122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #11329

Development of a Solvent-Based Prepreg Treater

Ms. Nikki Larson, Western Washington University

After receiving my bachelor degree in Mechanical Engineering from Bradley University, I started working for Boeing. While at Boeing I worked to receive my master's degree in Mechanical Engineering with an emphasis in Materials and Manufacturing. After leaving Boeing I spent several years in equipment research and development at Starbucks Coffee Company.

From there I decided my heart lied in teaching and left Starbucks to teach Materials Science Technology at Edmonds Community College. I eventually moved to Western Washington University where I have been faculty in the Plastics and Composites Engineering Program (formerly Plastics Engineering Technology) for the past 10 years. My research interests are in composite manufacturing.

Mr. William Rasnack
Nicole Hoekstra, Western Washington University
Chloe Boland, Space Exploration Technologies
Eric Leone
Isaac Santos
Katherine Rust Healy

A passionate engineer with a particular interest in sustainable practices and products. Currently working for Zodiac Aerospace as a Materials and Process Engineer, within Zodiac's Research and Development Department.

Dr. Tanveer Singh Chawla, Western Washington University

Dr. Chawla is an Assistant Professor in Plastics and Composites Engineering at Western Washington University, Bellingham. His research is in the field of manufacturing and repair of fiber reinforced composites.

Sunni Shoepe

Developing a Lab Scale Solvent-Based Prepreg Treater

Engineering and Design Department
Western Washington University

Abstract

A lab scale continuous process solvent-based prepreg manufacturing machine (prepreg treater) is a useful tool for small-scale production runs carried out by research teams involved in various projects related to advanced composites. Such a machine can also be used in school laboratories for teaching purposes. However, industrial compact prepreg treaters available for purchase are prohibitively expensive.

This document details the work done by undergraduate students at Western Washington University to design, develop, and qualify a modestly budgeted, solvent-based prepreg manufacturing machine to be used for investigation of new prepreg resin systems. The steps undertaken to manufacture the machine and qualify it are explained in detail and can be helpful to educational institutions that may have requirements of such a treater for research and/or teaching.

Definitions

Prepreg is commonly defined as a reinforced fabric that has been impregnated with a resin matrix. It is frequently used in place of a traditional hand layup for a number of reasons, including increased control over resin content, decreased scrap and mess, and generally improved reproducibility during processing. [1] Following impregnation of the pre-polymeric resin system into fibers, the prepreg is considered B-staged. At this point in processing, the resin has undergone a partial cure and begun to crosslink. As such, storage in freezers is required, to prevent further crosslinking of the material into a fully cured C-stage product. [2]

Prepreg is manufactured primarily using two processes: solvent coating and hot melt coating. In the solvent coating process, fabric is threaded between metal rollers and run through a resin bath, then fed through a series of ovens to partially cure the material. Following a short cooling period, the prepreg is ultimately wound up at the other end of the machine into a roll, for ease of storage [3]. The resin in the bath is dissolved in a solvent, typically an alcohol or acetone, to reduce its viscosity and increase its ability to penetrate the fibers. The solvents are released as volatiles in large in-line ovens as a part of the process during B-staging. In contrast, to produce prepreg using hot melt coating, fabric is run through a carrier paper containing a fixed quantity of resin, followed by the application of pressure with heated compaction rollers. This simultaneously impregnates the fabric and B-stages the resin. The fabric is then cooled and the paper removed.

1. Introduction

A major objective for the Department of Engineering and Design at Western Washington University (WWU) is to provide a hands-on technical experience alongside development of fundamental concepts. This is best achieved through the incorporation of industry-sponsored projects into curriculum, allowing undergraduate students to apply concepts from their coursework to real world problems and gain invaluable research experience. This project focuses on the development of a lab scale prepreg treater for the use in formulation, testing, and development of new thermosetting resins systems.

A major function of the treater's design is the ability to allow for processing flexibility in future enterprises. Qualification testing was performed using fiberglass cloth (E-glass 7781) and a phenolic resin, however future research will incorporate various resins systems and fabrics. As a result, all projects to modify and develop the machine have deliberately enlarged scopes, with the intent of preventing limitations upon future research. The current system is designed to handle processing of the following resin systems:

- Phenolic
- Epoxy
- Bismaleimide
- Benzoxazine

At present, no courses in the curriculum are utilizing the treater due to the ongoing development of the machine and process. However, following the completion and optimization of the machine, the department aims to incorporate the treater into the curriculum, either as a means of demonstrating the prepregging process, or as a hands-on laboratory activity. As a result of the treater's intentional design flexibility, the processing parameters can easily be manipulated for this wider range of uses.

2. Development of Treater

2.1 Design

Although both methods of prepreg production are industrially relevant, the research team chose to build a solvent-based treater in order to mimic the manufacturing conditions of the large-scale aerospace manufacturer that the team has been working with. The lab-scale treater, dubbed the Easy-Preg Treater, can be broken down to four main components, illustrated in Figure 1. The *bath* component houses fabric supply, resin impregnation, tensioning and pinching, the *ovens* B-stage the material, the *ventilation system* extracts volatiles, and the *take-up assembly* cools, tensions, controls lines speed, and applies poly-film to the prepreg before it is rewound.

