SPRING FRAME PRESS FABRICATION OF AEROSPACE PRODUCTION COMPONENTS

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ABSTRACT

Spring frame forming operations offer a number of unique advantages including tailor-able charge tensioning for ply drop locating, low cost stamp forming tooling concepts, rapid charge loading approaches, and rate enabling automated approaches to forming. Press forming thermoset composite components enables high rate manufacturing of small to medium sized parts. A set of demonstrators were manufactured with complex ply drops and pad ups in a matched mold process using CYCOM® 5320-1 prepreg, CYCOM® 970 prepreg, and a Solvay developmental resin, XEP-2750. The parts were manufactured in a simulated production environment on production equipment with trained production personnel. The part families incorporate features representative of primary and secondary aerospace structural composites with a number of processing characteristics including up to approximately 76 cm by 76 cm (30 in by 30 in) in-plane dimensions, a targeted 30 minute tool time, and the ability to accurately locate features like ply drops and pad-ups. These developments will lead to process specifications and controls for required, hot debulk cycles, preheat cycles, press consolidation and post cure as steps towards process implementation.

1. INTRODUCTION

Low part volumes and high part mix have historically limited the attractiveness of compression molding process development where single sided, low rate tooling was sufficient. Modern generation prepreg resin systems seem to have capability in multiple low pressure [1] and high pressure curing environments and lend themselves well towards processing flexiblity with mechanical performance retention. The demands of future high rate production platforms as well as leveraging developments taking place in non-aerospace industries have increased the justification for rapid low cost process development [2] and [3].

The reality of aircraft components leads to a number of operations that are required to laminate and shape part features from a relatively planar precursor. In standard processing approaches, this is largely accomplished through hand collation and multiple compaction cycles with consumable bags, edge dams, and breathers. When looking for automated methods to implement safely around large hydraulic equipment, a spring frame approach has evolved to meet most of the forming requirements. This spring frame approach allows an unformed charge to be safely loaded outside of a press operation and not tie up equipment and tool operation time to maximize throughput.

Manufacturing personnel should be able to choose the spring tensions and locations as driven by part geometry and forming requirements or as guided through modeling efforts. This conclusion is based on detailed studies investigating the manufacturing characteristics of thermoset prepregs in pressmolding operations. Customized tensioning devices can be sized based on experience or simulation tools to reduce wrinkling risks induced by material compressive zones in forming.

1.1 Thermoset Compression Molding

Thermoset compression molding is a method of composite fabrication that is not traditionally heavily relied on in the aerospace industry for primary and secondary structures. At its simplest, the molding material is preheated, placed into an open tool cavity, consolidated with hydraulic pressure at temperature, and the liquid thermoset material is converted to a solid. Then the part is ejected for finish machining and finishing operations. The mold is closed along a parting plane perpendicular to the press actuation direction and pressure is applied to the material in order to contact all mold surface area. Advances in press technology, automation and process data have greatly improved control of today's compression molding process for increased manufacturing robustness.

The compression molding approach outlined in Figure 1.1 demonstrates a process capable of high-volume, high quality, complex fiber reinforced composite components. The material is cut and kit using traditional aerospace broad good prepregs and collated with an automated pick and place system or through hand layup to create a 2D preform. Depending on the part geometry, and finished quality target, the material can undergo a hot debulk or pre-consolidation cycle to remove material bulk factor and some porosity. This cycle is recommended for most complex components with vertical walls but may not be necessary for more planar components. Once pre-consolidated, the blank can be preheated to soften the resin and then rapidly be shuttled into position over the matched mold tooling. The stamp forming process is conducted with a spring frame to locate the charge and tension the preform while the pre-heated tooling is being closed. When selecting the press closing speed, closing position, and closing pressure a number of variables must be set in order to consolidate the material at the correct point in the rheology curve to create internal hydrostatic pressure, minimize resin bleed out from the net resin prepreg, and not have a material that has advanced too far in its state of cure which may induce cracks.

