For thick woven composites two layers of Frekote-700 NC are applied to the mold surface. A coating of sand paste wax or Trewax is also applied to the surface for easy release of the composite panel. This is a precaution in addition to the Frekote being applied. A 2 mil (25micron) MYLAR film is used to protect the mold surface. This film facilitates the easy removal of the panel from the mold surface after the fabrication process is over.

### 5.3 Bottom Release Fabric or Peel ply:

The bottom release fabric or peel ply is a porous release material which leaves an impression on the part suitable for secondary adhesive bonding (like tabbing) without further surface preparation. This fabric also allows for easy removal of the fabricated panel from the mold surface. The peel ply sheet is Airtech Bleeder Lease 'B' and is cut to dimensions of 26" x 38" (1" overlap with perform on all sides)

### 5.4 Fabric Lay-up:

The fabric which is woven roving E-glass FGI 1854, stitch-bonded E-Glass FGI1800 A2 or stitch-bonded carbon Devold AMT AS's LT 650-C12 is cut to dimensions of 24" x 36". Six plies of similar dimensions are cut and stacked in the 0° direction in the case of the woven roving fabric and the stitch bonded glass fabric. In the case of the carbon fabric four plies of size 24" x 36" are cut and stacked in the 0° direction. The fabric is stored in a room with controlled temperature and dry atmospheric conditions. This prevents the contamination of the fabric from water condensation. Precaution to be taken in stacking is that the fill and the warp fibers should be perpendicular to each other and parallel to the corresponding fill and warp fibers of the other plies. This is a porous release material which facilitates the resin flow through and leaves an impression on the part suitable for secondary bonding without further surface preparation.

**5.5 Top Release Fabric or Peel Ply:**

Another peel ply is placed on the top of the stacked sequence of fabric. This allows for easy removal of the composite panel after fabrication from the vacuum bag. This is a porous release material which facilitates the resin flow through and leaves an impression on the part suitable for secondary bonding without further surface preparation. The peel ply sheet is Airtech Bleeder Lease 'B' and is cut to dimensions of 27" x 39" (1.5" overlap with perform on all sides).

**5.6 Distribution Medium:**

The distribution medium is NALTEX 14-291-R (red mesh) mesh laid on top of the top release fabric. This helps to maintain an even distribution of resin on the top of the panel and also facilitates the flow of resin through the thickness of the panel. The resin transfer media or distribution media is cut to dimensions of 32" x 35" (8" overlap in flow direction, 1/2" less on sides).

**5.7 Resin and Vacuum Distribution Line:**

A PE Spiral Wire Wrap tube of ¼" outer diameter was cut to 38" in length and is used as the resin distribution tube. This tube extends approximately 2" over the longest edge of the stacked layers. Another tube of similar dimensions is cut and is used as the vacuum line. These lines were laid above the distribution media at the two edges along the length of the stacked fabric lay-up. The resin line is closed at one end and connected to resin supply through the peristaltic pump at other end. The vacuum line is closed at one end and connected to a vacuum pump through the vacuum gage. It is standard practice to place the closed ends of these lines in opposite directions to each other.

**5.8 Top Mylar Film:**

Mylar film is cut to a dimension of 32" x 35" and placed atop the distribution media. This is done to protect the vacuum bag from the distribution media and also to protect the panel from the wrinkles on the vacuum bag, which could otherwise get molded onto the surface of the panel.

**5.9 Vacuum Bag:**

Nylon bagging film manufactured by Airtech known as Wrightlon, 2 mil Nylon, is cut to dimensions of 60" x 60", and was used as the vacuum bag. This film is placed over the mold area and was sealed firmly using extruded sealing compound (Richman Aircraft Supply #SM-5227). The sealant sealed off the vacuum bag and helped to maintain a uniform vacuum throughout the experiment.