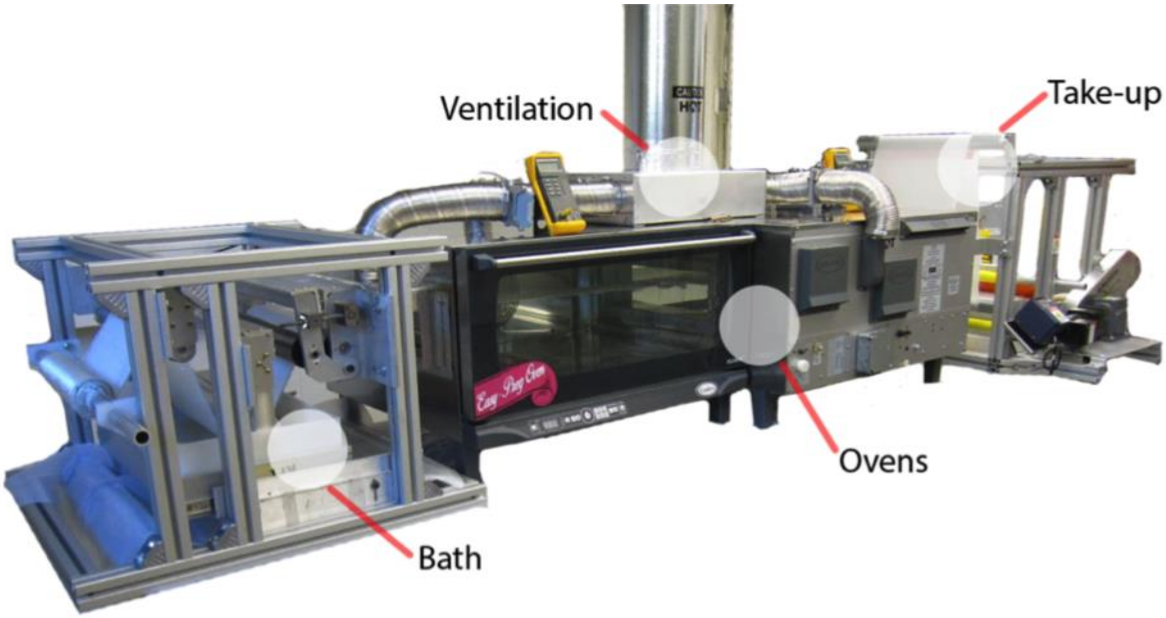

Figure 1. Easy-Preg Treater from left to right; Bath, Ovens, Ventilation and Take-up

~~Before the continuous line process layout was developed, works by previous students on the research team helped to automate the bath component, purchase ovens capable of B-staging material, address ventilation requirements of the machine and find a suitable location for processing.~~

2.2 Bath

The original component of the Easy-Preg Treater, now referred to as the bath, was designed and supplied by the aerospace partenr, and used in the production of prepreg via batch processing prior to the completion of the Easy-Preg Treater. It was designed to be capable of batch processing by incorporating the fabric supply, tensioning, impregnation, and poly-film application into one unit. This operation was completely manual and required one operator to advance fabric via a hand crank and another operator to cut the impregnated fabric. This method required B-staging of impregnated fabric in large ovens, making it a batch production process, rather than the desired continuous process found in industrial scale productions.

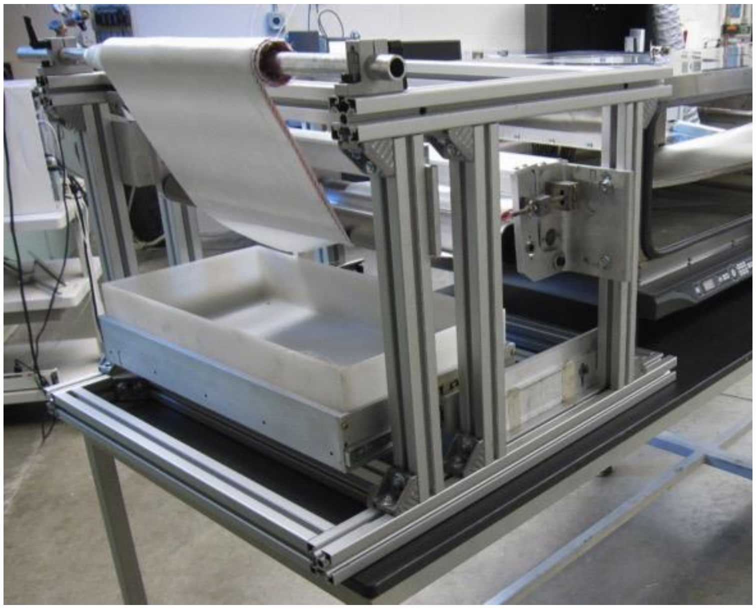

Figure 2. Bath Component

The machine was automated through the addition of a 230 AC gear motor (Leeson 1/15 HP Parallel Shaft gear motor). The motor is run by an inverter unit to allow for control over the speed (Fuji Frenic Mini ½ hp 115V). The shaft is turned by a gear and chain drive system for low maintenance and ease of altering gear ratios. Appropriate guards and safety labels were installed to promote safe student use.

Figure 3. Treater arrival with hand crank drive

Now obsolete, the existing hand crank was removed from the shaft, allowing a gear to be mounted for the chain drive. To properly mount the gear, a keyway was added using a manual mill. Key stock was fitted and the gear was mounted.

A shelf for the motor was constructed using 80/20 aluminum tubing and aluminum sheet stock. The shelf was mounted using the angle brackets and the panel holders were mounted to allow for clearance. Once the components were mounted to the shelf, the chain was fitted to connect the motor to the drive roller.

