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14. ABSTRACT The objective of this report is to describe thermoplastic composite materials and processes and to demonstrate fabrication methods for molding these materials into transit bus flooring components or other large components for use in buses and other mass transit applications. The primary goal of this work is to demonstrate that these technologies can provide lower cost, lighter weight, and improved performance structures for mass transit applications. This fabrication guide was written to outline the basic requirements involved in design and fabrication of large long-fiber thermoplastic composite parts by Vacuum Assisted Resin Transfer Molding (VARTM)or by Thermoforming woven prepreg.

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Long fiber woven, thermoplastic composite, VARTM, thermoform, manufacture cost, weight reduction

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Foreward

This fabrication guide describes steps required to apply the technology of long fiber and continuous woven thermoplastic composites in transit bus applications for the U. S. Department of Transportation and the Federal Transit Administration. The goals of improved safety, reduced weight, and lower cost are very important to the transportation industry. This report describes the design guidelines and fabrication methods related to the thermoforming and resin transfer molding of long-fiber thermoplastic composite transit bus components.

Notice

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The authors wish to express their appreciation to the Federal Transit Administration for the support of this work. We thank the C.A. Lawton Company for the use of their plastication equipment and North American Bus Industries for their guidance in component selection and design guidelines. We acknowledge the following for their contributions to the technical effort of this project: George Husman, Tim Hartness, Uday Vaidya, Greg Janowski, Krish Chawla, Joel Dyksterhouse, Patric Moriarty, Mike Dyksterhouse, Andy Grabany, Chad Ulven, Shane Bartus, and Brian Pillay. We acknowledge and thank Lisa White for her assistance with the preparation of reports.

Executive Summary

The Fabrication Guide for Woven Prepreg Thermoforming and Vacuum Assisted Resin Transfer Molding (VARTM) outlines part design, processes requirements, material selection, tooling, and equipment specifications related to the manufacture of large parts for the transportation industry using these methods.

This guide describes the process by which woven thermoplastic prepreg is produced and process as well as outlining the VARTM process for similar parts.   There is discussion of the expected mechanical properties and design constraints. Descriptions of the critical equipment and tooling are given with an emphasis on equipment capabilities and specific performance characteristics.

1. Introduction

The Federal Transit Administration (FTA) has encouraged innovative technologies to be implemented in mass transit applications, particularly when improvements in performance, cost, weight reduction, or safety may be realized. The results of efforts made by Southern Research Institute under FTA Project AL-26-7001-01 were directed to the fabrication of woven prepreg thermoplastic composite bus flooring subcomponents with demonstration of several contributing technologies. Primary considerations for this application were weight savings, to reduce fuel consumption, and cost savings to encourage usage in commercial applications. The choice of bus flooring as a thermoplastic composite application goal was the result of consideration of overall weight reduction calculations for several large-area bus components. The primary selection issue was based on the total weight of flooring installed on a standard transit bus as well as the potential increase in functional lifetime over conventional flooring structures.

2. Objectives

The intent of this report is to provide general guidance in the design, and fabrication of a large area component for use in a commercial transit bus using Vacuum Assisted Resin Transfer Molding (VARTM) or continuous woven broad goods processes. The major manufacturing issues addressed involve part material selection, processing and tooling.

3. General Guidelines for Thermoplastic VARTM

The use of VARTM methods with thermoplastic resin as the finished matrix of the composite is quite different from the usual VARTM process that utilizes thermoset resins in conjunction with a given fiber reinforcement. In the case of thermoset resins, there are a large number of viable candidates that possess the low viscosity and relatively low cost characteristics that are needed for commercial transportation applications. In the case of thermoplastic resins, two candidates were identified as feasible resins, Nylon 6 and cyclic polybutylene terephthalate (c-PBT). Only the Nylon 6 was economically attractive enough to pursue. The use of a Nylon 6 precursor, ε-caprolactam, was chosen because of its low viscosity and relatively low cost. Other thermoplastic resin precursors may become available in the future that are both inexpensive and amenable to VARTM processing methods. The Nylon 6 system used in our studies consisted of materials commercially available through the Brüggemann Chemical U.S, Inc. (Newtown Square, PA). The Brüggemann C10 catalyst and C20 activator were the raw materials used along with the generic ε-caprolactam in our trials . The manufacturer's guide specified using 1.2 to 3 % catalyst and 1.0 to 2.5% activator in an inert atmosphere.

3.1 Material Guidelines

The successful application of thermoplastic VARTM processing depends upon relatively low viscosity of the prepolymer and the compatibility of the resulting polymer resin with the fiber and the fiber sizing formulation. The prepolymer must have a viscosity less than 1000 cp so in order that it can effectively permeate the fiber perform in a reasonable period of time using vacuum forces alone to draw the prepolymer through the entire part. The pot life of the prepolymer must likewise be sufficient to insure that the prepolymer will make its transit through the part before significant polymerization occurs that could leave dry spots or poorly wet-out sections in the perform.

The issue fiber sizing compatibility with the resin cannot be ignored since the wetting of the fiber by the resin or prepolymer depends critically upon the compatibility of surface energy for fiber wetting and chemical compatibility in order that excellent coupling occurs. The realization of the fiber reinforcement mechanical potential depends critically upon the compatibility of the prepolymer and polymer with the fiber. Additional problems can also occur if the fiber sizing interferes with the rate of polymerization by either accelerating or inhibiting it. Acceleration of the rate of polymerization can prevent filling of the part due to increased viscosity of the matrix and inhibition of polymerization may increase the cycle time to unacceptably long periods or quench it altogether.

3.2 VARTM Processing Guidelines

In the particular case of polymerization of ε-caprolactam, moisture content of the prepolymer must be less than 200 ppm to avoid quenching the reaction. All resin lines and containers must be dry as well.

Recent developments in composites processing methods have focused on cost-effectiveness and ability to produce integrated structures using liquid molding techniques. Vacuum assisted resin transfer molding (VARTM) has emerged as a leading cost-effective process that utilizes innovative developments in one-sided tooling and vacuum-bag technology. VARTM is cost-effective for small or medium sized production runs because it eliminates many of the tooling costs associated with long high-temperature and pressure cycles incurred in an autoclave process environment. This process is a very attractive alternative to spray-up or impregnation methods, and is far less expensive than conventional manufacturing large-scale production methods such as compression or injection molding. The VARTM process is reduced to a simple single-sided tooling that requires only consumables in place of expensive molds. During the VARTM process, resin is infused into dry fabric preform placed in single-sided tooling that covered with an inexpensive vacuum bag film as illustrated in Figure 3.2-1.

