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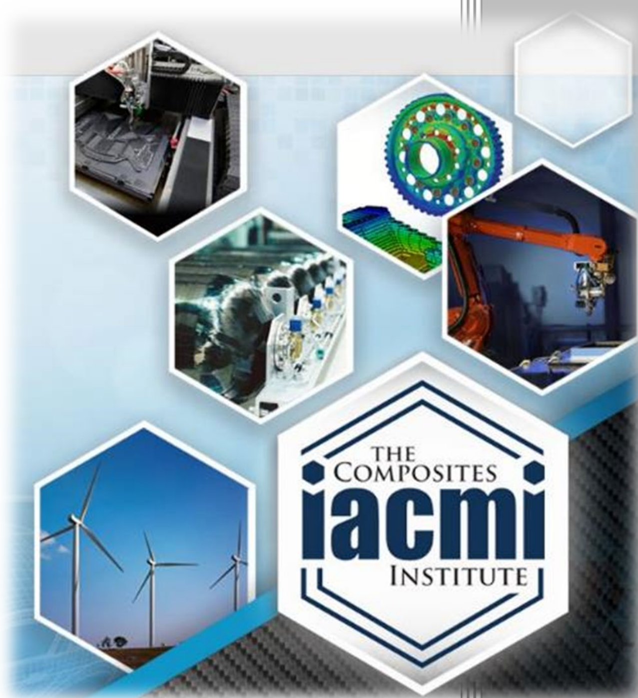
Demo 5: RapidClave Technology Demonstrations – Round II (Task 2)



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Date: 8/27/2021

Final Technical Report
PA16-0349-5.1-01

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Demo 5: RapidClave Technology Demonstrations – Round II (Task 2)

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Date Published: December 2021

Prepared by:
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Knoxville, TN 37932
Managed by Collaborative Composite Solutions, Inc.
For the
U.S. DEPARTMENT OF ENERGY
Under contract DE- EE0006926

Project Period:
(01/2020 – 12/2020)

Approved For Public Release

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LIST OF ACRONYMS

UDRI	University of Dayton Research Institute
Tg	Glass Transition Temperature
RFI	Resin Film Infusion
DSC	Differential Scanning Calorimetry
C	Celsius
CSM	Chopped Strand Mat
VOC	Volatile Organic Compound

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ACKNOWLEDGEMENTS

The information, data, or work presented herein was funded by the Office of Energy Efficiency and Renewable Energy (EERE), U.S. Department of Energy, under Award DE- EE0006926. UDRI would like to thank JobsOhio and IACMI for their support of this work, as well as O'Gara Armoring, Owens Corning, and Hexion for their invaluable partnerships.

1. EXECUTIVE SUMMARY

The purpose of this project task was to make automotive composite part manufacturing more cost competitive for low volume production and thereby drive composite application innovation. The strategy was to incorporate low-cost preforming, snap cure resins, and RapidClave® processing to create an alternative to conventional automotive composite manufacturing based on SMC. The program used RapidClave® technology from Globe Machine Manufacturing, fast-curing ("snap cure") epoxy resins from Hexion, and conformable/stretchable glass fiber reinforcement mats produced by Owens Corning for rapid preforming.

O'Gara Armoring retrofits vehicles to meet special security needs, such as larger doors to facilitate easier entry into the vehicle. O'Gara has a variety of custom vehicles in need of custom doors that require affordable tooling to produce approximately 100 ship sets/year. The project focused on a composite door panel application provided by O'Gara that is currently made by manual chopped fiber spray-up processing. UDRI reverse-engineered the current composite door panel and created tooling for use in the RapidClave®. UDRI designed an improved composite door using MultiMat fiberglass reinforcement from Owens Corning. UDRI made snap cure resin films from Hexion resin. Finally, UDRI conducted molding trials to compare autoclave processing with RapidClave® processing.

The technical goals of the project were to reduce tooling cost by 50% as compared to SMC compression molding and to reduce cycle time by 50% compared to current manual spray-up process. The approach to reduce tool costs is based on use of single sided tooling for use at 100 psi, as compared to matched metal SMC tooling. An added benefit realized from the program is that the Owens Corning mat provided more uniform thickness and improved performance. Tensile and flexural strengths and moduli were increased by at least 50%. This task also demonstrated a 75% decrease in cycle time.

O'Gara is evaluating the technology demonstrated in this project for some of their current production. Additionally, there are new products O'Gara is pursuing which require higher production rates than their current products. O'Gara has identified these new products as good candidates for the RapidClave® technology. The cost advantages demonstrated by this project would then lead to significant economic development.

In conclusion, this task successfully combined the RapidClave® technology from Globe with a snap cure epoxy resin film system from Hexion and preform material from Owens Corning. Further research is needed to better map the technical limits such as cycle time of these technologies. Additionally, the technology should be extended in terms of size and shape to include large parts outside of automotive applications, such as a small aircraft fuselage.

2. INTRODUCTION

Introduced to the market in 2007, RapidClave® offers an innovative composite process/curing approach that enables cycle times approaching that of compression molding with the added benefit of rapidly produced, low-cost tooling that delivers part quality typical of autoclave processing. RapidClave® technology challenged legacy thought processes and now has established a new paradigm for advanced composites curing technology. This innovative approach has been a key influence for material suppliers to innovate aerospace type polymer chemistries for even greater curing efficiencies that as recent as 10 years ago were simply viewed as "future state". These new and innovative polymer systems are now finding application in mainstream, high volume applications in the automotive industry, yet opportunities remain.

Related efforts, including the IACMI project RapidClave® Technologies Demonstration – Round 1, focused on coupling the RapidClave®, snap-cure resins, and low-cost tooling to show favorable comparisons to autoclave and compression molding processing. The project that this paper reports on is an extension of these efforts, but it goes a step further by focusing on dry fiber preforms and snap-cure resins in neat form, as opposed to the typical prepreg format. If successful, this would offer an alternative to parts currently made by spray-up processing by O'Gara, but more broadly, it would offer a technology that would be applicable to a wide range of automotive and aerospace applications.

3. BACKGROUND

RapidClave®

The RapidClave® has been demonstrated in composite production environments. Specifically, it was in use at Plasan Carbon Composites until recently to produce Corvette, C7 exterior, carbon fiber body panels [1]. Although capable of meeting the required production rate, the legacy equipment required part-specific, integrally-heated tooling that was very expensive to manufacture. Previous IACMI investment retrofitted the UDRI-housed legacy RapidClave® to remove the need for integrally heated tooling [2]. This was done by installing a hot plate with heated oil channels embedded within the plate. Individual tooling without integral heating could be placed on the plate and heat would conduct into the tool from the hot plate. This approach requires only one initial investment in the tool plate, rather than a recurring investment every time a new tool was required, saving more than $100-200k on each tool. Figure 1 shows the plumbing in a legacy RapidClave® tool.