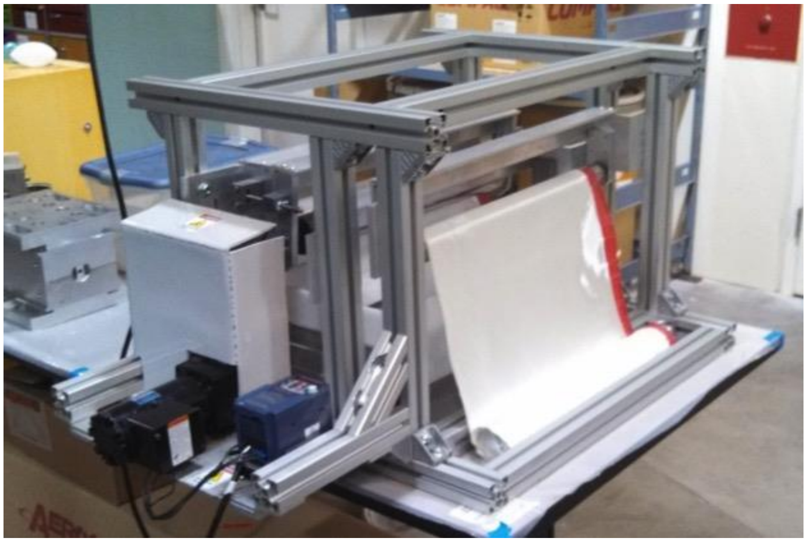

Figure 4. Shelf attached to bath with motor and inverter

It was also necessary to alter the drive roller to fix an inaccuracy of the rotation of the roller (run-out). The roller and cap assembly were put into the lathe as a whole unit to reduce variation that could be caused if components were to be assembled later on. A steady rest was used to reduce deflection, and the existing hole was drilled slightly larger to accommodate a small boring bar.

Figure 5. Fixing roller run-out on the drive roller

During the qualification run, the prepreg was tensioned via the addition of resistance – a method that was neither quantifiable nor reproducible. This method of tensioning also caused stiction, a phenomenon believed to adversely affect prepreg quality [4]. To overcome these issues, a closed loop tensioning system was purchased for the purpose of monitoring and controlling web tension. The tensioning system features a magnetic particle clutch driven by a second motor on the unwind roller, a transducer, and controller (Figure 6). It should be noted that standard web control systems are not capable of controlling line-speed, requiring future work to include additional measures to control line-speed variation.

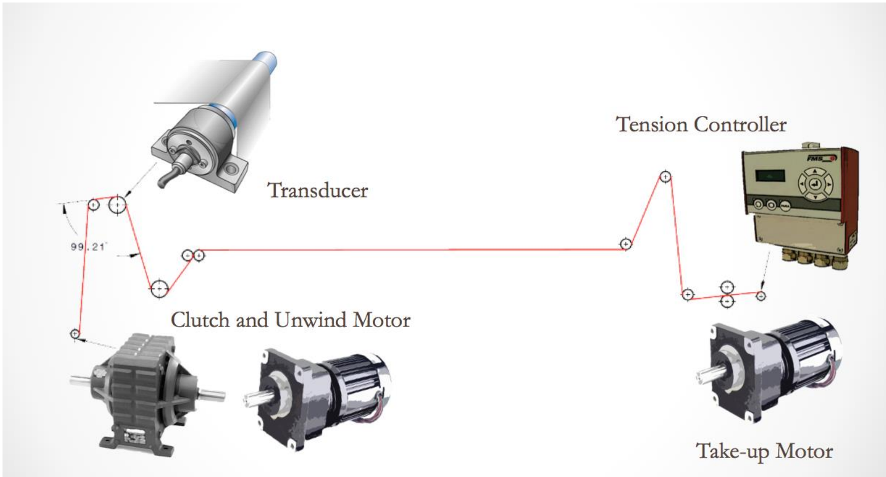

Figure 6. Schematic of closed loop tension system

The proprietary resin used in the qualification run was a phenol formaldehyde matrix with several different additives for adhesion and flame retardancy. During processing there was a visible separation of the resin over the duration of the processing. This separation caused variation in the prepreg manufactured and needed to be addressed.

An automated resin agitation system was required to ensure homogeneity of the resin throughout the operation. Automating the process removes the need for manual agitation from a user and improves the quality of the final prepreg. The scale of the agitation system needed to fit within the parameters of the bath component. Due to the lack of available space, an external system was be added to insure proper mixng of the resin. This system consists of a Caframo overhead stirrer, a 316 stainless steel propeller and reservoir for the resin. By having the agitation system separate from the bath a circulation system is required to transfer the resin to the bath and back into the agitation system. To accomplish this, a pair of peristaltic pumps and chemical resistant flexible tubing were needed. A Masterflex pump driver was required to operate the pumps at various flow rates. Operating the overhead stirrer is too aggressive for flexible tubing so rigid tubing was used to insure the stirrer will not affect circulation. The addition of the agitation system ensures there is no separation in the resin, thus reducing variation in the prepreg .

2.3 Ovens

The ovens are a critical aspect of the prepregging process for solvent coat processing as it is necessary for the prepreg to properly and uniformly B-stage. As a result, finding an oven that could meet footprint, control, and durability constraints while remaining within budget required much research. Many avenues of structure and industry were considered for a choice of oven including, vertical and horizontal layouts of industrial ovens, commercial baking, and custom ovens.

Ultimately, it was decided that two commercial countertop convection ovens (Cadco XAF-188), with a combined oven length of 60 inches, would be modified for fabric travel and B-staging. The ovens were chosen because they had an appropriate size for the allotted machine footprint could be easily modified and customized while remaining under budget [5]. An added benefit of using two ovens for this process is the ability to use zone heating for added design flexibility in research [6][7].

Among the modifications required to allow for fabric travel were: relocating electrical components, cuttings slots in each oven to allow for fabric travel, fabricating custom seals and adjustable gates to modify slot opening, and finally attaching the ovens together. Cutting slots in the sides of the ovens required extensive familiarization with the ovens and components. Holes were cut through both inside and outside of the stainless steel housings, and fiberglass insulation. Custom folding design seals were cut using a waterjet and installed to contain all fiberglass insulation and provide a durable finish to this alteration.