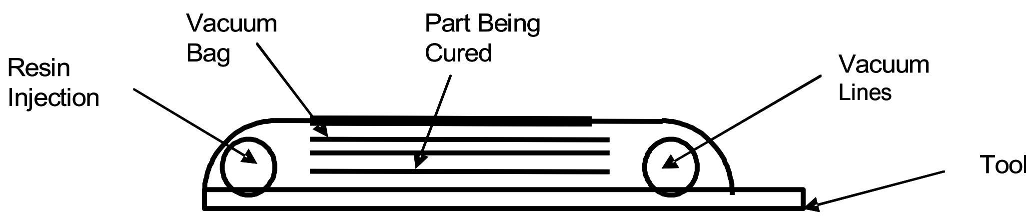


Figure 3.2-1 Low Cost VARTM Processing

A distribution mesh aids in distributing the resin evenly over the fiber preform. Large structural parts with inserts or multiple layers can be produced rapidly. In multi-layered constructions, the VARTM process can be effectively utilized to produce parts by co-injecting resin to cause simultaneous part wet-out. Other advantages of VARTM are low process volatile emissions, higher fiber-to-resin ratios and good repeatability. While most studies have considered VARTM for thermoset type systems, similar processing of thermoplastics has been limited to their inherently high viscosity. For VARTM to work successfully, the resin should lie in the 100-500 cps viscosity range.

3.2.1 FASTRAC VARTM Process

We have investigated the feasibility of using the FASTRAC VARTM approach for thermoplastic systems for production of transit bus floor structures. A cross section of the process is shown in Figures 3.2.1-1and -2. The concept uses a double vacuum bag. The top bag covers a channeled tool which is placed over the bottom bag that holds the plies under vacuum. Applying a vacuum between the two bagging materials causes the bag at the top surface of the plies to be pulled towards the channeling of the tool. This causes channels wide enough for the resin to race through. Once the resin reaches eighty percent of the distance of infusion, the channeled tool and the top bagging is removed. The vacuum now pulls the bagging tight over the plies helping to wet out the plies. This process provides significant time efficiency and ability to produce/process very large flat shapes. Figure 3.2.1-3 illustrates the kind of tooling heating needed to effectively polymerize the resin.