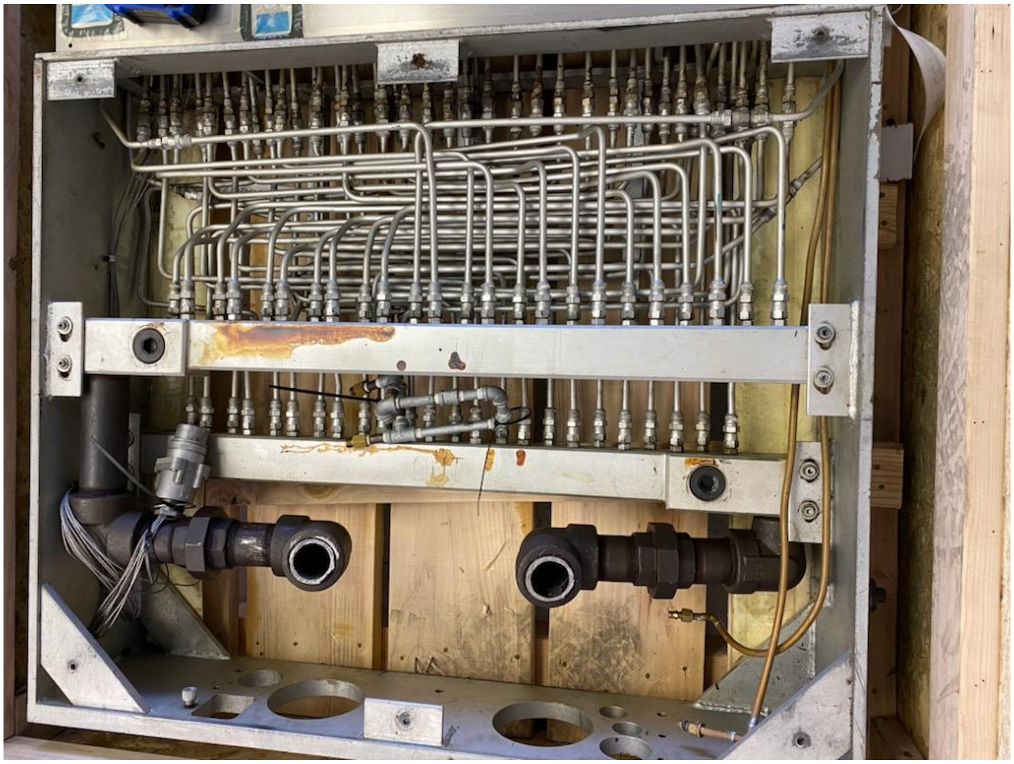


Figure 1. Typical plumbing for an integrally-heated tool

Also done during the retrofit was the inclusion of a hot air blower to supplement the hot oil heat. This allows for heated air to impinge on the cure tool from the top simultaneously to the heat conducting into the bottom of the tool through the hot plate.

The retrofit was done to address the high tool costs and slow heating response times. This project demonstration sought to validate that these deficiencies had been addressed, as well as show that the process could compete with autoclave, compression molding, and spray-up when cost, through-put, and performance are all considered.

O'Gara door panel

O'Gara provided a door panel part to serve as the baseline for an automotive, niche market (limited production) composite part. The original part is shown in Figure 2 and Figure 3. It is currently manufactured with a spray-up process. In this process, a chopper gun is used to cut and spray continuous tow onto a mold surface along with a resin matrix. It is a very low-cost process, but provides poor performance due to high resin content and discontinuous reinforcement. The large part thickness variations, ranging by +/-0.050", and poor surface finish requires surface primer and finish painting before part installation. Transitioning to a closed mold process would provide a more consistent and accurate part, saving finishing and rework costs; however, this could not come with a significant increase in cost in other areas of the fabrication. There was also a desire by O'Gara to improve cycle times for scale-up, which could be addressed with a combination of snap-cure resins and alternate processing equipment. Lastly, improved stiffness in the panel was expressed as a desirable outcome of the project, although it was viewed as an ancillary benefit.

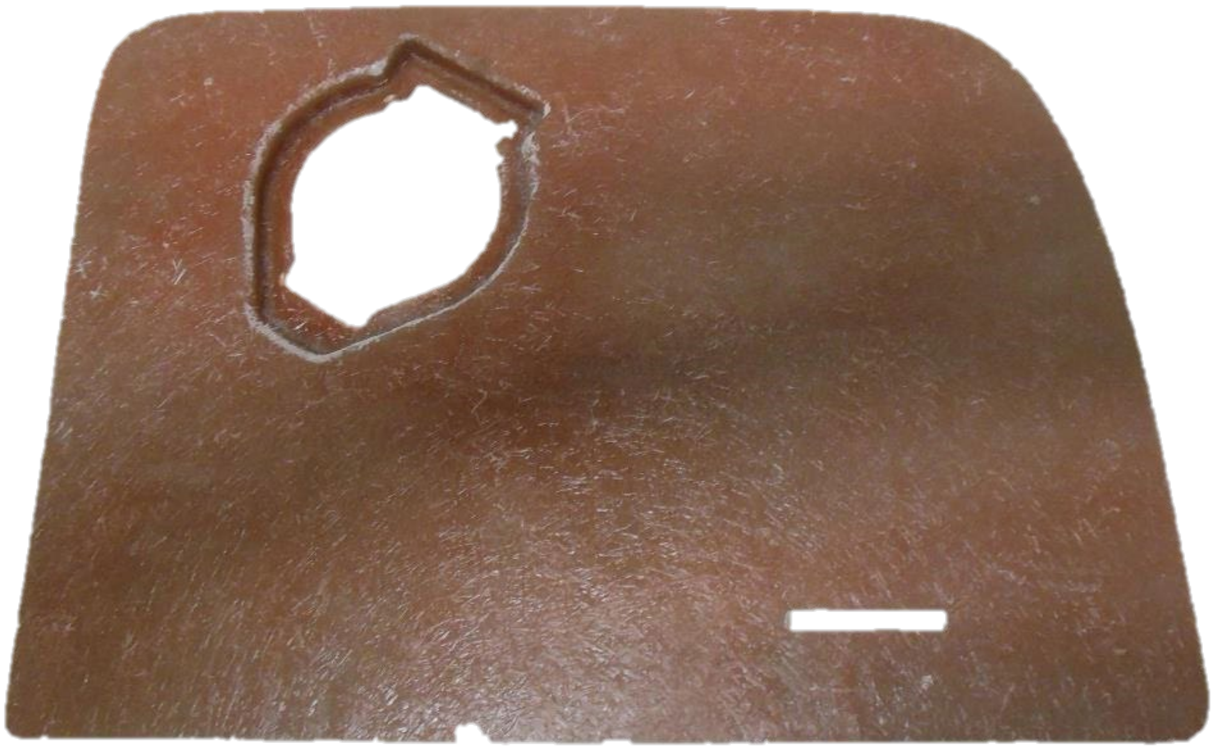


Figure 2. Photograph of Door Panel B-Side Showing Poor Dimensional Consistency

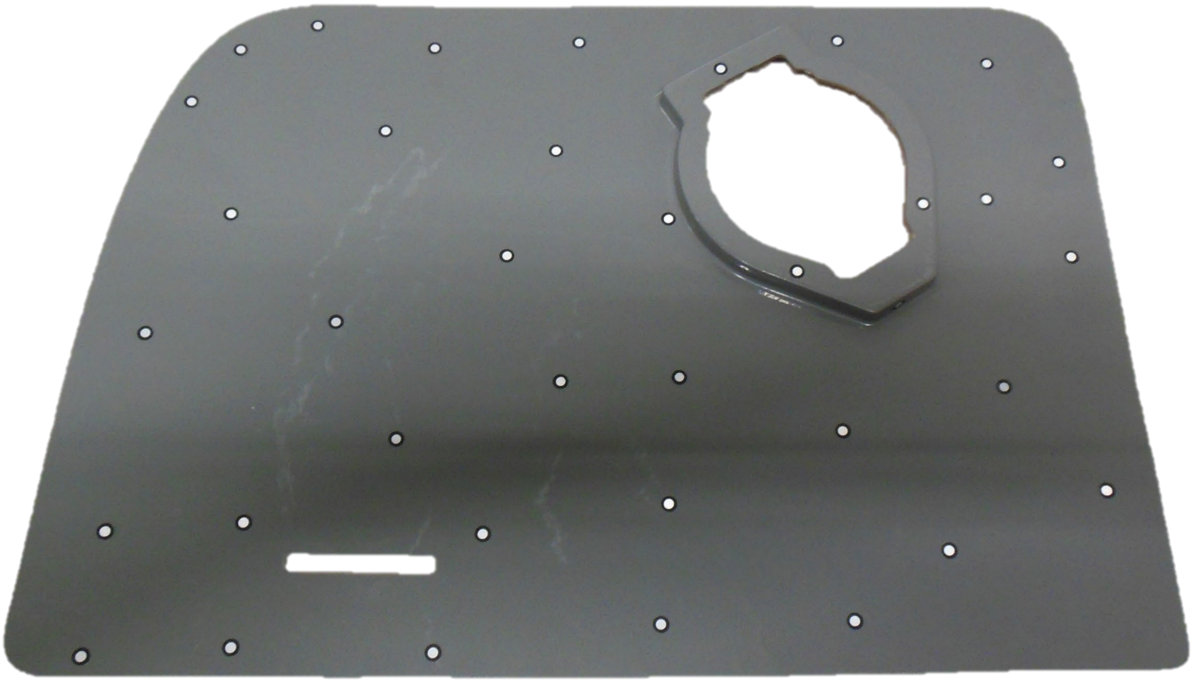


Figure 3. Photograph of Door Panel A-Side Showing Scan Marker Dots

4. RESULTS AND DISCUSSION

Through digital scanning, UDRI reverse-engineered a sample door panel provided by O'Gara and then designed a new door panel that used snap cure resin from Hexion and easily preformed fiber reinforcement from Owens Corning. UDRI developed a reusable composite caul to improve the molding process. UDRI performed molding trials on the new design in the baseline autoclave and in the RapidClave®. The following sections provide more detail on these activities.