Figure 7. Finishing hole cutting process (left), Custom slot seals (right)

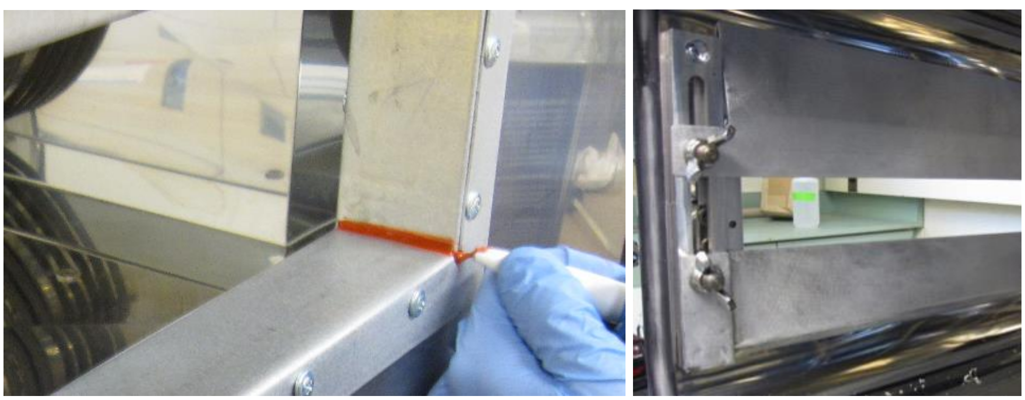

Figure 8. Finished seals with high temp silicon sealant (left), adjustable gates (right)

A critical factor of achieving consistently cured prepreg is uniform heating. To ensure this was the case for the Easy-Preg Treater, the ovens were fixed together while facing in opposite directions. The heat source of each oven is located in the back, raising concern that one side of the prepreg would recieve more heat. Even with the strong convection fans circling air, the oven direction was alternated to minimize any negative effects – the final configuration of the ovens should minimize rather than intensify any issues caused by heating element location. Thermal profiling was done throughout the modification process, and the end results showed minimal variation.

2.4 Facilities and Ventilation

It was necessary to complete a thorough investigation to find a suitable processing location within the facility that would ensure the safety of operators and other users in the lab. This is due to the in-line curing which pose health dangers to all users of the lab when solvents volatilize off creating toxic fumes. Several different volatile removal methods were also researched to determine which would best suit the lab-scale prepreg manufacturing process: VOC Air Purifiers, scrubber systems, a variety of types of thermal oxidizers, and dilution [8]. Due to the quantity of prepreg the machine is expected to produce and high cost of scrubbers, purifiers, and oxidizing systems, the venting solution that was determined for the process was capture and dilution [9][10]. This means that volatiles exit the duct system through vents in the roof of the building and dilute in the atmosphere.

In this investigation, an undergraduate student partnered with a member of the university's facility management department to evaluate the needs of the process in order to relocate the machine. Foot traffic, air exchanges per hour, fan cubic foot per minute (cfm), and available exhaust hoods were among the some of the top considerations. The treater was ultimately moved to a location with low student traffic and available ducts and hoods for fume extraction. The chosen processing location also had low-negative pressure capabilities, venting to the roof, a VOC sensor, and 18 air changes an hour [8]. As an added measure the treater was placed under an available fume hood and curtains were designed to be added if the process required additional ventilation.

The ventilation system designed for the treater was a response to the possibility of explosive solvent vapors building in the ovens and to address student safety when running the machine. It was not fully established until mid-way through the project that point of source (POS) capture of volatiles within the ovens during B-staging would need to be implemented.

The ovens already had preexisting exhaust, which provided a convenient source of direct ventilation for the ovens. Miniature exhaust hoods were also designed for each oven to capture volatiles that escape through the fabric slot openings when convection is running. The designed system features four points of capture that connect via stainless steel chimney liner to a plenum box (Figure 8). Blast gates control the flow from each point so that each point can be individually controlled. The plenum is an aluminum box that connects each point of capture to an 8-inch ventilation duct. Tuning and assessing the performance of the ventilation system was done with the assistance of a WWU facilities engineer. Using a digital manometer, a static pressure tip was placed in strategic locations within the ovens and ventilation system in order to read the negative pressure in that part of the system. As such, the plenum can be used to tune the system as a measure of reference if the machine is moved.

Figure 9. Ventilation system designed for POS capture at each end of the ovens and exhaust vents

2.5 Take-up assembly

The take-up assembly was constructed out of the same extruded aluminum as the bath component to maximize design flexibility and versatility. As fabric exits the ovens, it is run across three aluminum conveyor rollers that can be easily moved to adjust the length of cooling distance and thereby cooling time. After the fabric is air cooled, it is run between two sheets of protective polymer film and a set of padded pinch rollers which apply even pressure on the prepreg and film to adhere the two. The fabric is wrapped around a cardboard tube that slides easily off the take-up assembly after loosening a few setscrews. The take-up assembly features the most custom parts as nearly every component needed to be modified or fabricated by WWU undergraduate students.

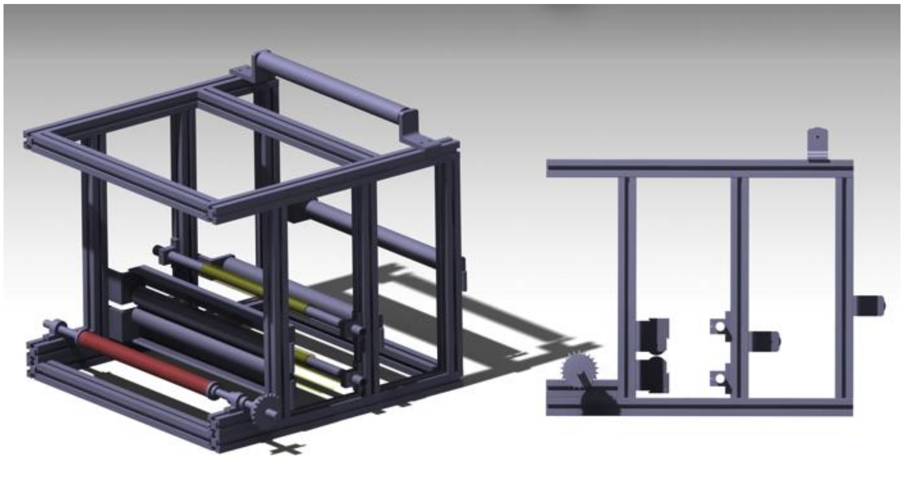

Figure 10. Take-up assembly modeled in CATIA

The unwind motor, previously driving the pinch rollers on the bath component, was moved to the take-up assembly to enable continuous processing. Additionally, a gear reducer was added onto the motor so that an appropriate range of residence time could be achieved to satisfy experimental purposes. With a line speed of 0.5-5in/min, the machine can run fabric through the ovens from 15 to 100 minutes. This allows for great flexibility when designing of experiments to optimize a variety of resin systems. The graph in figure models the inverter value and line-speed and gives an approximate/expected residence time on second y-axis.