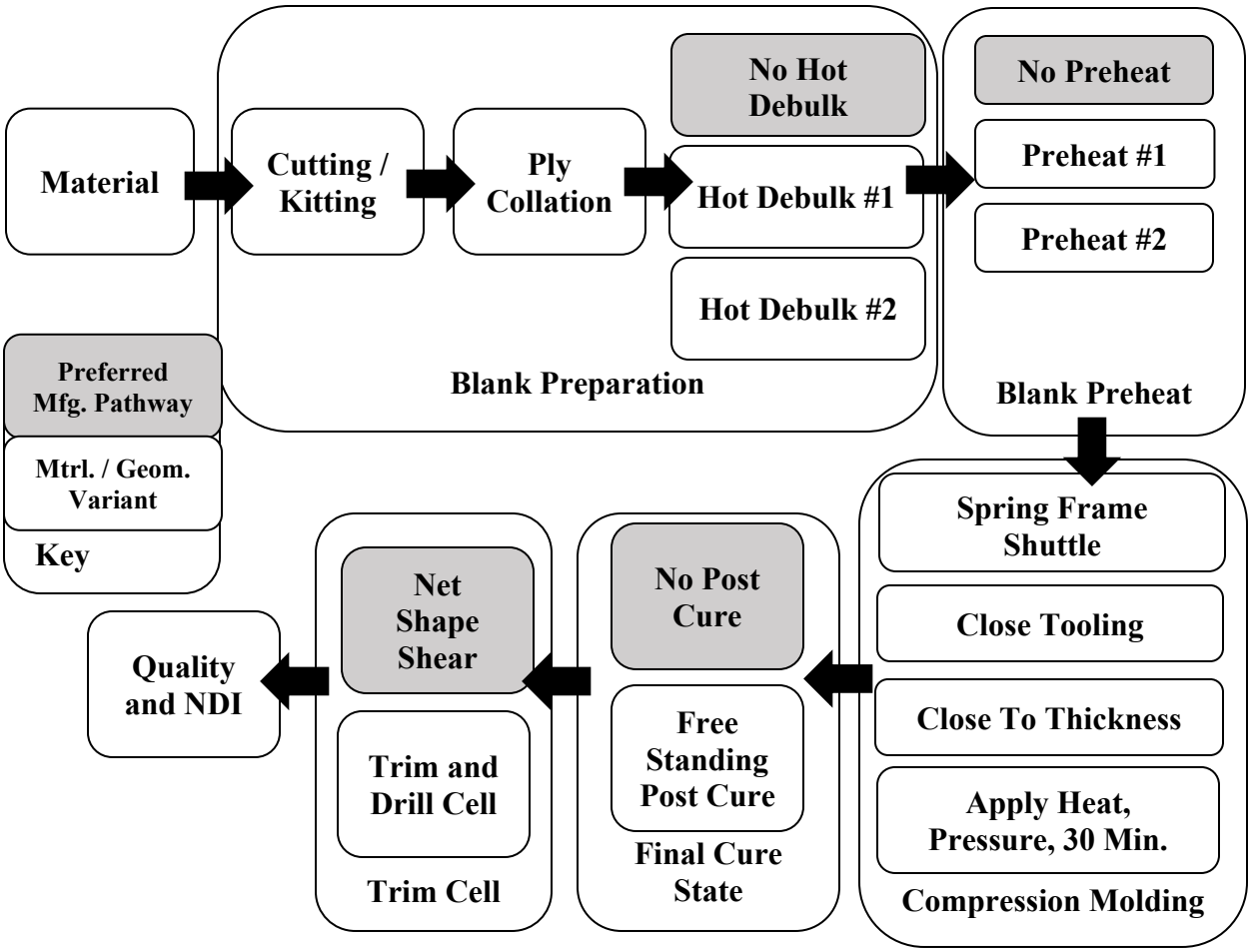


Figure 1.1: Simplified Spring Frame Compression Molding Process

The approach used in this processing flow was to minimize the part-on-tool-time by reaching an initial state of cure on the tool in 15-30 minutes and then transferring the partially cured but dimensionally stable component to an offline batch post cure to increase the manufacturing cells rate capability. The part left the tool in a formed but dimensionally stable green state. Parts were also investigated as part families that could all utilize the manufacturing cell to minimize equipment down time and maximize cell utilization. With this approach a single toolset could be configured to produce multiple part geometries. For example a c-channel with three varying flange angles down the length of a wing. Traditional processes for composite trimming and quality investigation were utilized in this demonstration.



Figure 1.2: Demonstration for C-Channels (TS-RAPM-003), Ribs (TS-RAPM-002), and Beaded Access Panels (TS-RAPM-009)

The manufacturing technology effort is a jointly developed program with a Boeing-led team, US. Government (DARPA) under the guidance of the Army Research Office (ARO) and Solvay as the collaborating material supplier. This manufacturing technology effort addresses the following:

- Minimization of touch labor through automated collation and forming of aerospace components of interest Figure 1.2
- Autoclave-like aerospace mechanical performance with a cure temperature of 177-ºC (350-370 ºF)
- Rate capable steel tooling with >1000 parts per toolset
- Leveraging a press manufacturing supply base for fabrication of small and medium sized aerospace composites

2. EXPERIMENTATION

2.1 Materials

Many of the experiments reported have been performed using either CYCOM® 5320-1 or XEP-2750 prepreg. Each material system offers its own advantages to processing flexibility and has nuances to resulting finished part quality. In an open tooled, spring frame process, the fully impregnated nature of XEP-2750 prepreg seems to offer the most robust processing results when compared to a partially impregnated product form.

Table 1: Material Investigation

Material Resin	Resin Content	Fiber	Weave	Impregnation Level	Preconsolidation Required
CYCOM® 5320-1 [4]	36%	T650	8 Harness Satin	Mid	Yes
XEP-2750	40%	T650	8 Harness Satin	High	No
CYCOM® 970 [5]	40%	T300	Plain Weave	High	No

The spring frame was identified as a viable and robust method for tensioning preform charges as the tool was being closed. The spring frame, spring type, spring tensions, spring locations, and spring attachment locations were all developed and locked in for each specific component of interest (Figure 2.1, Figure 2.3).

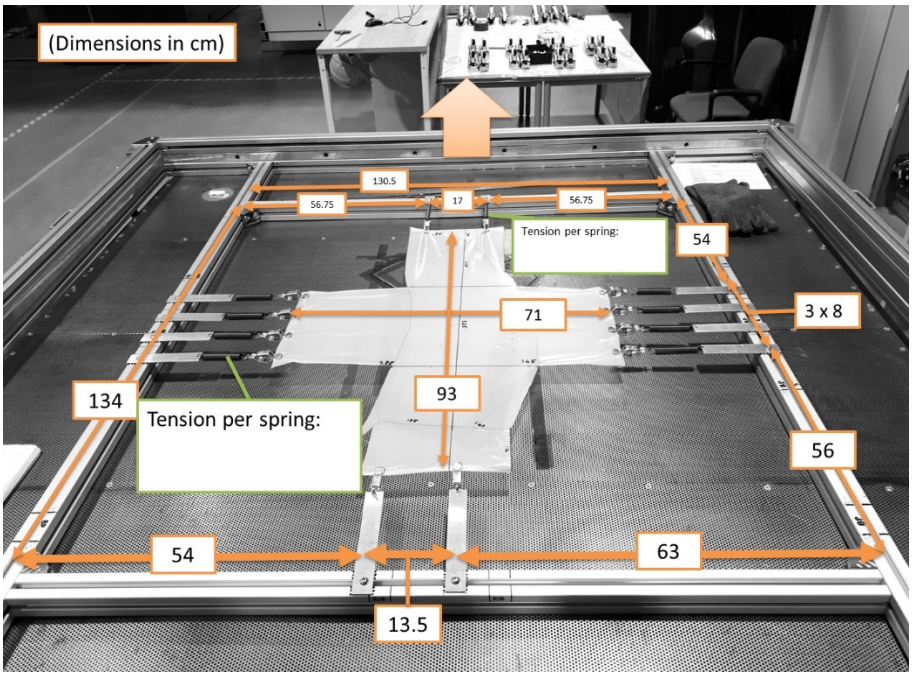


Figure 2.1: Spring Frame Design and Charge Locating for C-Channel (TS-RAPM-003)