**5.10 Peristaltic Pump:**

The use of this pump is the outcome of years of experience in resin impregnation techniques. This pump delivers fixed amounts of resin in the mold in particular time durations. It assures the in-plane and through-the-thickness soaking of the fabric in the resin. The quantity of resin (say cc/min) is dependent on the pump speed. The pump speed again is a function of the fabric-resin system and thickness of panel. The speed is decided upon based on experience and experimentation. Additionally, an ON-OFF timer is connected to the pump which keeps the pump running for certain periods and shuts it off for certain periods. The peristaltic pump was set to stay ON for 70% of a minute and turn OFF for 30% of a minute. It was set to run at 300rpm. At this set rate it took approximately 45 minutes to impregnate the entire perform. The pot life of the resin catalyst system was approximately between 80minutes and 100 minutes at room temperature.

### 5.11 Vacuum Gage:

A vacuum gage monitors the vacuum in the entire vacuum bagged setup during the resin impregnation process. It also detects any leaks in the bagging. A vacuum of about 2 torr is pulled initially to test the bag for any leaks before commencing the resin impregnation process. After reaching this vacuum the vacuum pump is turned off and all pipes sealed off and the vacuum gage is monitored for 30 minutes. If there is no drop in the vacuum over that period of time, a good vacuum seal is assured and the resin impregnation process can commence. During the resin impregnation process the vacuum is monitored and maintained at about 0.5 torr. If the vacuum is higher than that it causes the resin to boil within the bag, which results in air pockets in the panel.

### 5.12 Sealing the mold and creating a vacuum

After all the components mentioned in the section above have been stacked, the vacuum bag is spread over the mold plate and using the sealant tape the mold plate is sealed off. It is then tested for any leaks by creating a vacuum of about 2 torr. The vacuum pump is then shut off and the vacuum gage is then monitored to see if the vacuum of 2 torr holds in the bag for a period of about 30 minutes. Bag leaks are the most common problems observed during the fabrication process. This may be due to damage of the nylon film before cure. Nylon film is hygroscopic and subjected to moisture changes due to changes in the moisture level in the surrounding environment. Dry and brittle film can cause cracking when it is handled too much. There is also a possibility of leaks at the nylon material and sealant interface. Once the leaks have been removed and the vacuum bag completely sealed, the setup is now ready to be impregnated with the resin.

### 5.13 Resin preparation and degassing

The resin is mixed with the catalyst in the pre-calculated percentages as discussed earlier in Chapter 3. When the chemicals are added to the resin and mixed, the resin mixture becomes aerated. Thus this mixture needs to be degassed before it is injected into the mold. If it were not degassed, it would tend to cause air pockets in the fabricated panel. Thus the mixture is placed in a vacuum chamber, which is at approximately 5 torr and is degassed for about 10 minutes. Initially it can be seen that the resin begins to boil and the air is sucked out. Once there are no air bubbles in the resin mixture it is ready to be injected into the mold setup.

### 5.14 Resin impregnation

Once the resin is ready it is injected into the mold at a very slow rate. The flow of resin is controlled with the help of a peristaltic pump in such a way that it is allowed to flow in the distribution medium for some distance and then the resin inlet is shut off to enable the resin flow through the thickness. This cycle is repeated until the whole panel is soaked in resin. As mentioned earlier the peristaltic pump is set to run at 300 rpm with a 70% ON and 30% OFF timer setting. Once the entire perform and all components in the vacuum bag have been wet or impregnated the resin line is shut off. The vacuum pump is kept on for a while longer till there are no more air bubbles in the resin ejection line. The mold is kept at room temperature for the next 24 hours. This is termed green cure.