New Composite Door Panel Design

The composite design, along with the molding method, are the primary determinants of the part performance and manufacturing process efficiency. The composite door panel serves a non-structural cosmetic trim function and thus the objective was to meet or exceed the baseline mechanical performance while enhancing geometric consistency and reducing cost.

The composite design comprises choosing the resin system and the fiber reinforcement along with the details of the design, such as part thickness and fiber volume fraction.

The original part was made by chopper gun using a low performance polyester resin, which resulted in inconsistent part thickness and low thermo-mechanical properties. O'Gara wanted a redesigned part with similar or greater strength and bending stiffness, better dimensional consistency, and yet lower weight, cost, and cycle time. UDRI reverse engineered the existing part to provide a starting point for an improved composite design.

Since there was no CAD model for the existing part, UDRI digitally scanned the existing part and then created an accurate dimensional model of the existing part. Most of the part is flat except for a bump-out for a speaker. The existing part had 90 degree edges which caused several problems or undesirable features in the manufacturing process and the final part. In order to overcome these limitations, UDRI redesigned the speaker bump-out detail by removing sharp corners where possible, adding large fillet radii, and reducing the primary edge angle from 90 degrees to 60 degrees. The original design resulted in inconsistent part thickness because of the difficulty of forming the fibers to that shape. Additionally, the 90 degree geometry caused problems with the release of the molded part from the mold. Finally, the 90 degree edges are physically weaker and less desirable in the final part. Figure 4 shows a comparison between the original part and the redesigned part. The orange line shown in the detail on the right shows the original part shape for comparison to the redesigned part shape.

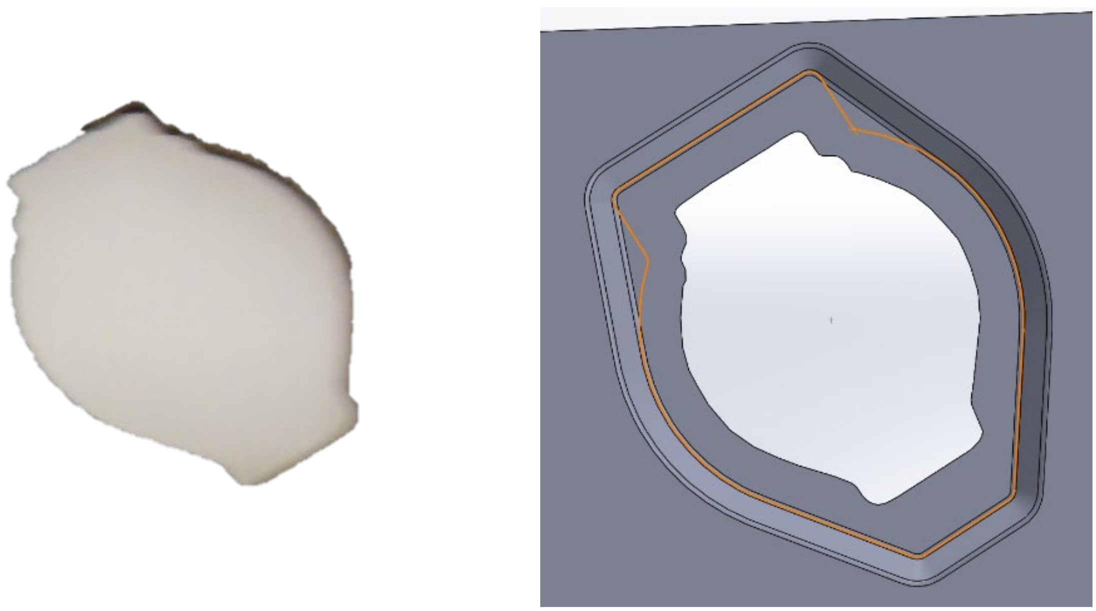


Figure 4. Comparison between Original Part (left) and Re-designed Part (right) Detail.

Snap Cure Resin

Resin cure time is very important to overall molding cycle time. Typical epoxy resin systems can have cure times of four to eight hours. For this program, a snap cure resin system was chosen. Hexion 06564 (referred to as "snap-cure resin" or "Hexion resin" throughout report) has a much shorter cure cycle, measured in minutes as opposed to hours, while still producing good mechanical properties and the high Tg needed for most automotive applications. The Hexion resin was procured, and the decision was made to film the resin for enabling resin film infusion (RFI) processing of laminates since the material is not available in prepreg form using the desired reinforcement.

A series of isothermal differential scanning calorimetry (DSC) experiments were run on the snap cure resin to help determine a cure cycle involving time and temperature. Based on the experimental results shown in Figure 5, UDRI decided to use a cure temperature of 120 °C which was thought to be a good compromise between a sufficiently fast cycle time and the risk of overly fast reaction. The reaction at temperatures higher 120 °C might be so rapid that the resin might gel or cure before the resin film infusion process was complete, and the exotherm might be so great that the peak temperature might degrade the final composite. The only advantage to a higher cure temperature would be faster cure, however the cure is only a few minutes and therefore there is little room for improvement.

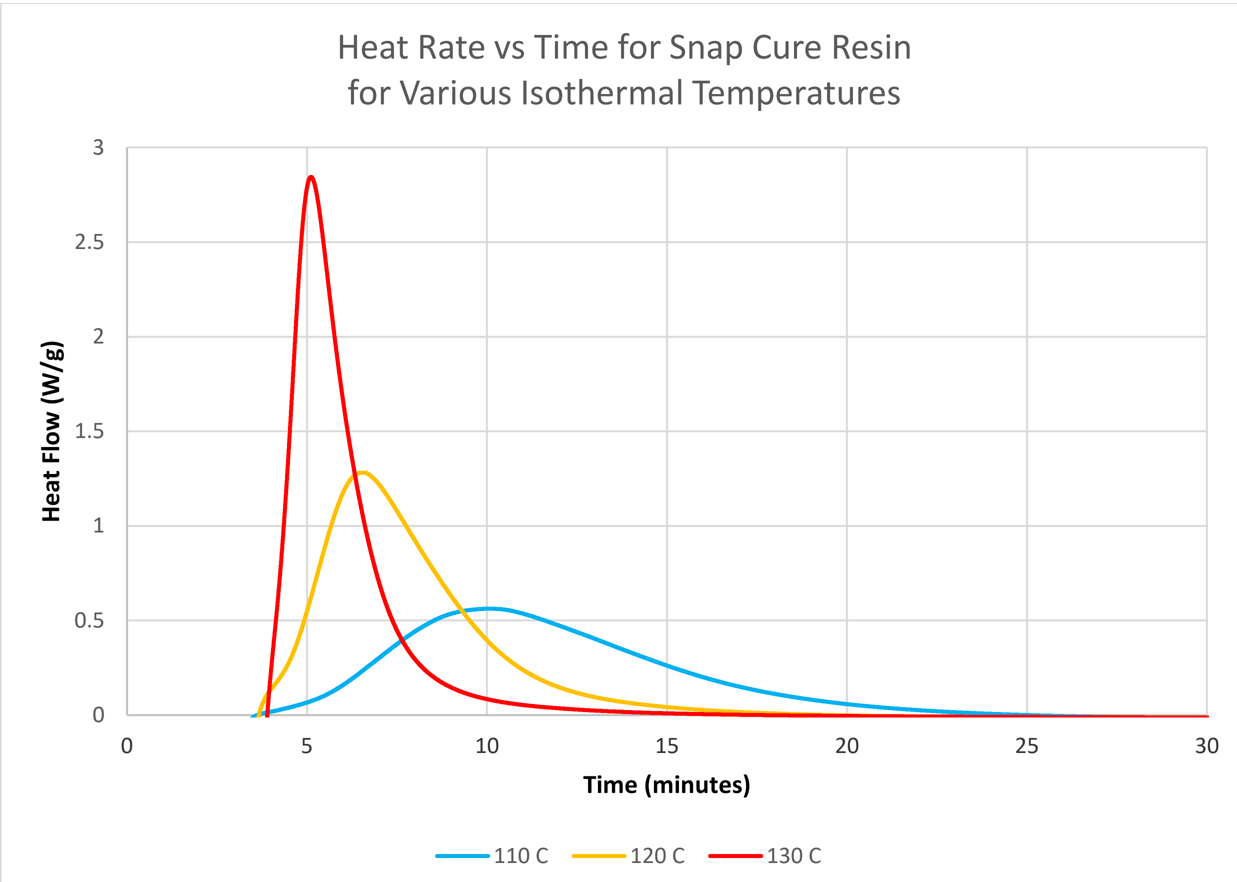


Figure 5. Heat Flow versus Time for Snap Cure Resin at various Iso-Thermal Temperatures