2.2 Test Methods

Components were manufactured at Solvay's Applications Center in Heanor, UK through an informed design of experiments based on what was tested previously and expected part quality, indexing one variable at a time. When sufficient quality was reached, the run parameters were set and repeated for three to five runs to verify process repeatability. The surface quality was then confirmed with non-destructive investigation and cross section cut ups. Selected panels were cross sectioned for porosity, short beam shear, fiber volume fraction, resin content, degree of cure, and glass transition temperature. Table 2 shows a simplified manufacturing study for representative as manufactured beaded access panels in Figure 2.2.

Table 2: Example Test Matrix Variables Spring Frame Forming Beaded Panel or C-Channel

Trial Run	Part ID	Material	Process	Debulk	Tool Temp (ºC)	Preheat Temp (ºC)	Preheat Time (min)	Tool Closure (min)	Time on Tool
1	Trial 1	CYCOM® 5320-1	Spring Frame 1	Debulk 1	177	93	2 min	5 min	30 min
2	Trial 2	CYCOM® 970	Spring Frame 2	Debulk 2	182	107	5 min	3 min	20 min
3	Trial 3	XEP-2750	Spring Frame 3	Debulk 3	187	121	15 min	2 min	15 min

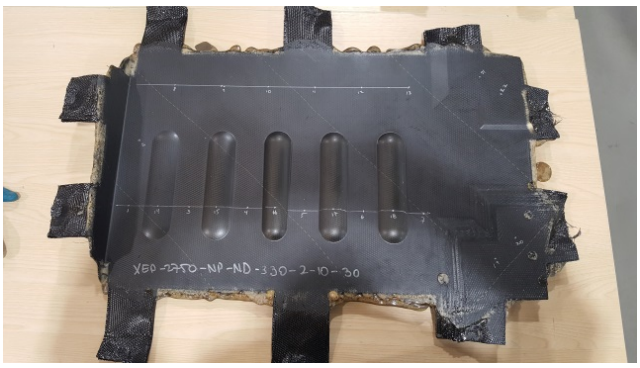


Figure 2.2: Representative TS-RAPM-009 Panel as Manufactured

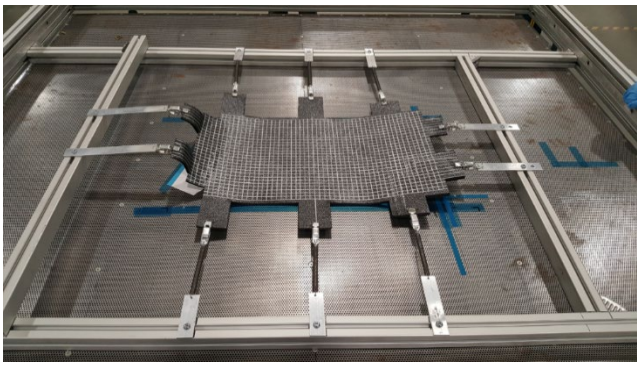


Figure 2.3: Spring Frame Loaded with a TS-RAPM-009 Prepreg Charge

Figure 2.3 shows a spring frame loaded with a charge prior to forming a beaded panel. The tabs are added during the ply cutting phase to locate the charge and flange regions and the pad-ups are interleaved in this configuration. Figure 2.4 shows the frame being shuttled and centering over the tool prior to forming a component. In this case, the spring frame can actuate up and down to tailor the forming of the charge in parallel with the action of the press closure. Ply locating for the pad up regions becomes critical for consolidating the part properly and having the material volume aligned with the tooling gaps.

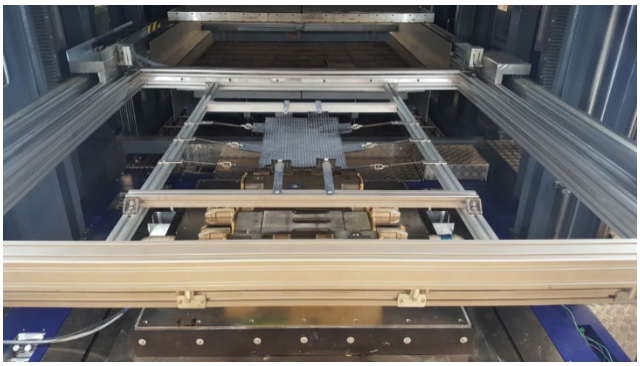


Figure 2.4: Frame Centered Over Tool Prior to Forming TS-RAPM-009 Configuration

3. RESULTS

3.1 Cured Panel Properties

As briefly outlined above, each panel was investigated for quality and finished state of cure. Selected non-destructive investigation (NDI) panels are shown in Figure 3.1 and Figure 3.3. It was readily apparent from the NDI results when a pad-up was not located correctly in the tool due to the attenduated response. Out of plane geometry regions were more difficult to investigate before cross sectioning.

Based on optical cross section results (Figure 3.2), it was shown that low levels of porosity can be expected due to the high consolidation pressures when the plies are located accurately in the tooling. In most cases porosity levels below 0.5% were easily maintained and the process once locked down was shown to be repeatable.