**Figure 2**
**Schematic of setup of VARTM process**

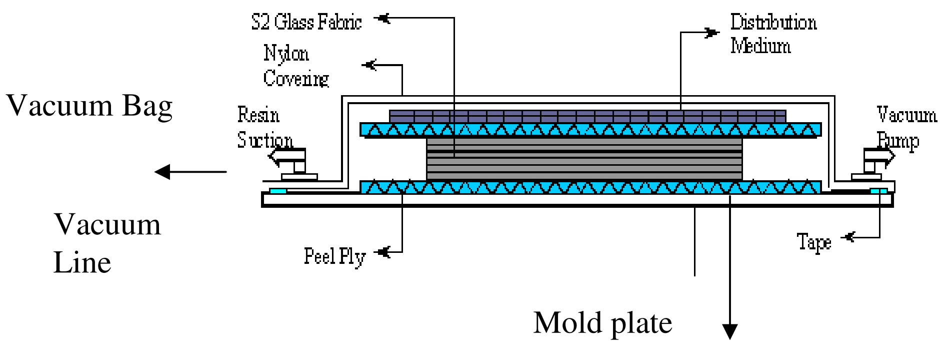
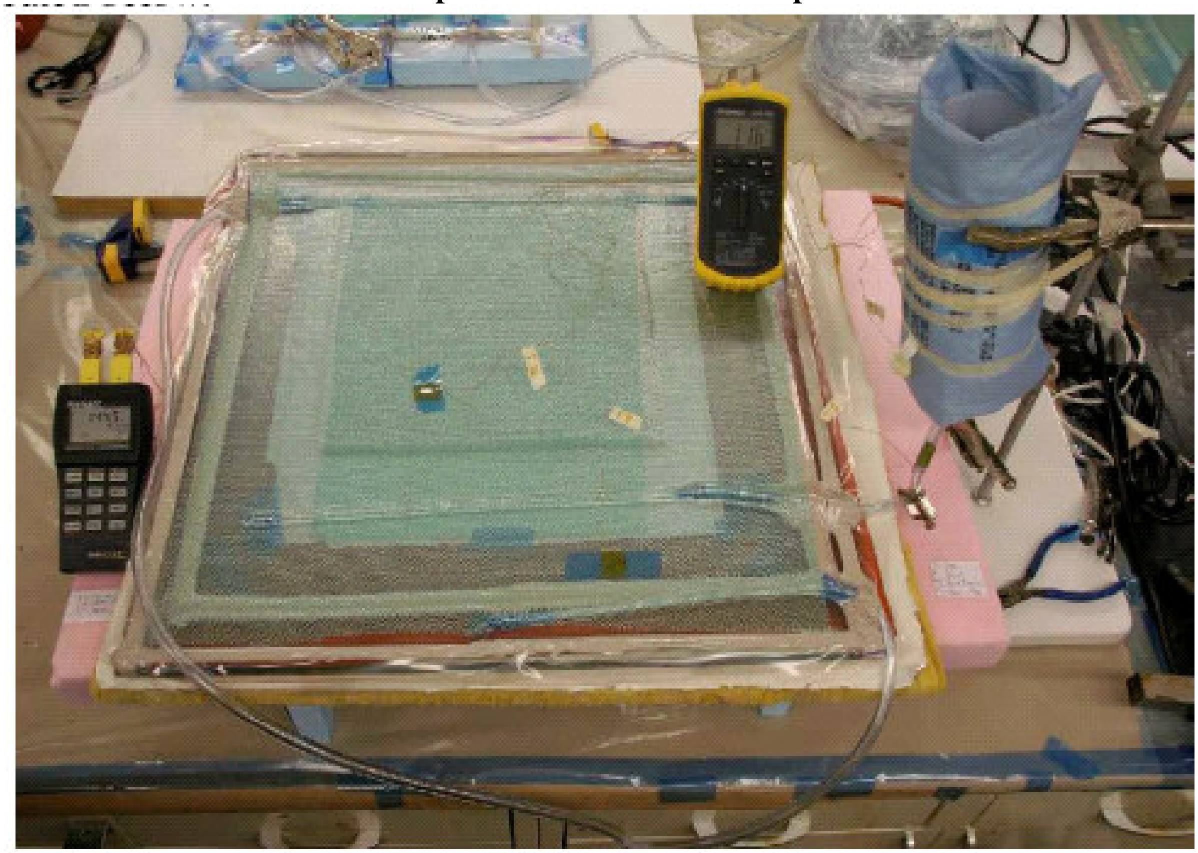



**Figure 3.**
**Experimental VARTM Set-up**



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