The Hexion 06465 snap cure epoxy is a three part system consisting of a resin, a curing agent, and a catalyst. The resin is designed as a hot melt system and is extremely viscous, even at elevated temperatures. A Ross paddle mixer with a high shear spindle, coupled with an oil jacket heated mixing bowl, was used to process the resin. UDRI added a defoaming agent to this resin system to increase the release of air during vacuum de-gassing after mixing. Figure 6 shows the resin system after mixing all components.

Figure 6. Snap Cure Resin after Mixing Resin, Hardener, Catalyst, and Defoaming Agent

The mixed and degassed resin was poured onto the filming line where the resin and two sheets of wax coated paper were squeezed between heated rollers to achieve the desired film thickness. The continuous sheet was cut into 24 inch long sheets of resin film. As shown in Figure 7. The processed resin film was stored in a freezer until it was needed during layup and molding.

Figure 7. Sheets of Resin Film being produced on Film Line

Reinforcement

Along with the resin, the fiber reinforcement is a major component of the composite design. Due to cost and performance requirements, carbon fiber reinforcement was not necessary and glass fiber reinforcement was chosen. Also, due to the relatively low mechanical property requirements, a discontinuous fiber material with greater conformability and easier preforming was chosen over a higher performing continuous fiber material that is more difficult to fit to a compound and contoured shape. UDRI investigated both the very common Chopped Strand Mat (CSM) material as well as the more specialized MultiMat from Owens Corning.

MultiMat consists of a layer of high loft knitted fiberglass sandwiched between two layers of short fiber chopped glass as shown in Figure 8. These three layers are held together by a small amount of through thickness stitching. While many materials have good drapability and in-plane shear, most fabrics do not have much ability for in-plane extension. In contrast, MultiMat has excellent in-plane extension and drapability.

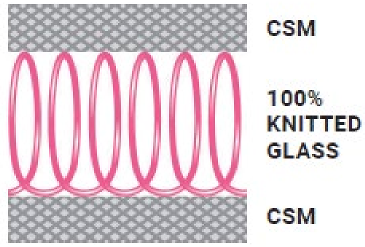


Figure 8. Cross-Sectional Diagram of MultiMat Fabric

In order to fit CSM to the speaker box, multiple layers of overlapping CSM were cut to specific shapes and relief cuts were needed to allow the fabric to fit. Due to its fiber architecture, MultiMat could be laid up in a single piece without the need for relief cuts. While CSM is less expensive than MultiMat on price per pound basis, the savings in terms of labor more than made up for the difference. As a point of reference, the difference in cost between the two fiberglass formats is less than one dollar per door panel. Figure 9 shows the MultiMat Fabric after forming.

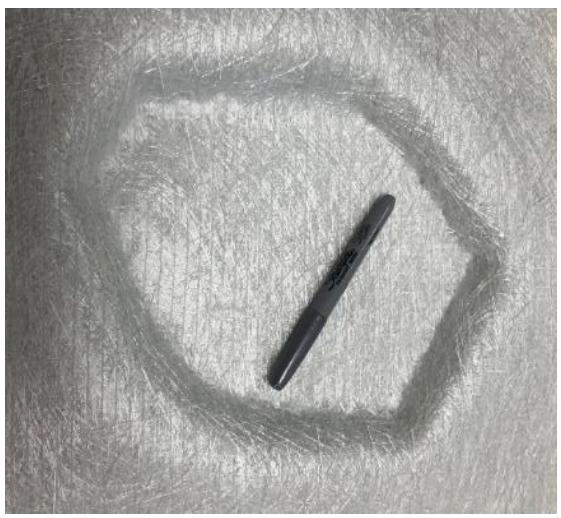


Figure 9. MultiMat Fabric formed against a preforming mold (marker used for size reference)

Composite Caul

This task investigated using a reusable composite caul as a cover to complete the vacuum chamber around the part during molding. A reusable caul allows a resin film and a fiber preform to be pre-loaded onto the caul and then rapidly cycled into and out of the RapidClave®, thereby reducing cycle time. A caul also eliminates the cost of disposable vacuum bagging materials and the labor of applying the vacuum bagging materials.

The machined tool surface defines the A-side of the part. The other side of the part is referred to as the B-side. A composite caul was made over the B-side of the part. The composite caul extended around the perimeter of the machined tool onto the tool plate and then terminated in a reusable rubber seal. Figure 10 shows the side of the composite caul that is in contact with the part during molding.

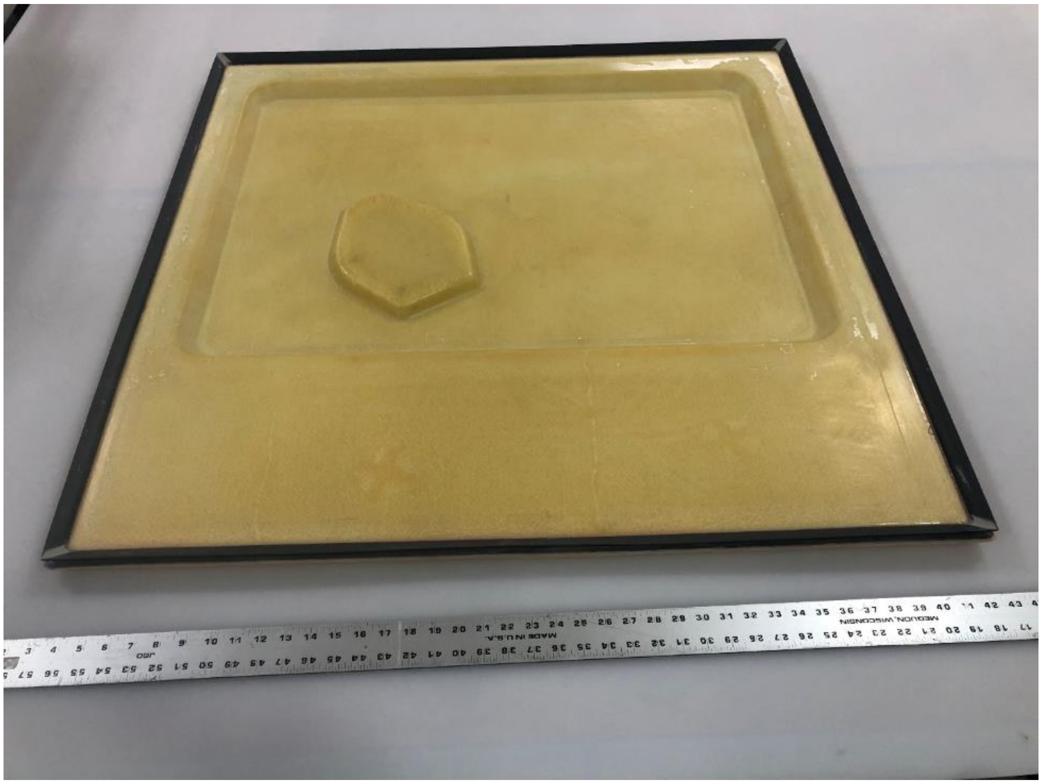


Figure 10. Part Side of Composite Caul showing perimeter Seal

Replacing consumable vacuum bagging with a reusable caul or reusable rubber bag can reduce costs and improve cycle time. Reusable bags, and especially reusable cauls, reduce worker exposure to high temperature molds and keep layup times short enough to avoid premature curing with snap cure resins.