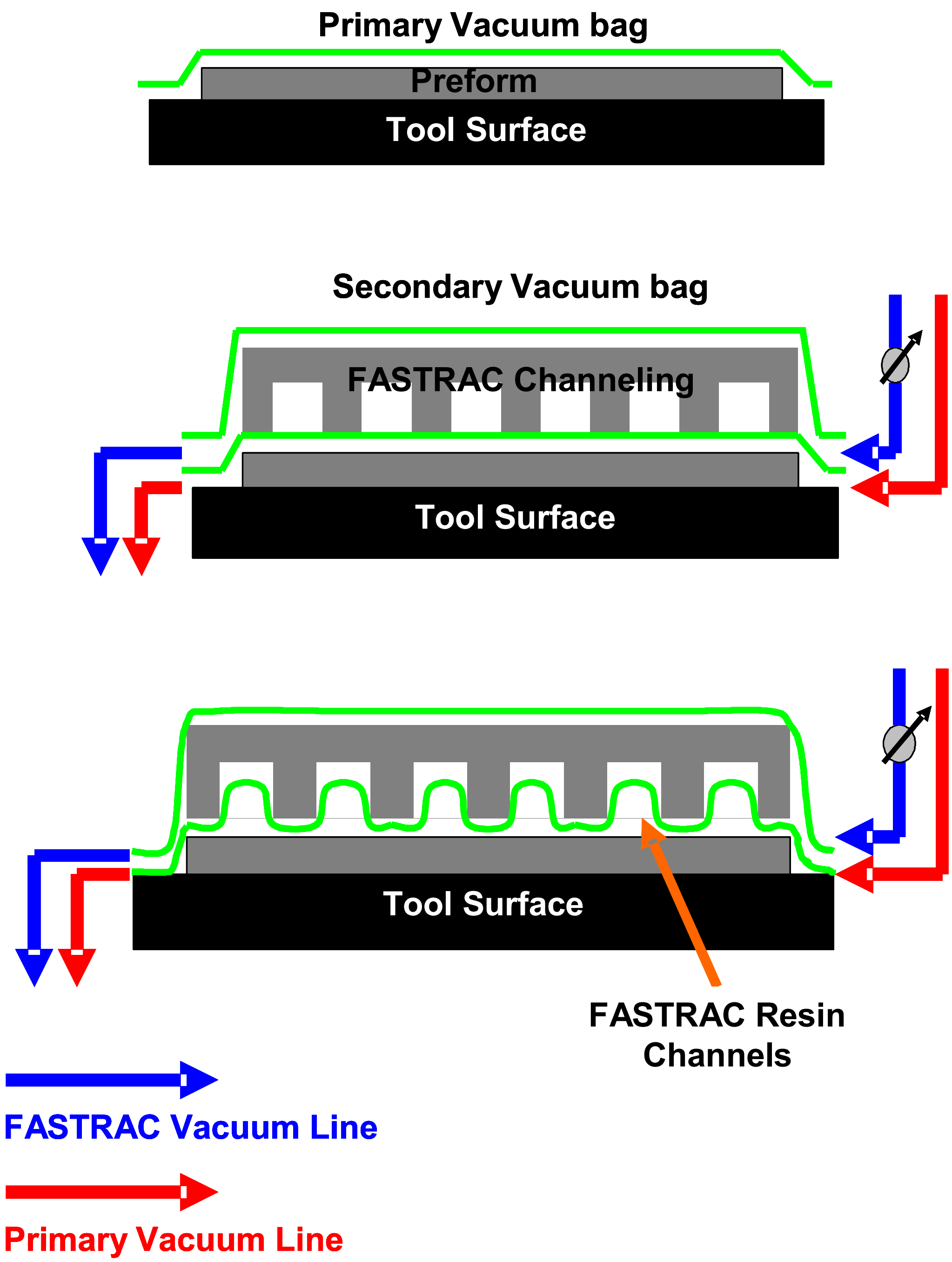


Figure 3.2.1-1 Illustration of FASTRAC Process for Rapid Processing

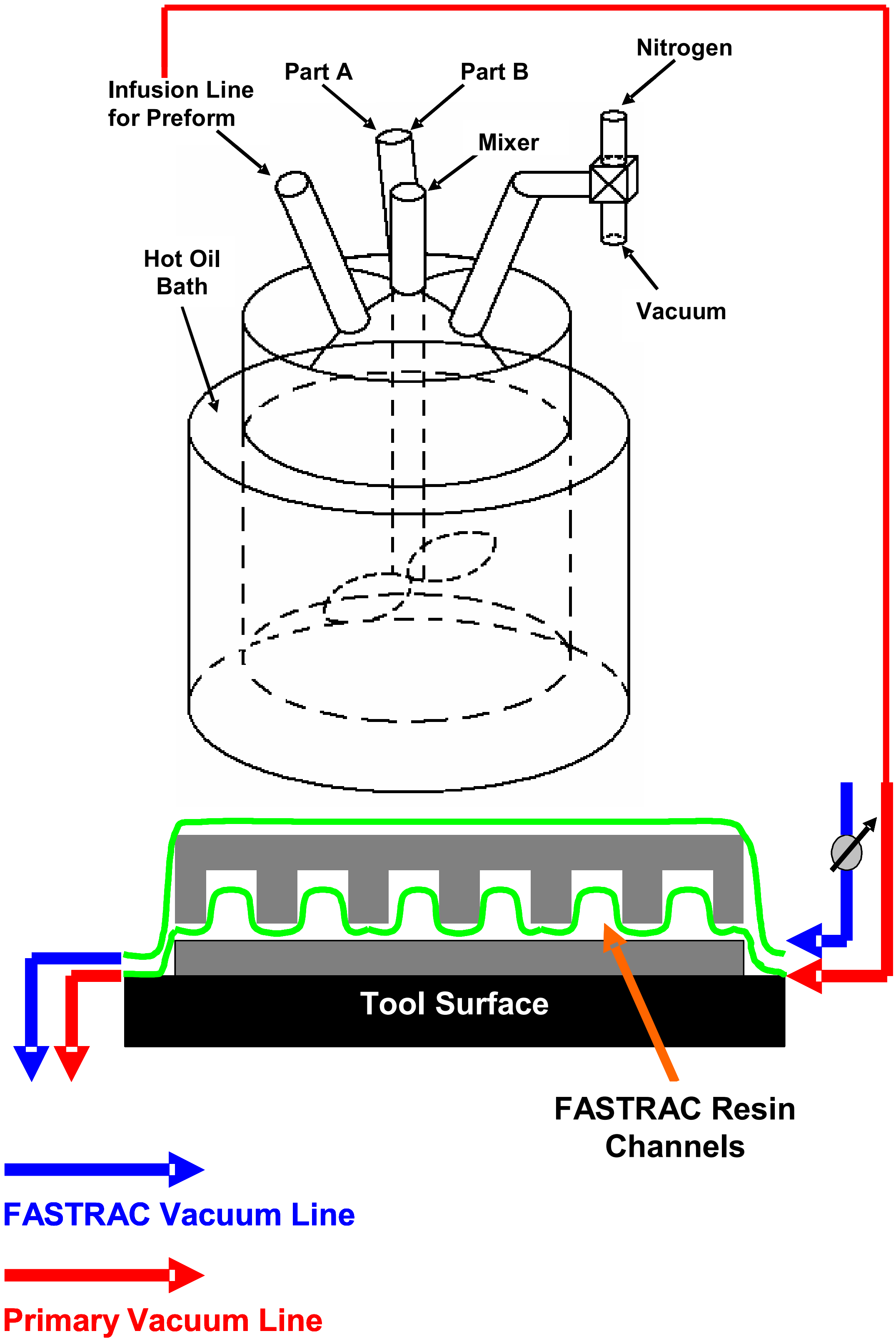


Figure 3.2.1-2 High-Temperature Setup for Nylon VARTM Processing

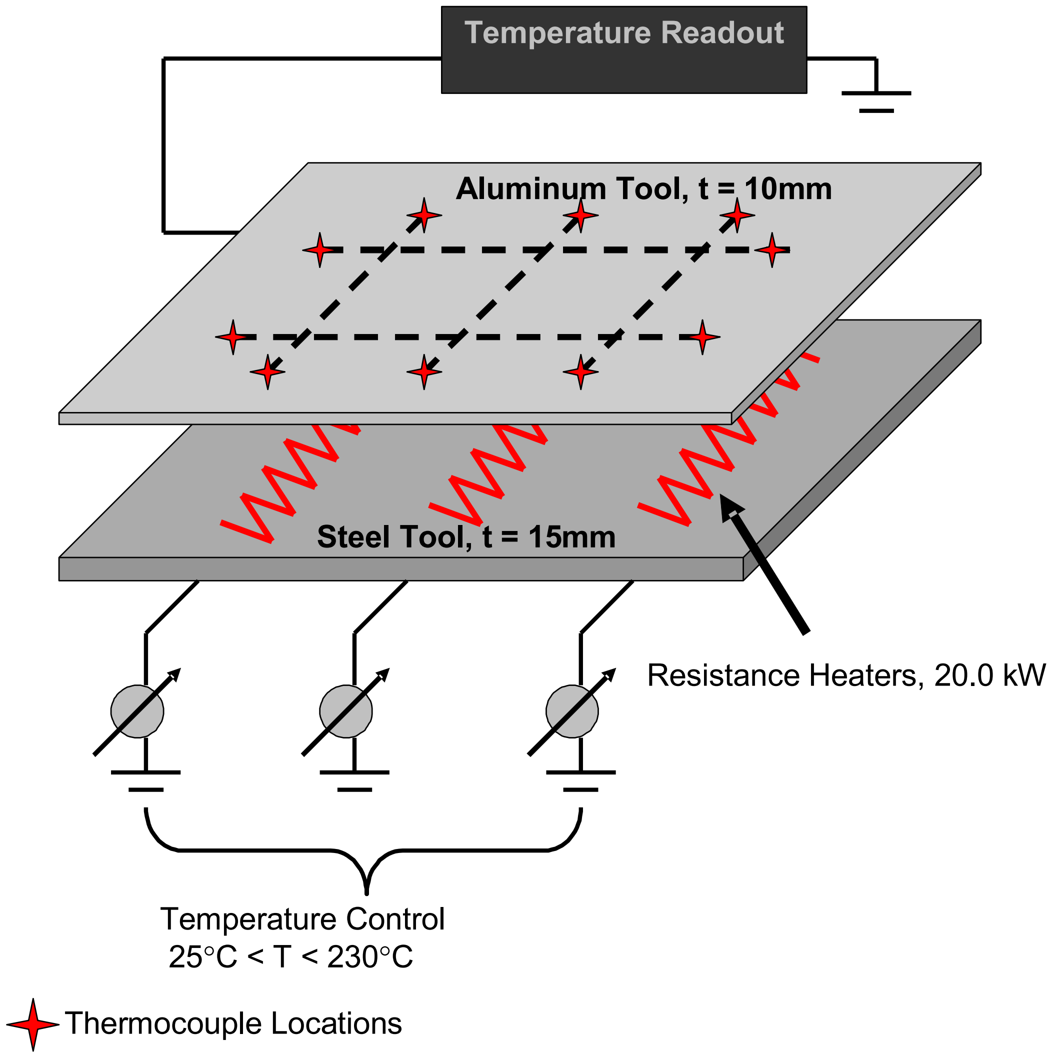
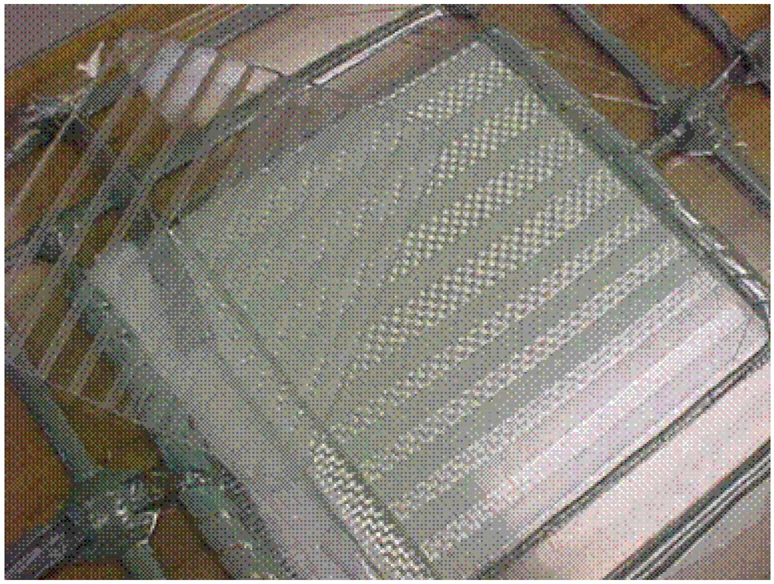