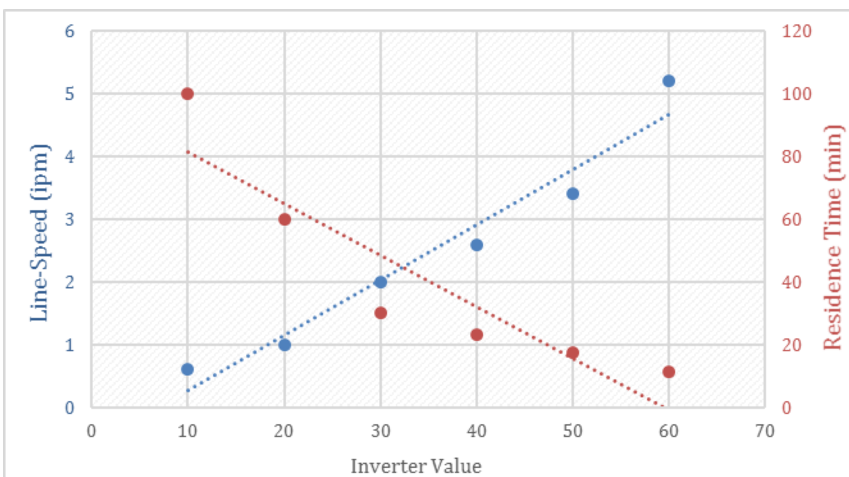

Figure 11. Line-speed and residence as a function of inverter value

It was expected for line speed to vary as the motor set value is held constant for the duration of the processing run due to the diameter increase in the take-up (drive section of the machine). However, the line speed of the prepreg was nearly doubled in the end of the processing run due to the change in diameter. This variation in line speed directly caused variation in oven, and cooling time, and therefore needed to be addressed. To do so a speed control system was designed which could analyze feedback from a rotary encoder that sends 200 pluses for each revolution, and convert this into line speed. This actual line speed is compared to the set line speed by a micro controller which adjusts the voltage output to the motor accordingly. The set speed is able to be modified by the help of an LCD display and four buttons. This system is currently in the testing phase and will be operational before the further use of the treater is continued.

3. Cost Analysis

Table 1. Material cost break down

		Item Description	Price	Vendor
Bath	**Frame**	T-slotted Aluminum Framing	$200.00	McMaster Carr
		Brackets and Hardware	$120.00	McMaster Carr
		Rollers	$100.00	Estimated
		Machined polyolefin bath	$	Estimated
Ovens		(2) Cadco XAF-188 Convention Ovens	$4,800.00	Food Service Warehouse
		Fiberglass rope seal	$11.00	McMaster Carr
		Sheet metal for portal seals	$50.00	Estimated
Ventilation		Aluminum sheet for hoods and plenum	$75.00	Estimated
		15' - 3" Rock-Flex 316Ti Stainless Steel Chinmeny Liner	$175.00	Rockford Chimney Supply
		Galvanized steel extensions	$20.00	Hardware Sales
		3" Aluminum Woodstock Blastgate	$40.00	Amazon
		High temperature chinmey sealant	$15.00	Hardware Sales
Agitation System	**Reservoir**	Overhead Stirrer	$1245.00	Grainger
		14Qt. Pail	$41.50	McMaster Carr
		Pitched Propeller	$61.45	Grainger
		SS Shaft	$61.45	Grainger
		Ring Stand	$14.51	Grainger
		Clamp Rod End	$18.02	Grainger
		Compression Coupling	$5.16	McMaster Carr
		Barbed Couplings	$11.69	McMaster Carr
	Pump	Flexible Tubing	$73.75	McMaster Carr
		Peristaltic Pumps	$250.00	Omega
		Mounting Plate	$6.54	N/A
		Adaptor Plate	$30.00	Omega
	Bath Attachment	SS 3/8 Tube	$16.54	McMaster Carr
		I Beam Clamps	$8.98	McMaster Carr
Take-up	**Frame**	T-slotted Aluminum Framing	$200.00	McMaster Carr
		Brackets and Hardware	$120.00	McMaster Carr
		Rollers	$100.00	Custom
	Take-up	Steel Finished-Bore Roller Chain Sprocket for #40 Chain,	$30.04	McMaster Carr