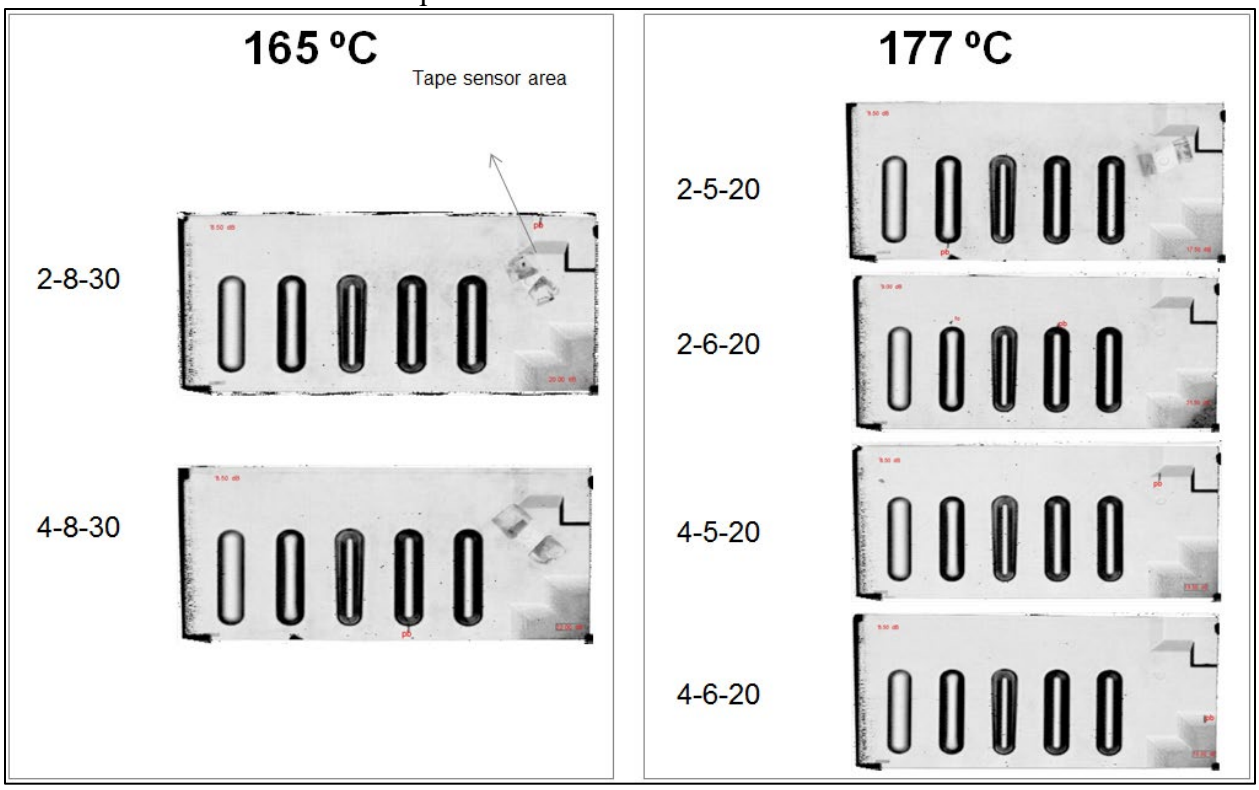


Figure 3.1: XEP-2750 TS-RAPM-009 Beaded Panel NDI Results

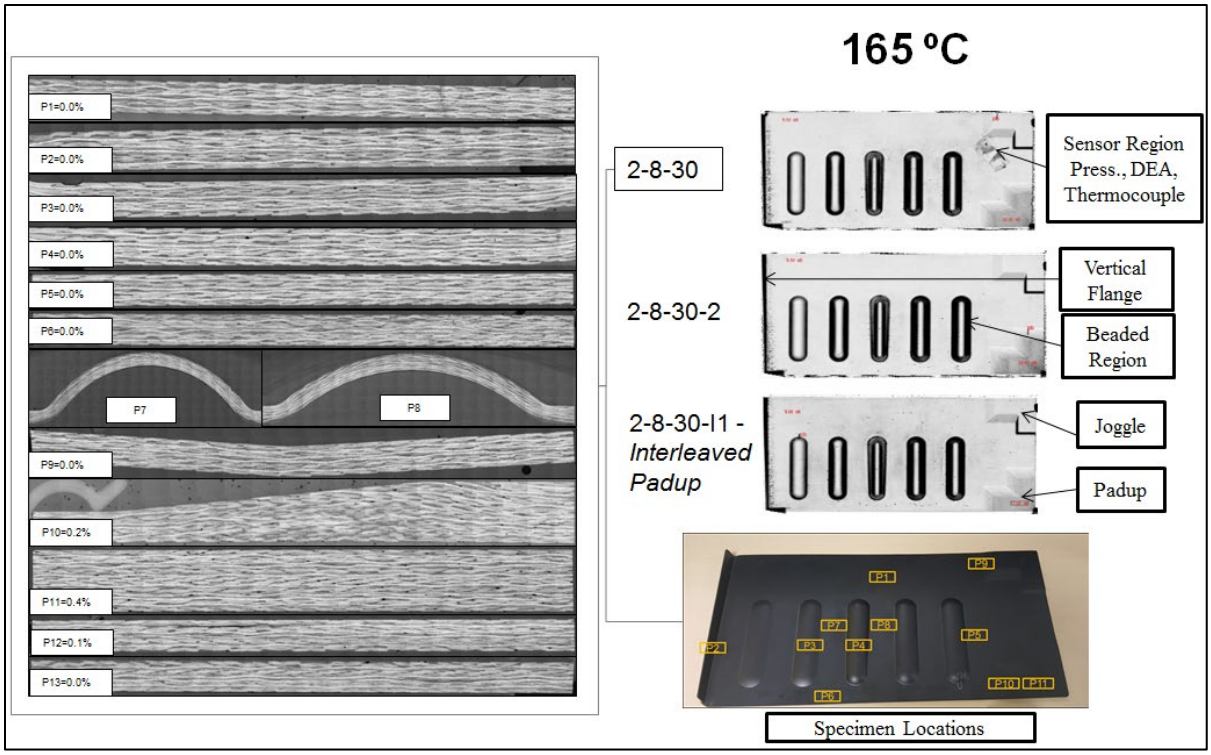


Figure 3.2: XEP-2750 Cross Sections for TS-RAPM-009 Configuration

Similarly, based on nondestructive inspection and optical cross section results, Figure 3.3 and Figure 3.4, it was shown that low levels of porosity can be expected with CYCOM® 5320-1 prepreg due to the high consolidation pressures when the plies are located accurately in the tooling. In most cases porosity levels below 0.5% were easily maintained and the process once locked down was shown to be repeatable. In some cases it is worth noting that the location of the padup could shift in the tooling. Initial trials were run with padups stacked on the surface of a ply layup, the padups were located near the periphery of the part and if they were not located correctly then the padup could squeeze out of the part and result in a region of low pressure during cure. Once the padup was interleaved in the ply stack, more representative of traditional methods, the risk of porosity reduced. In the case of later components, if the padup was in the middle of the part and surrounded by material locking the padup in place, the same risk of porosity was not seen.