Figure 3.2.1-3 Heated Tooling Schematic for Flat Plate

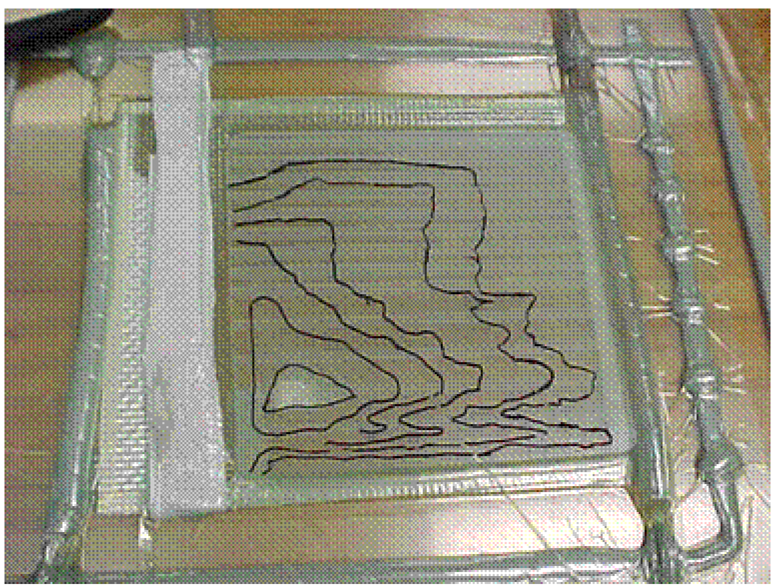
The FASTRAC processing system has been successfully implemented using higher viscosity thermoset resins with very short gel times. We have successfully used the process in castable thermoplastic systems such as reactive Nylon 6 resin.

Thermoplastic resins polymerize at temperatures of between 100° C to 200 ° C. Nylon 6 polymerizes at 120° C to 150° C and cyclic polybutylene terephthalate (c-PBT) at 180° C to 200° C. Therefore, there is a need to provide a controlled high temperature processing setup for VARTM. Furthermore, the sensitivity to moisture during the polymerization step necessitates a controlled inert processing environment for Nylon 6.

An example resin wet-out of Nylon 6 on E-glass fabric was demonstrated and illustrated in Figure 3.2.1-4 and -5 .



(a)



(b)

Figure 3.2.1-4 Various Stages of Processing of FASTRAC Processing
(a) Bagged Preform, showing infusion channels
(b) Flow of resin through the channels

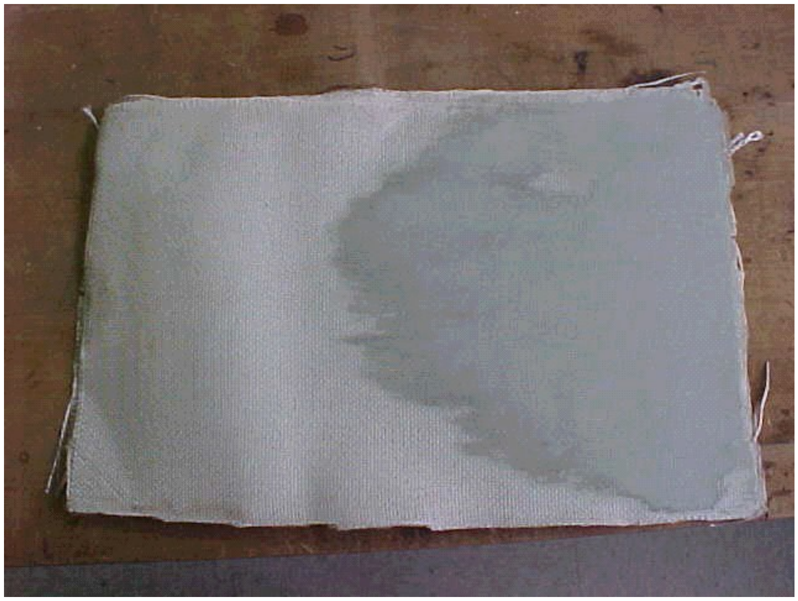


Figure 3.2.1-5 Wet Out Characteristics of Nylon to E-Glass Fiber

The Nylon 6 system described here consists of caprolactam monomer using Brüggolen C10 catalyst and Brüggolen C20 activator (Brüggemann Chemical U.S., Inc., Newtown Square, PA). The manufacturer's guide specified using 1.2 to 3.0 % catalyst and 1.0 to 2.5% activator in an inert atmosphere.