	assembly	1/2" Pitch, 22 Teeth, 5/8" Bore		
		11-tooth ANSI #40 Steel Finsihed-Bore Sprockets for ANSI Roller Chain	$8.74	McMaster Carr
		Cast Iron Base Kit for 1.33" Center Right-Angle Speed Reducer	$12.67	McMaster Carr
		Partially Keyed Steel Drive Shaft 3/4" OD, 1/8" Keyway Width, 36" Length	$44.90	McMaster Carr
		2ft 2" X 2" Mulitpurpose Aluminum 90 Angle	$21.99	McMaster Carr
		Black-Oxide Steel Set Screw Rigid Shaft Coupling with Keyway for 1/2" Diameter Shaft	$12.65	McMaster Carr
		Roller chain, ANSI #40, 3-ft	$13.62	McMaster Carr
Motor Drive		FUJI Frenic Mini Series, 1/2 hp 115 volt, 1-phase, 2.5 Amps	$170.00	Sabina Motors and Controllers
		Leeson Motors Gearmotor-Parallel Shaft, 19RPM, 1/15HP, TENV, /208-230V, AC	$340.00	Global Industrial
		Right-Angle Speed Reducer Shaft Input, 30:1 Ratio, 1.33" Center, Left Output	$370.00	McMaster Carr
Tensioning System		MAGPOWR C-10 MAG. PART. CLUTCH	$845.00	Grosel Industrial Sales
		FMS CMGZ309.ACV.B90.W Digital Tension Controller	$1,850.00	Grosel Industrial Sales
		FMS CA203 Tension Sensor for dead shaft idlers	$1,100.00	Grosel Industrial Sales
		BROTHER GEAR MOTOR Hp: 1/20 Hp Voltage: 115V, 60 Hz	$385.00	Grosel Industrial Sales
Speed Control		Rotary Encoder - 200 P/R	$30.00	SparkFun
		Arduino Due	$50.00	SparkFun
		Basic 16x2 Character OLED - Yellow on 1 $24.95 Black	$25.00	SparkFun
		Custom 3.3-10v board	$10.00	

4. Safety

Inherent to the solvent coating process is the release and volatilization of solvents used to lower resin viscosity. Measures for safety were evaluated at each step in the process, a majority being the safety of the operators and users in the lab when material is B-staging. Occupational Health and Safety Administration (OSHA) permissible exposure limits (PELs) were investigated for each volatile so that the values are known when they are being processed. As an added measure of safety, it was proposed that an alarm system be installed within the processing location to that users can are aware if a ventilation failure is to occur. This alarm would be triggered by total fan shut down or if volatile content was to exceed a permissible value.

A push for the Engineering Department is to receive certification from university Department of Health and Safety (DOHS) so that the process could be cleared for more frequent and permanent use. In the qualification run of the treater, DOHS and facility engineers took measurements to analyze the effectiveness of the modifications to prevent risk of exposure. Using an organic volatile sensor which counted carbon levels in ppm, it was determined the room stayed at a near constant level during the run and negotiations for certification are underway. Major spikes in the carbon count occurred when the oven doors were opened and when scrap material was C-staged.

5. Testing

5.1 Testing Methodology

23 ft. of prepreg was produced during the initial qualification run. Nine samples down the center of the roll evenly spaced (6 inches from each end.) Five samples were also taken down each side one inch from the edge.

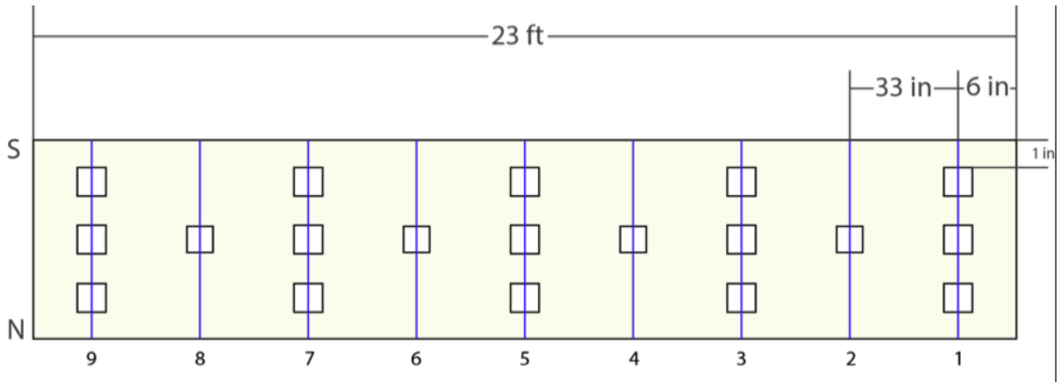

Figure 12. Illustration of sampling

Volatile content was determined through thermogravimetric analysis (TGA) with a single heating cycle up to 1000°C using a ramp rate of 25°C/min. The values used to quantify volatile content were taken from the TGA thermogram as the percent weight loss of the first slope of the curve. Resin content was determined using the same thermograms generated by the TGA when investigating volatile content. The value used to quantify resin content was the weight loss percentage of the second curve.

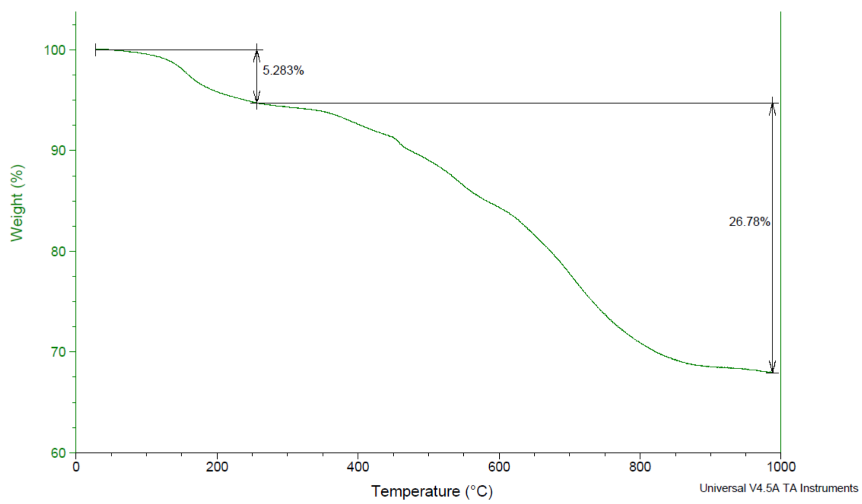

Figure 13. Example thermogram indicating weight loss curves used for analysis

The burn off test was conducted following the ASTM D3171 standard in order to gather data from larger scale samples. This was done because of the samples required to for the TGA are very small (milligram) can be a major source of variance because of the properties of composites. With small sample sizes, it is uncertain if the segment sampled is representative of the whole. Larger sample sizes like those used by the burn off test can help with smoothing out variation.