Figure 3.5 and Figure 3.6 indicate consistent porosity measurements in the beaded access panel as a function of part region and material type. With the threshold target of 2% porosity or less, the as manufactured components were consistent as long as the processing parameters were consistent. On one instance the equipment faulted out resulting in a panel with a time to close dwell time which was too long and a corresponding negative impact on the part porosity due to the resin rheology being too far advanced.

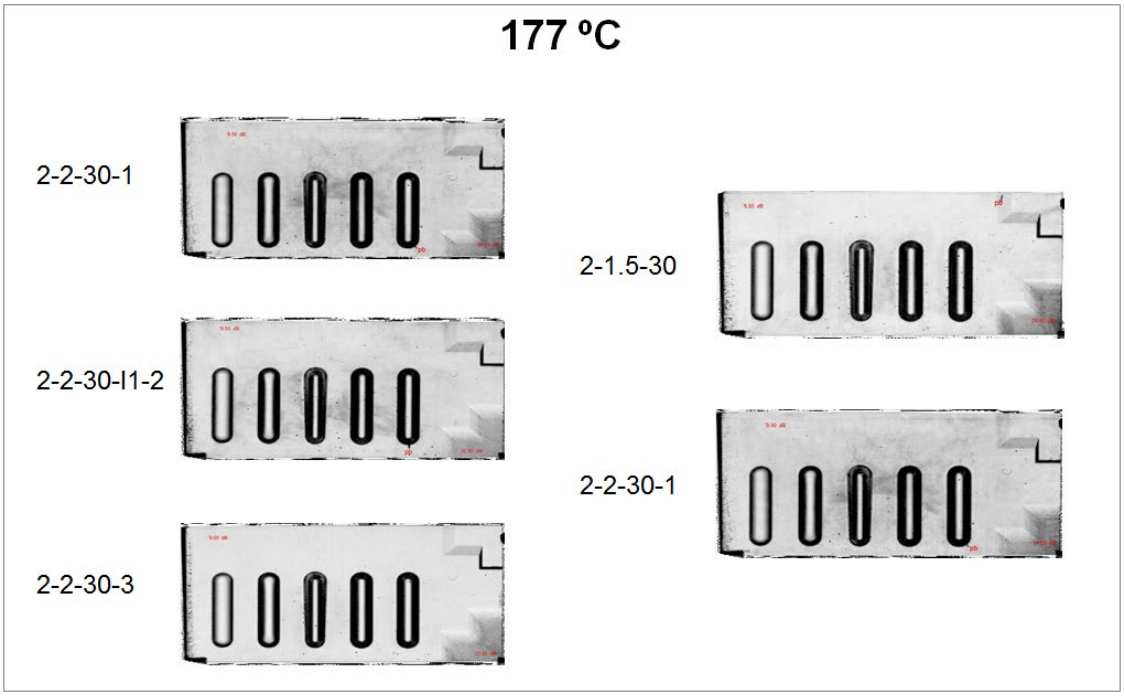