The following process was employed using carbon fiber preforms.

- Teflon tubing was slit and used for resin distribution over the width of the preform.
- Four layers of 210 x 210 mm de-sized woven carbon fabric were used in the lay-up.
- The woven carbon preform was vacuum bagged on a heated processing table. High-temperature bagging materials and sealant tape were used to seal the preform.
- The caprolactam (200g) plus activator (3g) was heated at 75 degrees C in an oil bath until it reached a fully liquid state. The solution was continuously agitated using a mechanical stirrer.
- When the entire solution was in a liquid form, the catalyst (6g) was added to the solution.
- Dry nitrogen was used to continuously purge the system to prevent any moisture from getting into the flask.
- The carbon lay-up was heated to 120 degrees C and also purged using dry nitrogen.
- The resin was then infused into the preform.
- After the resin filled the preform, the temperature of the heated table was raised to 150 degrees C to complete the polymerization

The best conditions for processing were achieved by using 3 % catalyst and 1.5 % activator. The two tanks were heated to 90 °C, then mixed dispensed into the fabric and heated to 150 °C. Under these conditions, the polymerization process was achieved in approximately 3 minutes.

Figures 3.2.1-6 and 3.2.1-7 il1ustrate the infusion process.

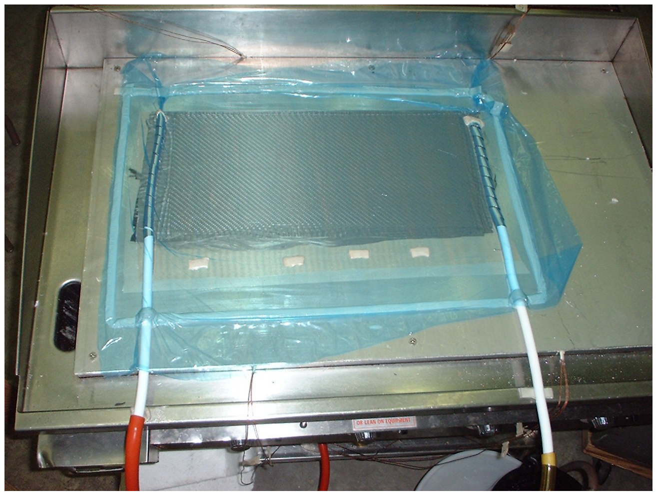


Figure 3.2.1-6   Carbon Fiber Preform Bagged under Vacuum and Prepared for Infusion with Caprolactam

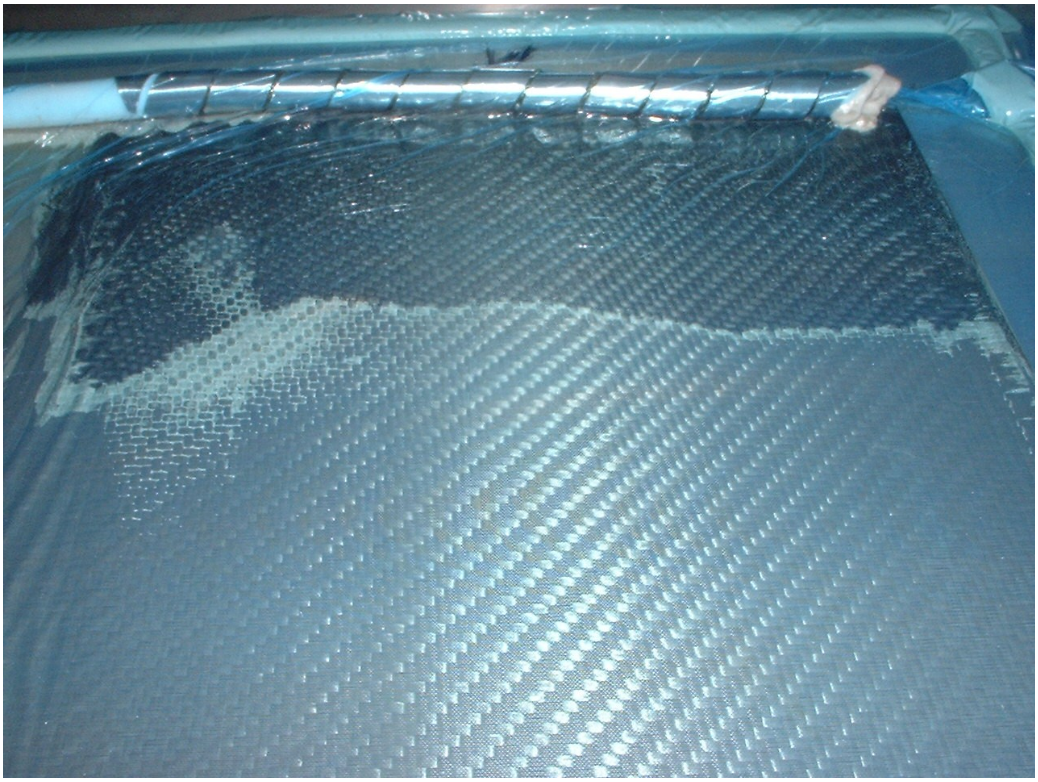


Figure 3.2.1-7 Resin Infusion of Caprolactam in Progress

The primary caveats for the Nylon 6 polymerization is the exclusion of moisture and rapid infusion of resin throughout the preform to insure uniform time and temperature history.

4. General Guidelines for Woven Thermoplastic Broadgoods

The use of woven thermoplastic composite broadgoods is an efficient method for laying up a substantial area and thickness of composite for processing in a thermoforming environment. An important requirement for the effective thermoforming with vacuum bag pressure is that the prepreg tape used to weave the fabric must be evenly and completely wet-out by the resin. The degree wet-out of the fiber by the resin is dependent on the compatibility of the resin and the fiber sizing as well an even application of the resin to the fiber under appropriate processing conditions to avoid dry fibers. The prepreg tape can be woven into broadgoods with various weaving patterns appropriate to the application. The choice of fiber type, resin, and fiber content may be adjusted to fit the mechanical and cost constraints of the final part desired. Generally, in the case of polypropylene/glass tape the percentage of fiber by weight can be set from 30 percent to 60 percent without great difficulty.