Molding Trials

Several molding trials were conducted to characterize the cycle time for the RapidClave®. The cycle time is composed of a sequence of steps needed to produce a part and get ready for the next part. The focus was on the molding process itself and it was assumed that this molding process was the rate limiting step. Preform preparation time was excluded. It was assumed that there is only one machined tool for the RapidClave®cure, however there could be multiple composite cauls that rotate through the process. The composite cauls are relatively inexpensive compared to the machined tool.

Initial molding trials used a standard epoxy system (EPON 862/W) in an autoclave while the team waited for the arrival of the Hexion resin and RapidClave® availability. Autoclave runs with the Hexion resin continued once received, and switched to the RapidClave® when it became available.

For the autoclave runs, the MultiMat fiber reinforcement was formed against a preforming tool and resin film was applied to the fiber reinforcement to make a complete preform. It was assumed that this preforming step was completed in parallel outside of the molding cycle so that the preforming would not add any time to the molding cycle. Figure 11 shows the formed fabric reinforcement sitting on the machined tool. A layer of snap-cure resin film partially covers the fiber reinforcement.

Figure 11. Fabric Reinforcement with Resin Film

After placing the preform on the tool, the release plies, breather, and vacuum bagging are applied and a vacuum is drawn on the part. See Figure 12. This is a time consuming step that requires skilled labor. A composite caul was not used on this particular run.

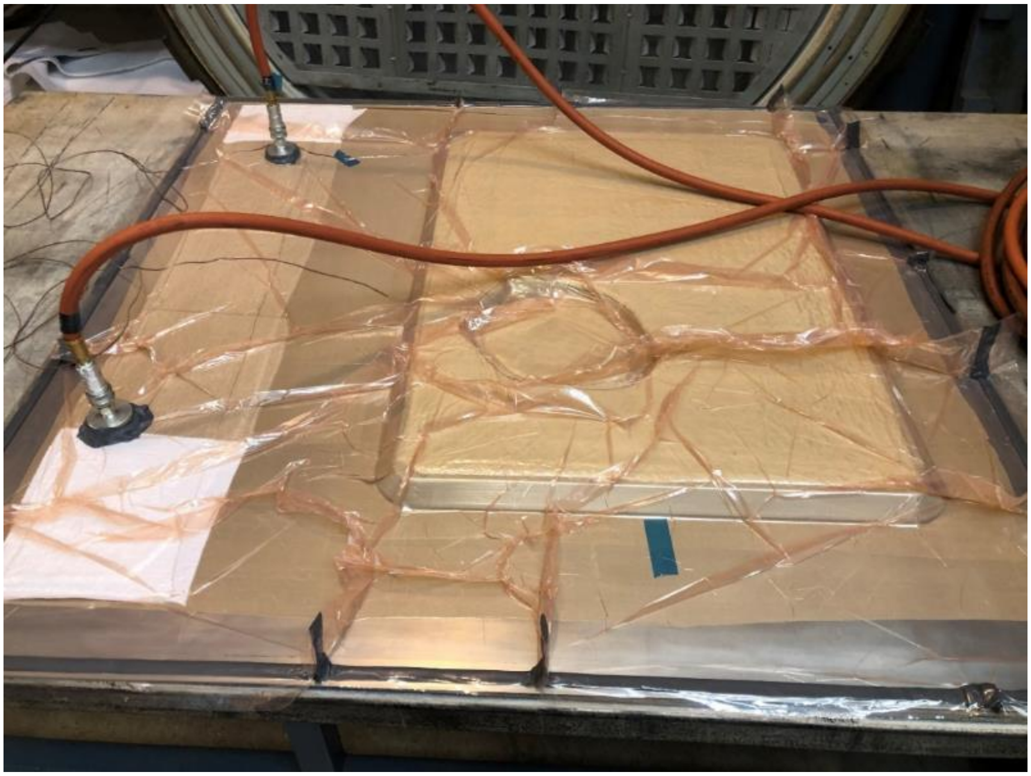


Figure 12. Tool and Preform Vacuum Bagged and Ready to Go into the Autoclave

The final part is shown on top of the machined tool in Figure 13. The part quality was good, with very little excess resin and uniform part thickness.

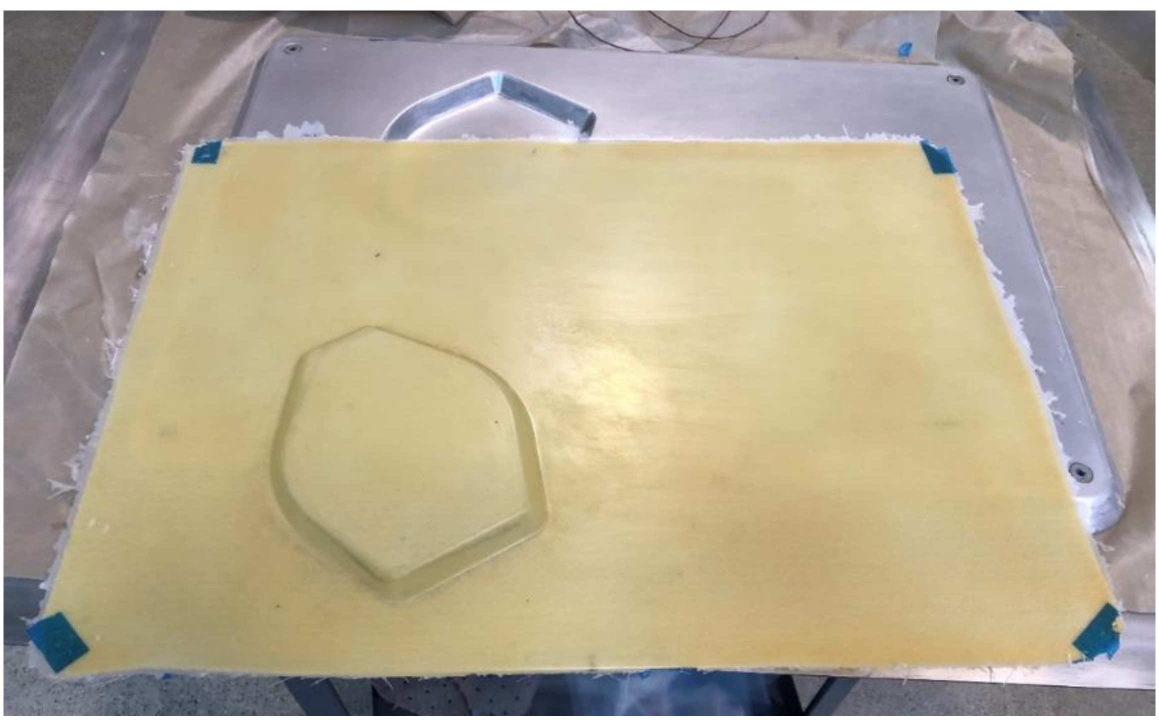


Figure 13. Snap Cure Door Panel Molded using Autoclave on top of Machined Tool

O'Gara inspected and reviewed the part molded in the autoclave using the snap-cure resin. They were impressed with the part stiffness and strength and the dimensional consistency. The surface quality met their needs; however, even better surface quality would allow them to reduce processing steps. Surface quality was not a focus of this task. With proper attention to mold surface polish, the desired part surface quality would be achievable.

For the RapidClave® processing, UDRI applied the snap cure resin film to the composite caul as shown in Figure 14. The MultiMat fiber reinforcement was applied to the resin film as shown in Figure 15. The resin film had enough tack to stay attached to the caul and to keep the fiber reinforcement in place. Figure 16 shows the composite caul covering the preform and machined tool which is sitting on the RapidClave® tool plate. Vacuum ports in the tool plate supply a vacuum source to the cavity during molding in the RapidClave®. Figure 17 shows the composite door panel after molding in the RapidClave® and before trimming.