Figure 3.3: CYCOM® 5320-1 TS-RAPM-009 Beaded Panel NDI Results

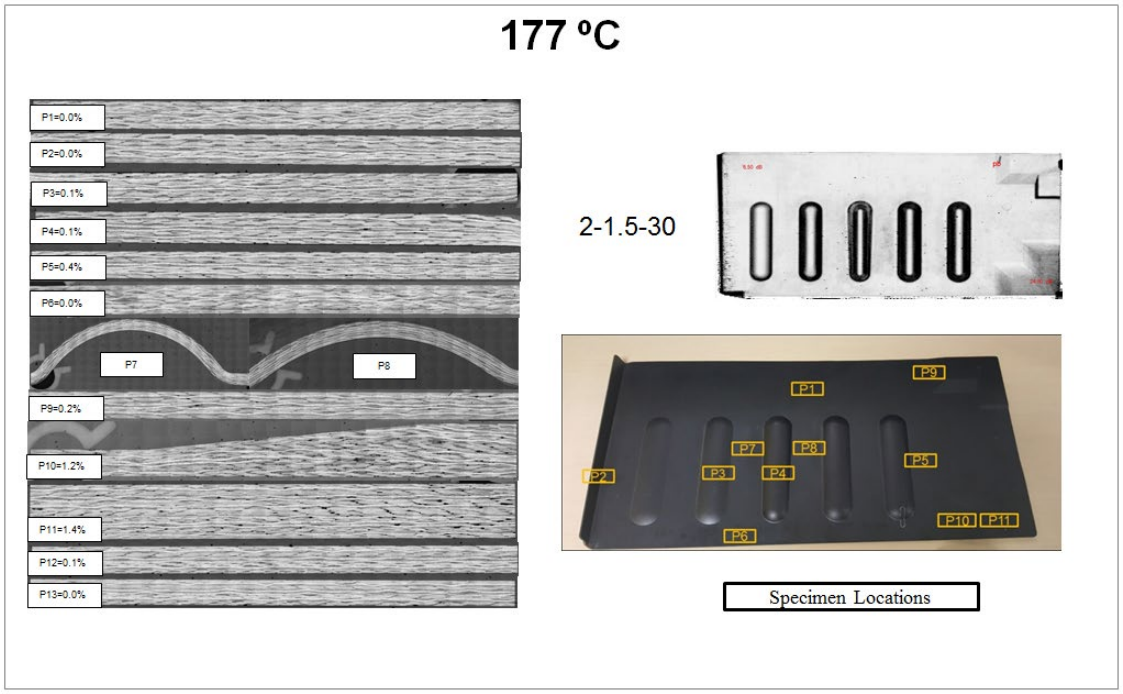


Figure 3.4: CYCOM® 5320-1 TS-RAPM-009 Beaded Panel Cross Section Results

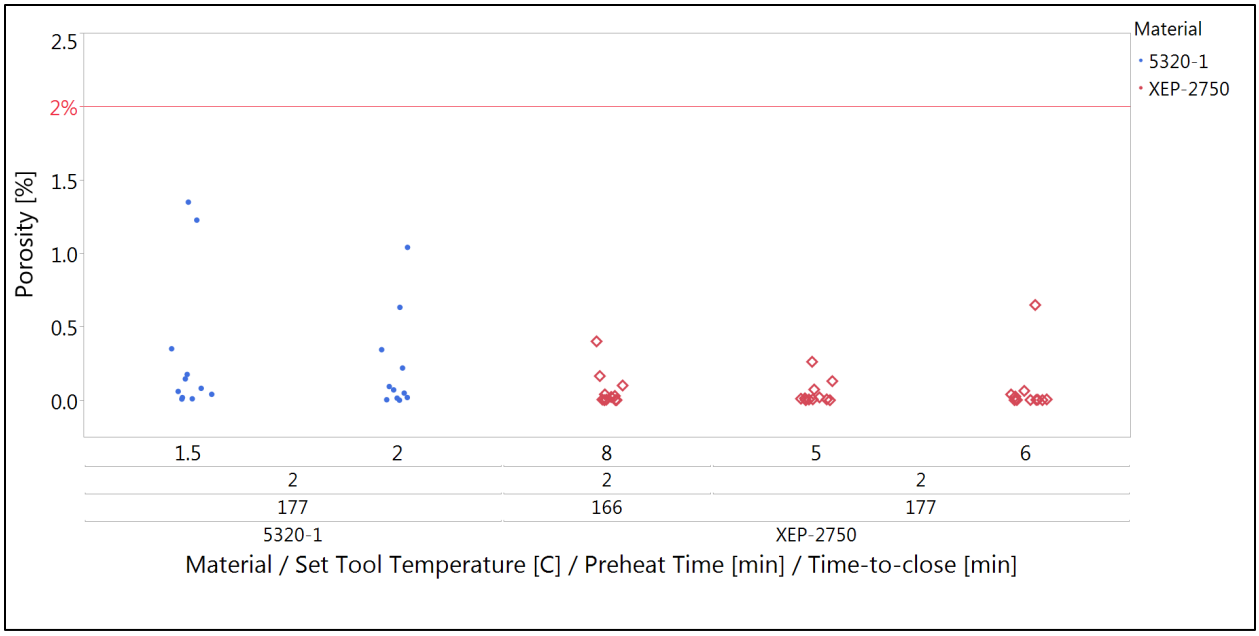


Figure 3.5: Porosity % for CYCOM® 5320-1 and XEP-2750 TS-RAPM-009 Beaded Panel Dissection Results, Red XEP-2750, Blue CYCOM® 5320-1

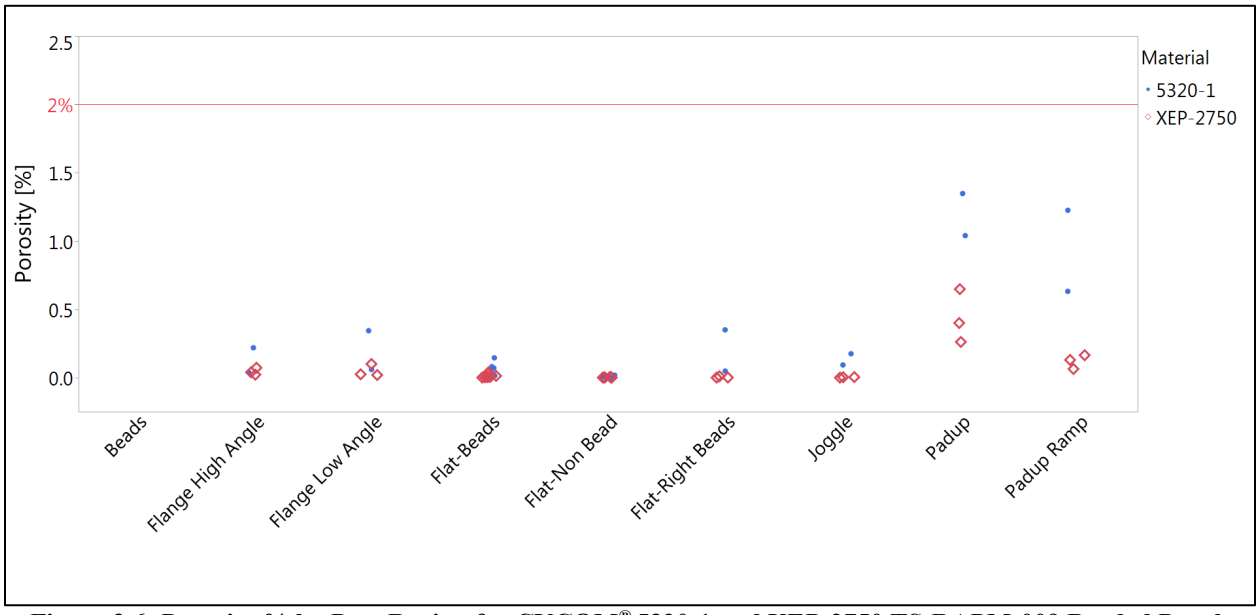


Figure 3.6: Porosity % by Part Region for CYCOM® 5320-1 and XEP-2750 TS-RAPM-009 Beaded Panel Dissection Results, Red XEP-2750, Blue CYCOM® 5320-1