5.2 Results

The results from the TGA indicated that volatile content on average was around 6.6 ±0.181% for the roll of prepreg and resin content for the roll was found to be around 23.74 ±1.514% (by an average of all samples).

Table 2. Raw data from thermal testing

Sample	**Volatile content (%)**	**Resin Content (%)**
1	5.283	26.78
2	5.68	13.04
3	6.579	24.31
4	6.672	24.59
5	6.313	13.21
6	6.852	25.14
7	6.622	22.45
8	6.933	13.66
9	6.608	23.1
1N	7.701	29.97
3N	6.922	21.28
5N	6.865	23.06
7N	6.875	23.27
9N	6.327	22.33
1S	5.717	23.91
3S	6.427	23.81
5S	7.096	25.96
7S	7.04	27.45
9S	6.631	25.28

Table 3. Average volatile and resin content across the length of the roll

	Volatile Content (average percentage)	**Resin Content (average percentage)**
North Edge	6.938 ±0.185	23.980 ±1.893
Middle	6.281 ±0.164	21.970 ±1.146
South Edge	6.582 ±0.186	25.282 ±0.506
Roll	6.600 ±0.181	23.740 ±1.514

Table 4. Average burn off along roll (ASTM)

	Mean Burn Off (percent)

Beginning of roll:	35.28 ±1.196
Middle of roll:	37.09 ±1.196
End of roll:	37.22 ±1.196

6. Analysis

6.1 Volatile content

The data from table 3 suggests that volatile content is greater on the edges, with a lower average value in the center. The nine middle points were plotted into a control chart using the standard deviation from the data set of 0.5% and six sigma between the upper and lower control limits. The plot does however indicate a linear trending relationship between volatile content and run time (figure 13). It is evident from the plot that as run time increases volatile content also increases. This trend complies with the prediction that volatile content would increase as the process continued (due to the increasing line speed).

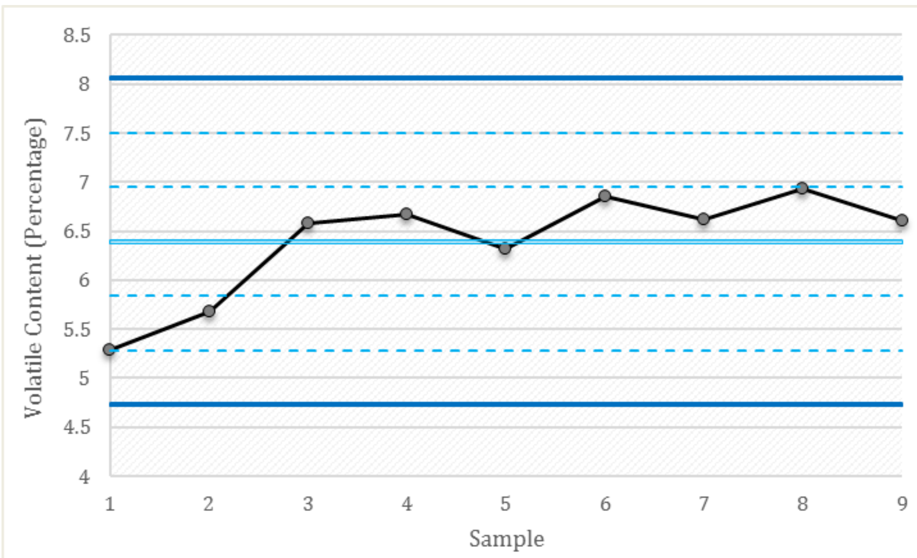

Figure 14. Control chart illustrating volatile content over run time

6.2 Resin content

The data suggests that resin content, similar to volatile content, is greater on the edges, with a lower average value in the center. It would seem appropriate that these two tests show the same trend such that if there is more resin on the edges of the fabric the volatile content should be higher as well.

Plotting the nine middle data points into a control chart, there was no indication of a trending relationship. This goes along with the prediction that as run time increased, resin content would remain constant. The only issue with the data is a fairly high standard deviation of 5.68%, there is room for improvement in lowering the standard deviation of the samples to achieve a more uniform resin content.

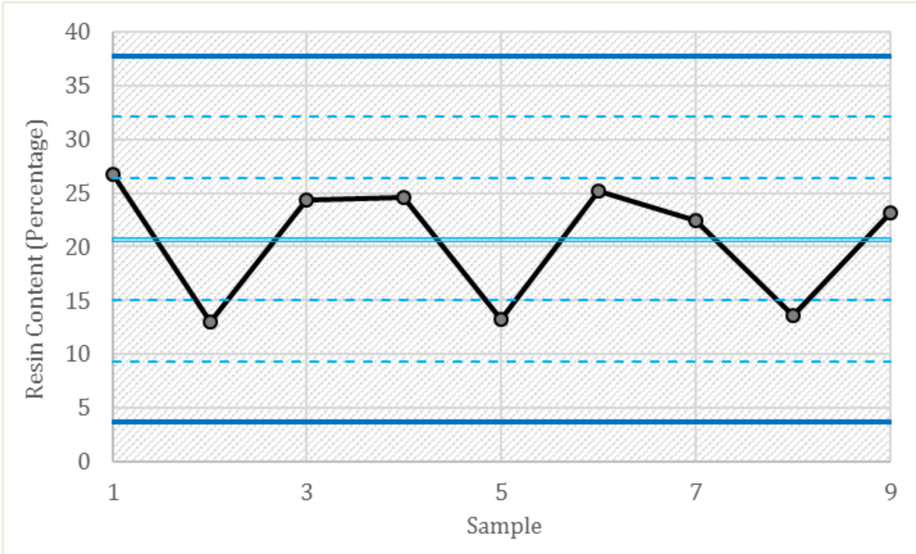

Figure 15. Control chart illustrating resin content over run time

6.3 Resin burn off test

The results illustrated in table 4 show that the standard deviation for resin burn was 3.68 ±1.196%. It was also noted in the in table 1 that the range for burn off percentage is smaller than that of resin content calculated from the TGA. This suggests that it is possible that variation is being reduced by larger sampling sizes.