Polypropylene/E-glass tape was produced in a 12.7 mm width and then woven in to a fabric as shown in Figure 4-1. This material is about 1 meter wide. A closeup view is shown in Figure 4-2.

Figure 4-1 Roll of Woven Polypropylene/E-glass Fabric

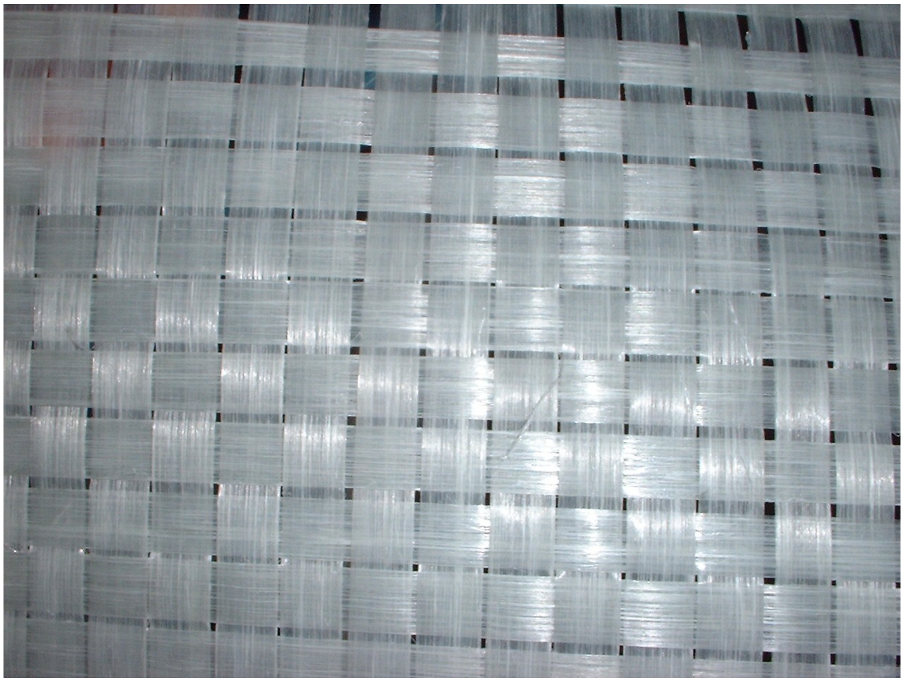


Figure 4-2 Close-up View of Woven Polypropylene/E-glass Fabric

The woven fabric was consolidated in a heated double belt press formed the raw woven fabric into a dense composite. A sheet of that material is shown in Figure 4-3.

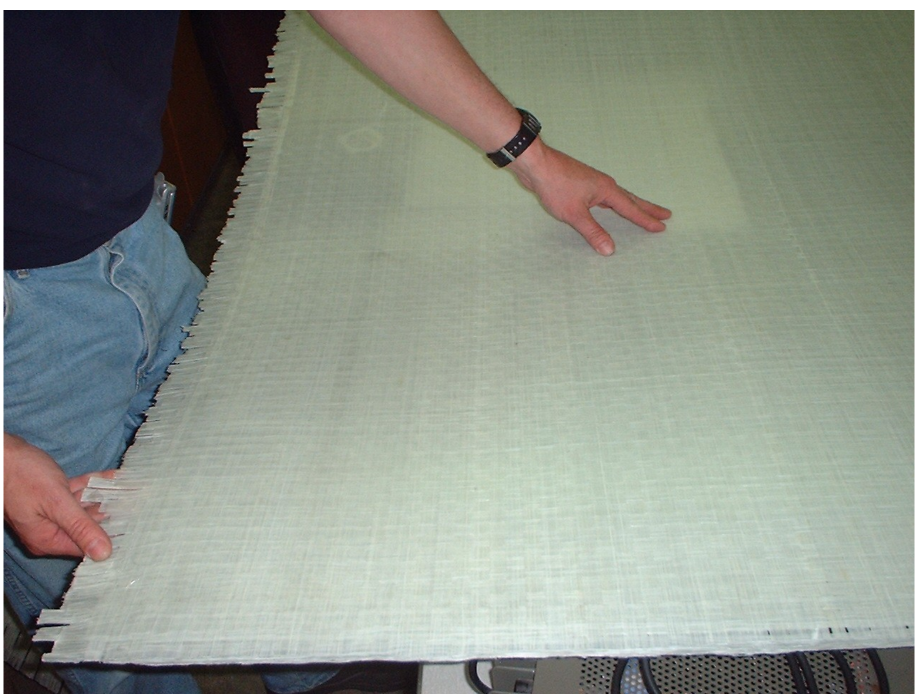


Figure 4-3 Consolidated Sheet of Woven Polypropylene/E-glass

A close up of the same material is shown in Figure 4-4. The consolidated forms can be used as-is as structural panels, subsequently formed in standard thermoforming operations, or joined to other components by fusion or adhesive bonding.

Figure 4-4 Close-up of Consolidated Woven Polypropylene/E-glass

The woven material can be consolidated by vacuum bagging and or bagged and autoclaved if additional pressure is need to form the part. A prototype bus floor subcomponent was fabricated from this woven form of thermoplastic composite material using vacuum bagging methods with a heated tool.

4.1 Processing Guidelines For Thermoforming Woven Broadgoods

The particular materials chosen for the woven broad goods were polypropylene (BP/Amoco 9965) and E-glass (Owens Corning 225 4588). The tapes were made using the DRIFT process and then woven into broad goods. Figures 4.1-1 and 4.1-2 show the weaving process that was performed by American Iwer, Greenville, SC.