3.2 Improved Processing

Once processing parameters had been established for the TS-RAPM-009 beaded panels, the process was repeated for the TS-RAPM-002 rib configuration. The first ribs had a more restrictive design matrix followed by repeating each material and processing solution 3-5 times for the most robust looking components (Figure 3.7). The quality investigations showed ribs that

were quite repeatable and met low porosity targets as well as minimal fiber wrinkling and fiber waviness, Figure 3.8. It is also worth noting that the mindset coming into this component was that being a matched mold process, the part thickness variation would be minimized. While still largely true, it was found after reviewing material processing parameters and finished part cured ply thicknesses, that the tooling gap in the flanges was fixed and consistent but the web thickness could vary as a function of the prepreg resin content (less than +/-2%) and process. Part porosity and surface quality are optimized when hydrostatic matrix resin pressure is maintained during part consolidation. Figure 3.9 shows how the part cured ply thickness could vary between the flanges and the webs as resin was allowed to migrate inside the cavity. Figure 3.10 shows a characteristic tool model, the spring frame shuttling over the compression mold, and finished as-manufactured components for two material systems.

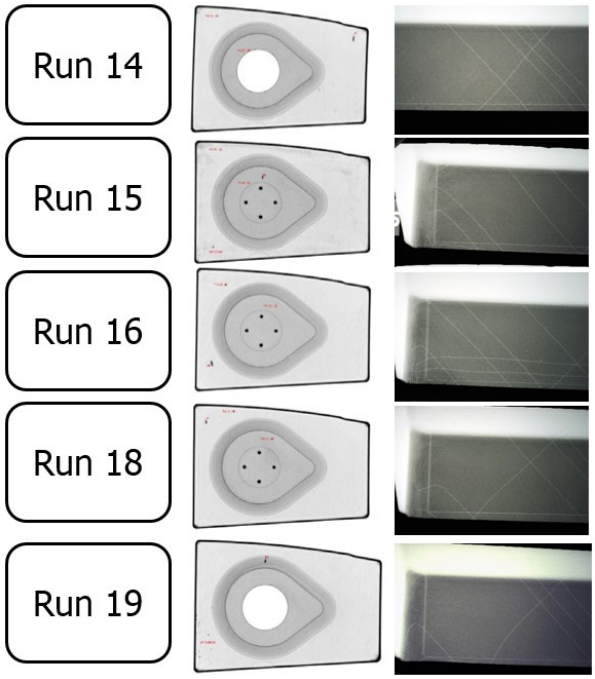


Figure 3.7: Identical Processing Conditions Investigated for Process Repeatability, NDI Scan and Flange X-ray for TS-RAPM-002 rib

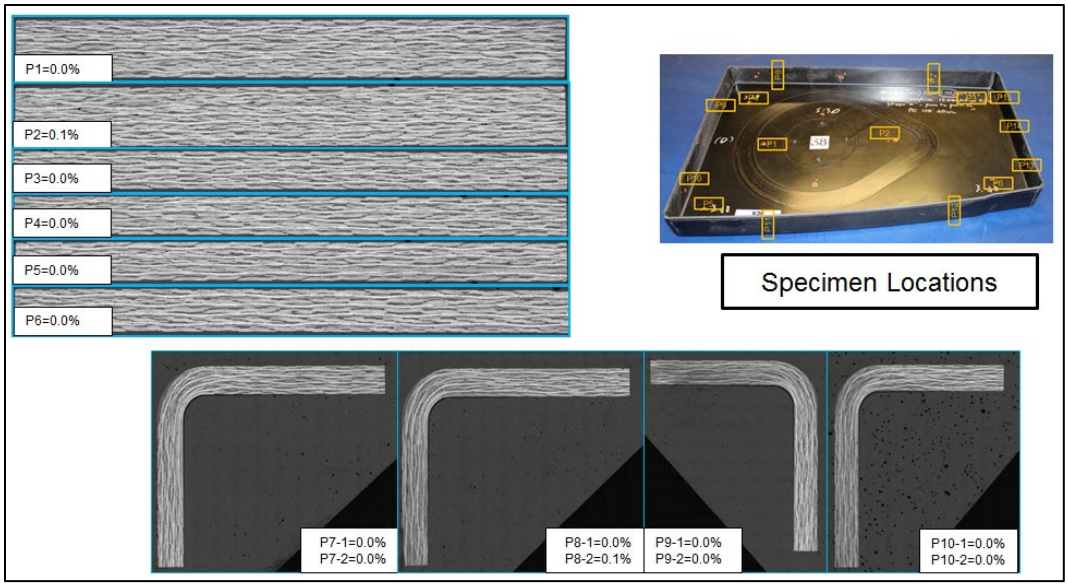


Figure 3.8: TS-RAPM-002 Rib Dissection Sections for Porosity Investigation, Optical Porosity