While this and standard errors are improved over the calculated value for resin content, it is important to note a lack of trending in the control chart. As discussed previously in Section 5.3, as the prepreg travels over time, it is not predicted that resin content should change with time. The shape of the control chart also matches a seemingly random orientation as seen with in resin content observed with the TGA data.

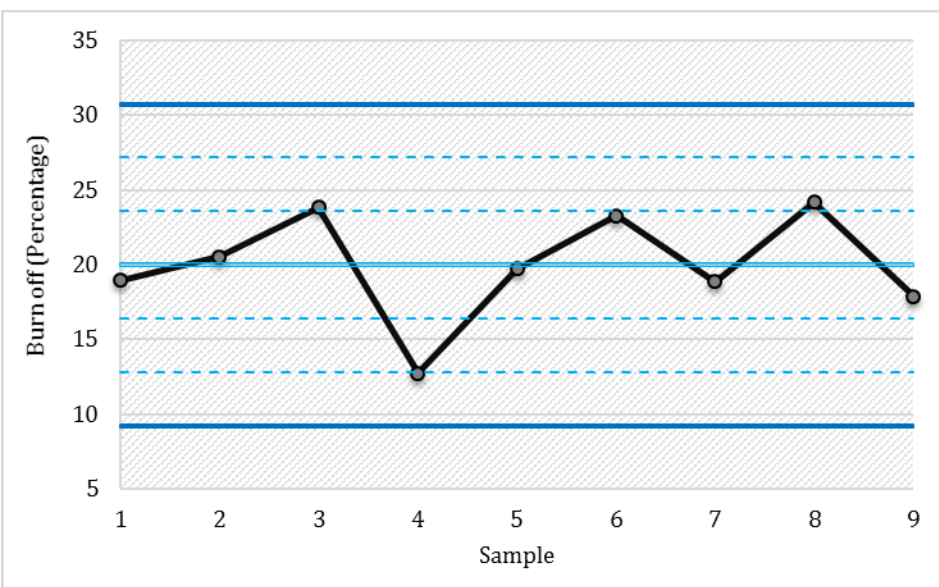

Figure 16. Control chart illustrating percent burn off over run time

7. Lessons Learned

7.1 Tracking of fabric and poly on the take-up roller

Tracking of the fabric and poly film on the take-up roller was a challenge as expected. Although care was taken to align the rollers, take up shaft, poly rollers and components, prepreg did travel to one side of the take up roll considerably during the qualification run. While it is believed that a majority of this issue was due to sliding components, is important that measures are taken to correctly align and square each roller and component of the machine so that fabric does not stray on take-up roll. A recommendation is to conduct dry fabric runs to test alignment of the take-up so that issues do not occur during a processing run.

7.2 Resin buildup in ventilation system

One of the most surprising discoveries after the short trial run, just fewer than two hours, was the residue buildup within the galvanized steel extension from the plenum [11]. When this concern was brought up to the sponsor, it was learned that this buildup is due to rapid cooling of the gas within this section of the ventilation system. To protect the plenum from similar buildup that will eventually limit the effectiveness of the system, a duct valve will be installed at the bottom of the extension so that the valve can be closed to limit buildup. The extension will need to be replaced/cleaned as needed.

7.3 Oscillation of fabric caused by convection fans

During dry tests and in the qualification run it was observed that the convection current created by the fan in the ovens resulted in oscillation of the unsupported fabric. It is not known if this will have an adverse effect on the quality prepreg produced, but it seems unlikely to be entirely benevolent. To reduce the effect, high temperature silicon rollers with Teflon covers will be placed in the ovens to support the fabric.

7.4 Sampling

An investigation will need to be conducted prior to further characterization of data from future runs. While there is evidence to suggest that sample size could have an effect on the variation of the results it is not completely certain to what severity. It was also discovered after analyzing results that for improved accuracy, the samples tested should have been C-staged. Instead the samples were tested as B-staged prepreg [11].

8. Potential Uses

Primarily designed as a tool to aide in research, the treater is also a very functional and easy to use machine that could be utilized in a number of current courses. Among some of the most relevant courses that could incorporate the machine into their curriculum are:

1. Data Analysis/Design of Experiments
    a. Factor recognition
    b. Responses and Effects
    c. Screening Designs for determining main effects of processes
    d. Optimization and Response Surface designs
2. Advanced Composites
    a. Hands on demo to what prepreg is and how it is manufactured
    b. Custom prepreg for specific projects
3. Advanced Materials and Processing
    a. Custom resin formulations
    b. Further work with DOE
4. Intro To Polymer Chemistry
    a. Custom resin formulations
5. Industrial Quality Assurance
    a. Control charting of results from testing
        i. Cpk studies
        ii. Measurement Systems Analysis
6. Capstone Projects
    a. Senior projects
        i. Resin formulating
        ii. Process Improvements

As a hands-on development tool for students through use in demonstrations or labs, students could experience a process not used by many at an undergraduate or even graduate level.

9. Summary

The research team was able to successfully automate the lab scale prepreg treater into a continuous system within the prescribed budget. The treater was qualified through a processing run that produced 23 feet of prepreg which was tested for volatile content, resin content, and burn-off. Test results suggest no unpredicted trends and an overall consistency that is better than expected from an initial run. Although further improvements should be made to address the challenges seen during the initial processing run, this project has proven its potential success by achieving the goals of the sponsor company and the engineering department at WWU. As the final modifications are made the treater should be added into the curriculum to give undergraduate students a hands-on experience with a processing method that is used in the advanced composites sector.

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