Figure 4.1-1 Picture of Loom Weaving Thermoplastic Prepreg

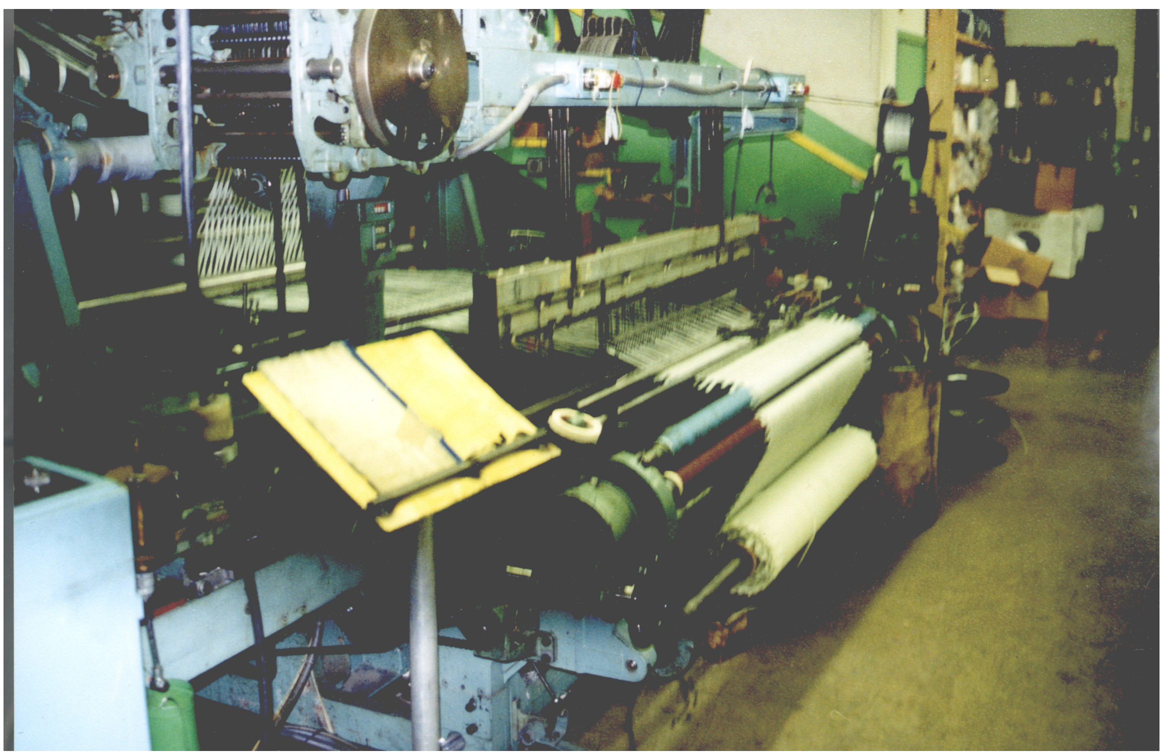


Figure 4.1-2 Take-up Accumulator for Woven Prepreg Fabric

Each layer of fabric when consolidated is about 0.6 mm thick. Flat parts can be made in various thicknesses and widths using a heated double belt press. The flat portion

Multiple layers of woven prepreg may be consolidated into a single flat sheet using a belt press concept like that shown schematically in Figure 4.1-3.

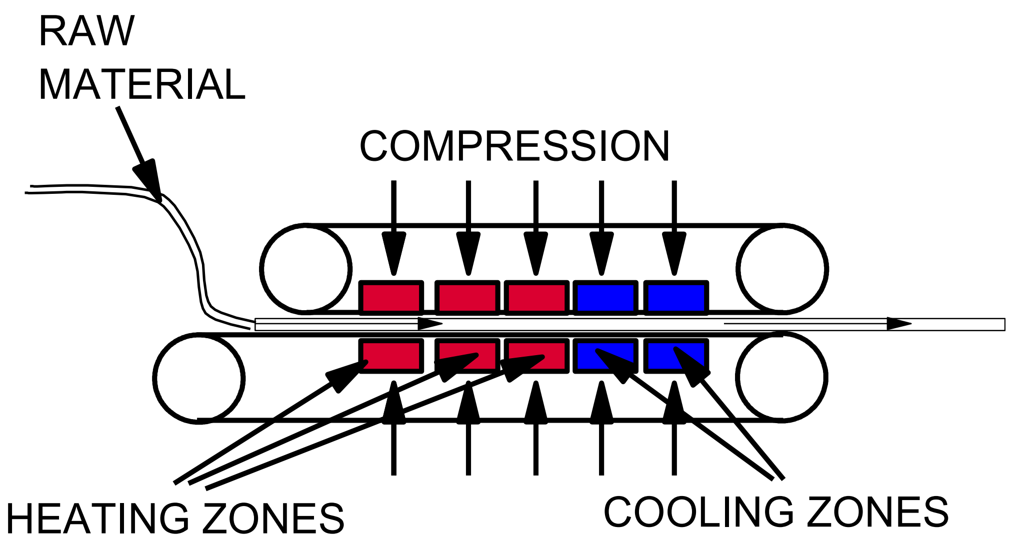


Figure 4.1-3 Schematic of Double Belt Press

4.2 Guidelines For Double Belt Press

The major considerations for the selection or use of a double belt press for consolidation of woven prepreg are cost, size and production rate. Double belt presses are expensive; therefore, matching the size and production capacity to the need is very important. Plan for 80 percent operational time based on a 24 hours per day/7 days per week schedule.

The thickness of the product is determined by the numbers of plies fed into the press. The size of the press determines the width limits and the rate of production. Raw material is introduced at room temperature and then heated under compression until the sheet is consolidated. The sheet remains under pressure until the cooling zones are passed and the material can be handled. A cutting station may be located near the output of the press for cutting the sheet to practical dimensions. Material can be processed at a fairly high rate. The linear velocity of a large belt press is nominally 5 meters per minute for a 3 to 4 mm thick material about 1.25 meters wide. This rate of production could produce about 2 metric tons per hour of 60 percent glass/polypropylene sheet material. Power requirements for such a press would be in excess of 1000 kw, and that is primarily associated with heating and cooling functions.

4.3 Guidelines for Discontinuous Woven Material Handling and Processing

The handling and processing of discontinuous woven materials has application for single part fabrication that cannot be achieved with a continuous constant profile process. The primary areas to be mentioned here are fabric cutting and vacuum bag thermoforming.

4.3.1 Fabric Cutting

Cutting woven prepreg is an operation that should be minimized during part design with a consideration for tooling constraints as well. The chief difficulty that one encounters in cutting a pattern out of a woven material is that of having tapes on the edge of the cutout falling out during the cutting operation or during handling. For any significant volume of production, cutting with a water jet or laser technology is needed to reduce edge damage. Laser cutting has the advantage of not wetting the material, but heat-sealing the edges that would reduce handling damage. For low volume applications, mechanical cutters are acceptable as long as the handling damage is minimized.

4.3.2 Vacuum Bag Thermoforming

A processing method that has similarities to the VARTM process is the vacuum bag thermoforming process. The tooling for vacuum bagging is single-sided which reduces cost. The tooling can be made from a variety of materials depending on the volume of parts and the rate of production needed. In addition, all of the bagging components and tooling need to gracefully handle the process temperatures encountered with the resin system utilized. Aluminum tooling has the advantage of machinability and high thermal conductivity which can reduce both heating and cooling time. Steel is the most durable tooling, but also the most expensive. Kirksite is a zinc-based alloy that can be used for prototyping tool that may be recast and recycled after its use.