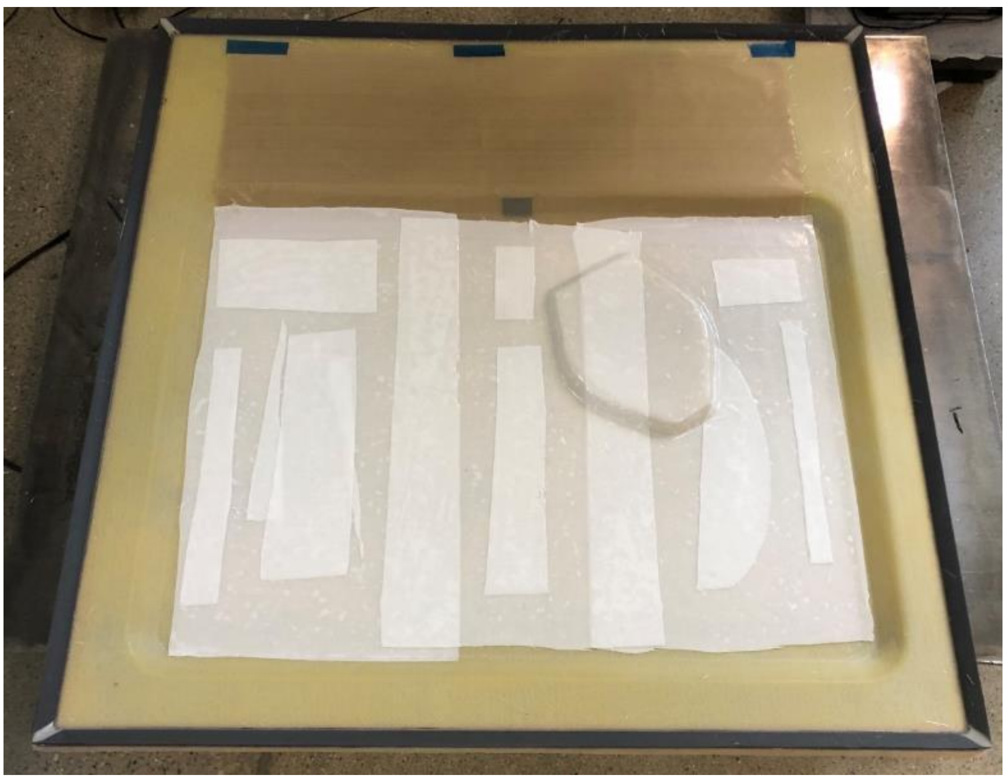


Figure 14. Resin Film Applied to Composite Caul

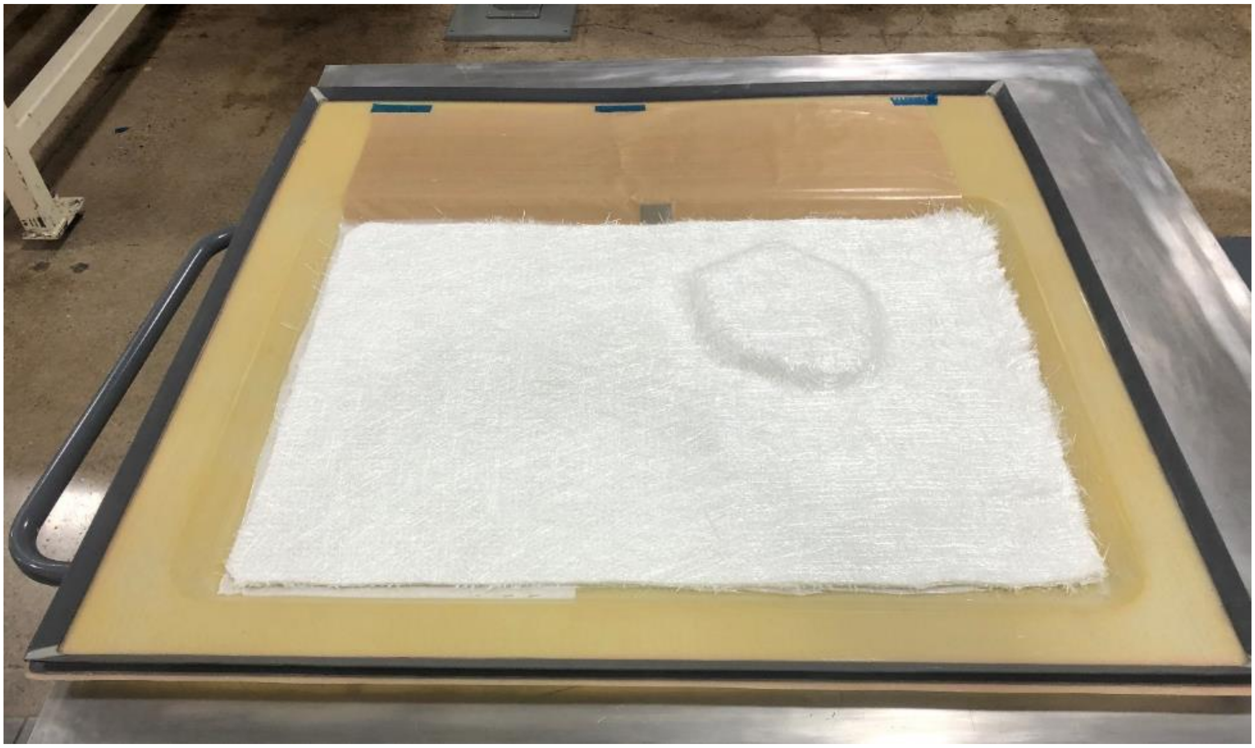


Figure 15. MultiMat Preform Applied to Resin Film on Composite Caul

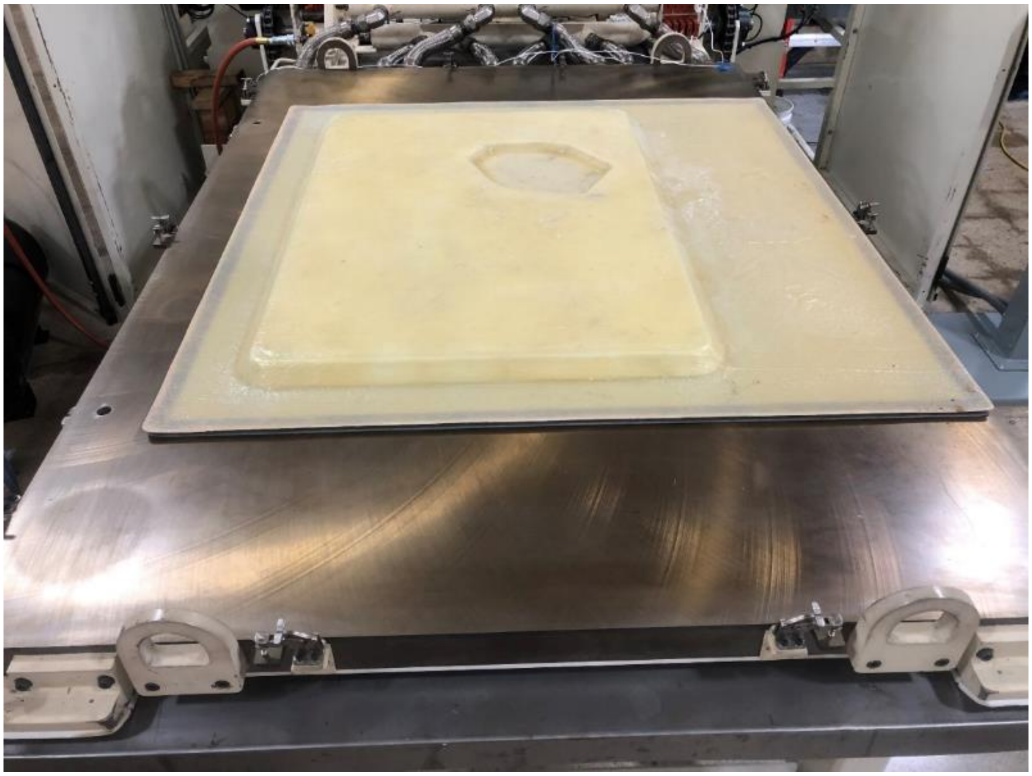


Figure 16. Composite Caul Covering Preform and Machined Tool Sitting on RapidClave® Tool Plate

Figure 17. Composite Door Panel Molded using RapidClave® before Trimming

O'Gara inspected and reviewed the part molded in the RapidClave. They agreed that its stiffness, physical appearance, and surface quality were equal to that of the autoclave panel, which had previously been deemed superior to the chopper gun baseline panel.