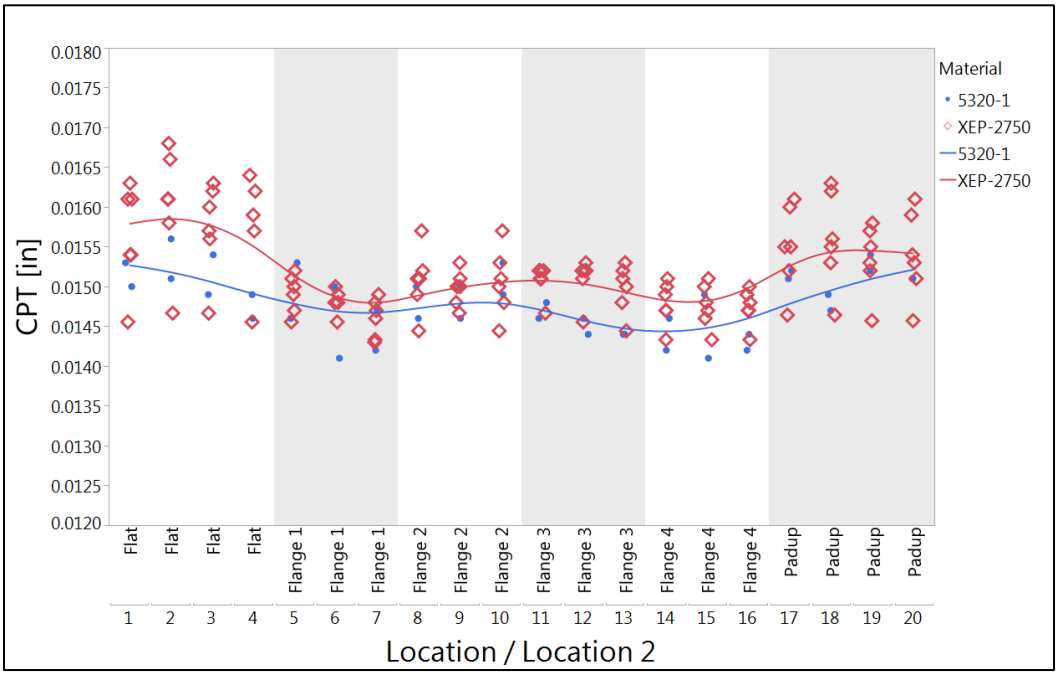


Figure 3.9: TS-RAPM-002 Rib Cured Ply Thickness Changes Controlled by Tool Gap, By Material (blue = CYCOM® 5320-1, red = XEP-2750)

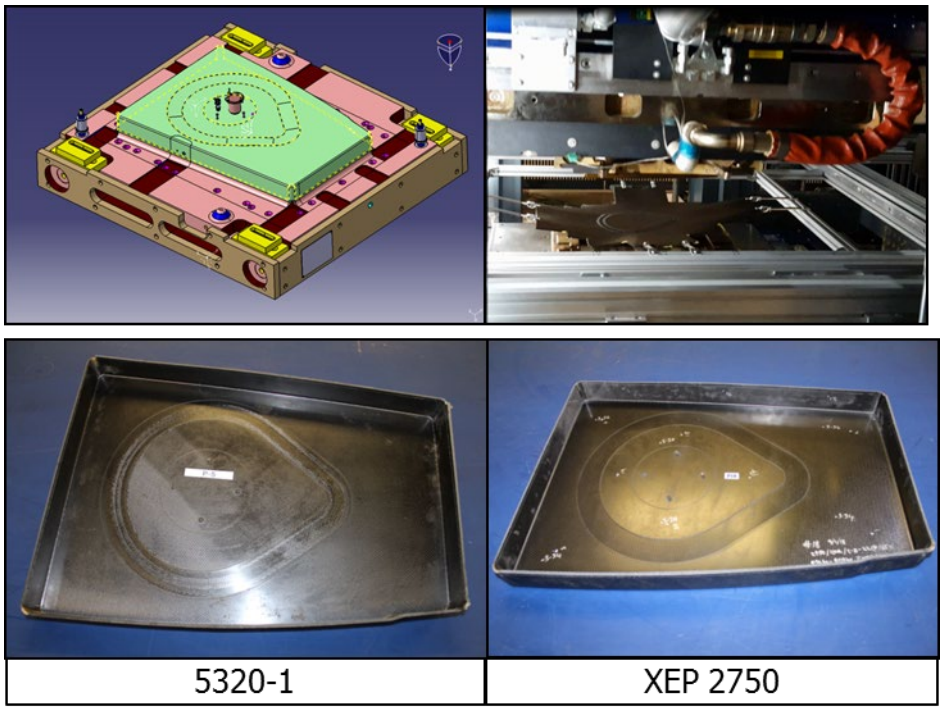


Figure 3.10: As Manufactured CYCOM® 5320-1 and XEP-2750 TS-RAPM-002 Rib Components

3.3 Discussion of the Influence of Material Cost

Moving to a heavily automated manufacturing cell and rapid cure processes enables lower part cost. At increased manufacturing rates, the part conversion cost reduces significantly, particularly due to reduction in direct labor time, overhead, and tool / equipment utilization. After optimizing layup, reducing cycle time, and simplifying the cure process, the influence of material takes up a larger total percentage of the finished part cost. The reader is invited to review the cost trade study for futher discussion [6].

4. CONCLUSIONS

As the aerospace industry continues to focus on lower cost and faster production methods to enable low cost stuctures, new manufacturing approaches must be adopted by the industry. Compression molding of thermoset materials has shown technical feasibility to manufacture aerospace performance components with reduced cycle times and increased throughput potential. Thermoplastic and thermoset infusion composite materials have made inroads on low cost, high rate part manufacturing. Through improved materials and the Compression Molding Process including spring-frame blank delivery, thermoset composites provide a competitive option for high rate, low cost part fabrication. The utilization of non-standard processes with standard qualified aerospace materials (such as CYCOM® 5320-1 prepreg) and intentionally designed aerospace capable materials (such as developmental XEP-2750 prepreg) has been proven as a viable pathway. The spring frame forming approach offers novel forming capability coupled with compression molding compatibility. This has set the stage for future implementations of non-autoclave compression molding for high rate aerospace structure.

5. ACKNOWLEDGMENTS

This effort was jointly accomplished by a Boeing-led team and the United States Government (Defense Advanced Research Projects Agency, DARPA) under the guidance of the United States Army Research Office, ARO. The authors would like to acknowledge the guidance and support of Dr. Jan Vandenbrande of DARPA/DSO and Dr. David Stepp of ARO. The information in this paper was approved for public release by 18-01129-CORP. Research was sponsored by the Defense Advanced Research Projects Agency (DARPA) and was accomplished under Cooperative Agreement Number **W911NF-16-2-0087**. The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied, of the Defense Advanced Research Projects Agency or the U.S. Government. The U.S. Government is authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation herein.

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