Regardless of the choice of tooling material, one must size the heating and cooling function so that the respective heat and cool cycles are acceptably rapid. For most applications, direct electrical heating is the most inexpensive approach to getting the tooling and prepreg up to processing temperature. Cooling can be effected with water spray into internal channels of the mold that will turn of steam and be vented away safely. It is also feasible to use circulating oil as a heating and cooling medium, which eliminates the wiring associated with the cartridge heaters. Sizing of the heating capacity of the tooling is dependent on the mass of the tool, the heat capacity of the tooling material, and how rapidly the tool is required to heat up. The same constraints hold for cooling capacity. Figure 4.3.2-1 shows an example of an aluminum mold with associated cartridge heaters. This particular mold weighed about 320 kg and could be raised to a temperature of 50˚C in about 6 minutes. This required about 42 kw of heating.

Figure 4.3.2-1 Aluminum Mold Half Showing Inserted Cartridge Heaters

Figure 4.3.2-2 shows a mold prepared for vacuum bagging of a woven thermoplastic material. This prototype mold has material hold-down clamps to keep the prepreg conformed enough to the mold until proper vacuum bagging can occur. In a production situation, automatic slides would perform the hold-down function to achieve a shorter cycle time. The thickness of vacuum bag consolidated parts is controlled by the number of layers of woven prepreg stacked in the mold. In case of the sine wave rib structure, eight layers were stacked to obtain a 5mm thick part. The eight layers were consolidated in two steps because of the difficulty in manually handling all eight layers at once.

Figure 4.3.2-2 Mold Prepared for Vacuum Bag Thermoforming

Once a part is consolidated, it can be used or bonded to another component. In production circumstances, vibrational or ultrasonic bonding is very effective. On a more limited prototype production, hot melt adhesives can be used effectively as shown in Figure 4.3.2-3. On a large part the adhesive can be applied in the proper place and quantity and permitted to cool before the secondary operation of putting the parts together and heating to bond, Figure 4.3.2-4.

Figure 4.3.2-3 Part Bonding with Low Temperature Melt Adhesive

Figure 4.3.2-4 Placement of Secondary Part to be Adhesively Bonded

It is usually desirable to minimize extra bonding operations for the sake of both economics and strength.

5. Design Guidelines for Woven and VARTM Thermoplastic Composites

The basic guidelines for woven thermoplastic or VARTM components are similar to those encountered in other composite structures.

The most important guidelines are the following:

- Design with the process and tooling in mind
- Simulate when possible
- Do not assume isotropic mechanical properties of the materials
- Use continuous processes such as belt press consolidation or hot roller forming when feasible
- Avoid adhesive bonding by designing part and process to form it in one step if possible
- Avoid changes in thickness where ever possible for the sake of mechanical performance. At least minimize it. Thickness variations encourage warpage due to different cooling dynamics. If changes in part thickness cannot be avoided, it is best to taper the change gradually over a long distance. The length of the transition in thickness should be at least 3 times of the change in thickness. Avoid changes in thicknesses that are more than 3 mm. Stage thickness transitions with prepreg layers stepped to minimize thickness steps.
- Avoid sharp edges and sharp radii in a part design. These can cause a high level of stress concentration and is often the reason for part failures. Sharp edges and transitions may also increase fiber damage.

Ribs located on one side of the part may be seen on the opposite surface. If this is a problem in the design, avoid ribs in this area or alternatively reduce the mass of material by reducing the thickness of ribs thereby minimizing sink marks. Ribs should be drafted with approximately a 1° angle to assist in part extraction. The thickness of the rib should not exceed 0.6 times the wall thickness. A radius between rib and wall reduces stress concentration. True ribs are not feasible with continuous weave prepreg so that the caveats that are true for the VARTM process are not strictly applicable with the woven thermoforming process.

Glossary of Abbreviations and Acronyms

Cadpress	Software for mold-filling of long fiber thermoplastic composites, The Madison Group, Inc.
c-PBT	Cyclic polybutylene terephthalate
Copolymer	Combination of two or more polymers into one molecular chain
DRIFT	Trade name for a directly impregnated thermoplastic composite
Dynatup	Trade name for an instrumented falling dart impact test
E glass	Common grade of fiberglass used in commodity composites
Falling dart test	Impact test defined in ASTM standard D-3029
FASTRAC	Trade name for a resin transfer molding method
GMT	Glass mat thermoplastic composite
High melt flow	Polymer with melt flow index greater than 50 g/10 minutes
Homopolymer	Polymer consisting of similar subunits in the molecular structure
Izod test	Impact test defined in ASTM standard D-256
Longitudinal	Sample orientation in the direction of predominant fiber orientation
PA6	Nylon 6, polyamide
PP	Polypropylene
Random	Material with fiber orientation equal in all directions
Size	Coating applied to fiber bundles to assist with respect to handling and surface compatibility
Transverse	Sample orientation orthogonal to predominant fiber orientation
VARTM	Vacuum assisted resin transfer molding

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 3.0 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)
1 square yard (sq yd, yd^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (l)
1 pint (pt) = 0.47 liter (l)
1 quart (qt) = 0.96 liter (l)
1 gallon (gal) = 3.8 liters (l)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

PRESSURE (APPROXIMATE)

1 POUND/SQUARE INCH (lb/sq in) = 6897 PASCALS (Pa)

TEMPERATURE (EXACT)

$[(x - 32)(5/9)]^\circ F = y^\circ C$

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeters (mm) = 0.04 inch (in)
1 centimeters (cm) = 0.4 inch (in)
1 meter (m) = 2.2 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectares (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

VOLUME (APPROXIMATE)

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (l) = 2.1 pints (pt)
1 liter (l) = 1.06 quarts (qt)
1 liter (l) = 0.06 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

PRESSURE (APPROXIMATE)

1 Pascal(Pa) = 1.45×10^{-4} POUND/SQUARE INCH (lb/sq in)

TEMPERATURE (EXACT)

$[(9/5)(y + 32)]^\circ C = x^\circ F$

QUICK INCH-CENTIMETER LENGTH CONVERSION

INCHES	0	1	2	3	4	5	6	7	8	9	10

CENTIMETERS 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25

25, 40

QUICK FAHRENHEIT-CELCIUS TEMPERATURE CONVERSION

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°