Physical and Mechanical Testing

Mechanical testing was done on a baseline panel made with a spray up process and compared against data collected on the MultiMat material and snap-cure resin system. As shown in Table 1, the MultiMat/snap-cure laminates yielded a 70% increase in tensile strength and 49% increase in tensile modulus. A similar, but exaggerated, trend was seen with the flexural data (Table 2). The test laminate showed a 122% increase in flexural strength and 80% increase in modulus.

Table 1. Tensile strength (left) and modulus (right) of baseline and Mulitmat/snap-cure laminates

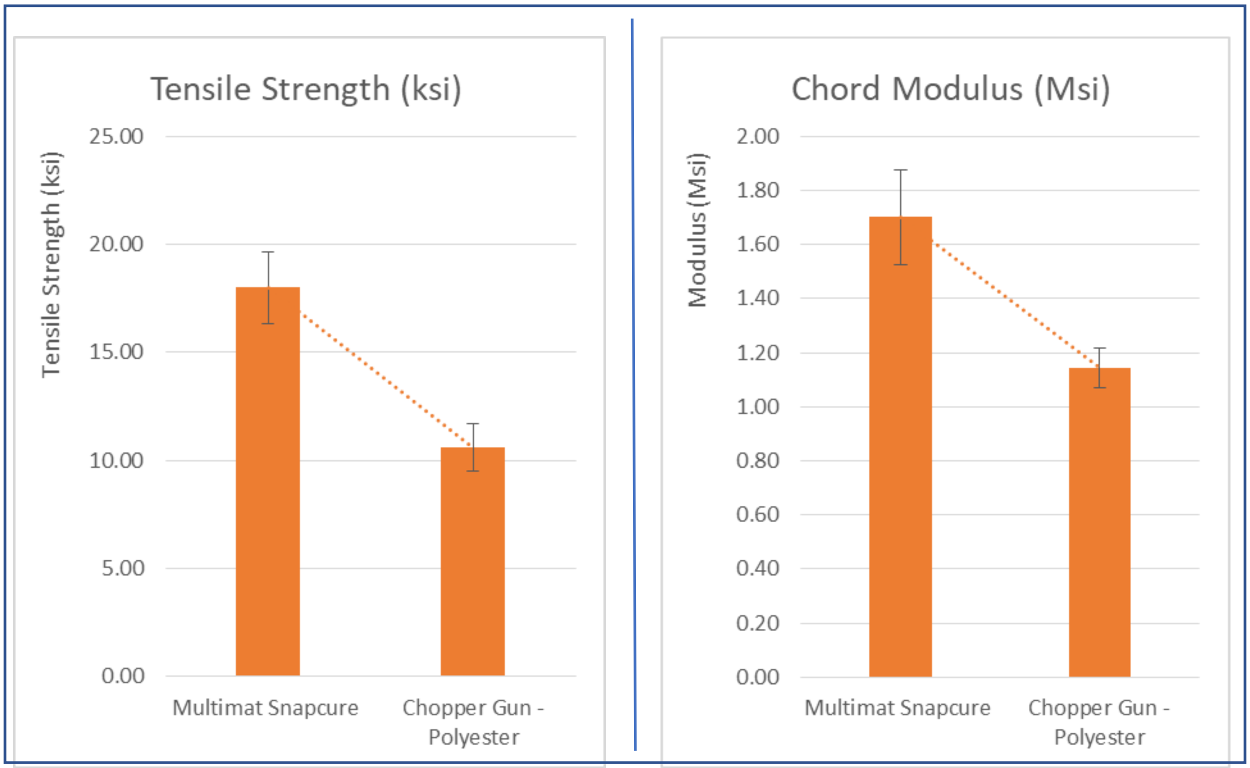
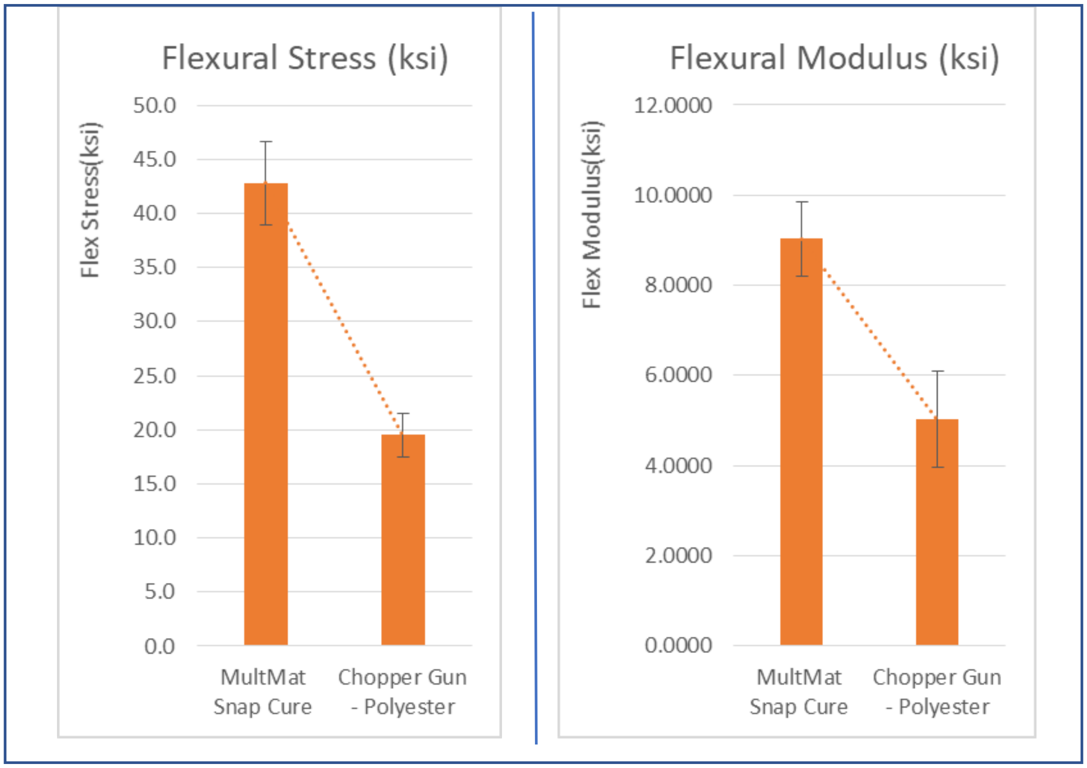


Table 2. Flexural strength (left) and modulus (right) of baseline and MulitMat/snap-cure laminates



The Tg of the composite made from snap cure resin was 194 °C whereas the Tg of the original part was 120 °C. The higher Tg for the composite made from snap cure resin means the composite will retain its stiffness at higher temperatures much better than the original part. This higher temperature performance is important for many applications including many automotive applications.

Surface finish and thickness variability were improved on the MultiMat/snap-cure laminate. With the exception of outliers around the one edge of the laminate, the thickness varied by no more than 0.020” to 0.030”, with a maximum thickness at 0.109”, on the new panel. See Figure 18. The spray-up panels saw peaks of almost 0.130” and variations of 0.050”. This large variation, coupled with poor surface finish, required O’Gara to rework every panel that it installed. Based on their observation of the new panels, it was their belief that this rework could be eliminated.

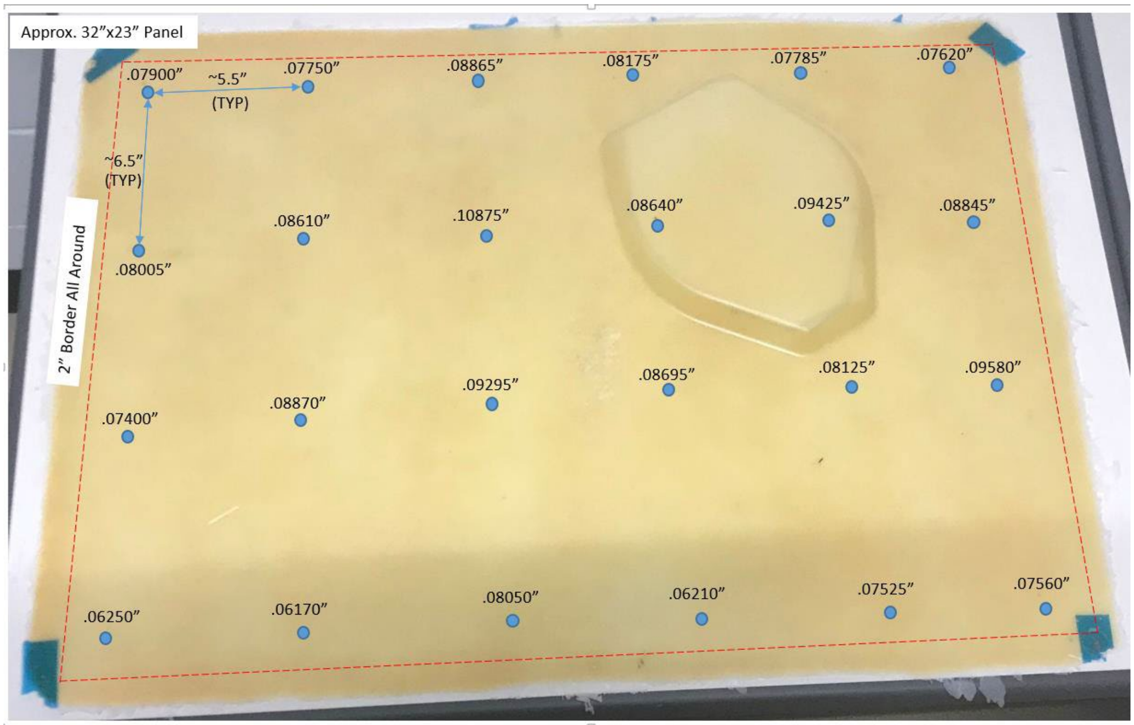


Figure 18. Thickness measurements of new door panel laminate

The data reported above was conducted on MulitMat/snap-cure laminates cured in the autoclave. The project goal was to conduct the testing on panels made in the RapidClave®, but equipment issues compressed the timing of the project and prevented this from happening. Based on physical inspection of the RapidClave®-cured panels showing similar thicknesses as the autoclave panel, and the equivalency of the temperature and pressure conditions that both panels were exposed to, the research team is confident that the reported trends in the mechanical data will extend to RapidClave®-processed panels, but this will need to be confirmed in future work.

Cycle Time Discussion

The baseline process for making the door panel is a spray-up process. This is an extremely quick lay-up process, taking just a minute or two for an operator to fully spray a part the size of the door panel. The sprayed part is then left to cure, the duration of which is heavily affected by the resin chemistry. The chemistry of the resin for the current door panel is unknown to UDRI, but a reasonable assumption of two to four hours is appropriate. Based on UDRI's experience with spray-up resin chemistries, it is likely that the actual demold time is longer, but this rate was used to avoid any unfair comparisons between the two processes. Clearly, the limiting factor in throughput is the time-on-tool of the part due to the cure cycle. Additional tools would allow higher production rates, but this would come at a cost.

A time study was conducted with the snap-cure resin, MultiMat reinforcement, and RapidClave® processing. As shown in Table 3, total cycle time from the start of lay-up to demold of the finished part, was 29.5 minutes. Due to the formable nature of the MultiMat, the time needed for lay-up of the part was only 9.5 minutes, almost equal to the time needed to cure the part. With the addition of an inexpensive second caul, lay-up could be done in parallel to the cure of the previously laid up part, essentially bringing the cycle time down to 20 minutes. In an eight-hour shift, this would allow 24 doors to be produced. With a spray up operation, one would need 6 molds, assuming a 2 hour cure.

Table 3. Cycle study of RapidClave-cured laminate

Step in Process Cycle	**RapidClave® Snap Cure (min)**
Apply Reinforcement and Resin to Caul	9.5
Put Caul with Preform on Mold	1.0
Pull Vacuum on Part	1.0
Cycle Mold Into Chamber	1.0
Pressurize Chamber	1.5
Heat Mold to Target Temperature	2.5
Cure Time of Resin	10.0
Depressurize Chamber	1.0
Cycle Mold out of Chamber	0.5
Remove Caul	0.5
Demold Part	1.0
Total Cycle Time	29.5

As a second point of comparison, running the snap-cure materials in an autoclave required a cycle time of 141 minutes, which was heavily dominated by the time required to heat up and cool down the autoclave chamber. The use of the RapidClave® allowed for an almost 80% reduction over autoclave processing.

In summary, the baseline process provides a cycle time of 120 minutes (estimated). Switching to an autoclave as a means of increasing performance requires a 141 minute cycle time, even with the snap-cure resin system. The snap-cure system cured in the RapidClave® provided a 75% decrease in cycle time over spray-up and an 80% drop compared to autoclave.

5. BENEFITS ASSESSMENT

The baseline manual spray-up process is an extremely low cost, low capital process. As such, it is difficult to compete with if only cost is considered. However, O'Gara had a strong interest in improving part performance and consistency, as long as it did not come with a detrimental cost increase. The part performance improvement was significant, as reported in the previous section, despite the fact that both use discontinuous reinforcements.

If capital costs are ignored, the manufacturing costs are expected to be only slightly higher for RapidClave® processing. A single operator could be expected to manufacture 24 door panels in the RapidClave®, performing a lay-up while the previous part is being cured. At an estimated $60/hour shop rate, that equates to $20/part in labor cost. If a spray-up operator is using a six mold rotation, the same production rate could be achieved. Actual touch labor would be reduced, given the one to two minute spray-up time, but this will partially be offset with the labor needed to trim off the overspray from the finished parts. With an adequately designed tool, the trim operation in RapidClave® processing could be eliminated. Not included in this labor figure is the touch time currently needed to rework every spray-up panel to get the desired surface finish. If included, this would heavily skew the numbers in favor of the new door panel process.

The raw materials costs for the MultiMat reinforcement and snap-cure epoxy will certainly be higher than that of the glass roving and polyester used in the spray-up process. The cost of the spray-up materials was not available to UDRI, but the cost of the MultiMat and snap-cure resin was calculated to be $7.46 per door panel ($5.87 for resin and $1.59 for fiberglass). Even if material costs are double, the impact is only a few dollars per part. In actuality, the reduction in waste, coupled with the reduced laminate thickness possible due to the higher mechanical properties, narrows the gap between the two material systems to make it even more inconsequential.

O'Gara reported the per unit cost of the door panels from their current vendor was between $425 and $475 (exact number could not be disclosed). To make the same panel in the RapidClave®, labor costs equaled $20 and material costs equaled $7.46, as reported above. The RapidClave® costs $800/day to run, accounting for electricity, compressed gas, and amortized maintenance costs, which adds another $34 to each part. The cost of the cure tool and multiple caul plates was $5000. Assuming a life of 1000 cycles, this adds another $5/part. This comes out to a total of $66.46 in direct costs for the new door panel. Obviously there are other costs that are not being accounted for, including overhead, profit, and miscellaneous manufacturing costs. With a margin of $350-400 between the cost of the new door panel compared to the cost of the baseline panel, these should be able to be addressed.

One additional benefit to the new door panel process is the fact that it's a closed mold operation. As opposed to the spray-up process, there is no concern about volatile organic compound (VOC) exposure to workers or release into the environment. Styrene emissions for polyester spray-up operations are becoming increasingly restricted, requiring nontrivial engineering measures to be added to production space and close monitoring of employee exposure. Although it is difficult for UDRI to place a financial benefit to this, it is certainly a consideration in future production of this part.

6. COMMERCIALIZATION

O'Gara is evaluating the technology demonstrated in this project for some of their current production. Additionally, there are new products O'Gara is pursuing which require higher production rates than their current products. O'Gara has identified these new products as good candidates for the RapidClave® technology. The cost advantages demonstrated by this project would then lead to significant economic development.

Although O'Gara's application could be considered niche and relatively low-volume, the technology developed in the project can extend into much larger volume markets. With the simple replacement of carbon reinforcement in place of the fiberglass MultiMat, the technology becomes immediately applicable to many high-performance applications.

Although many markets would benefit from RapidClave® processing, the urban air mobility (UAM) market perhaps stand to gain the most. Within the next ten years, the market is projected to be worth over $15B [3]. This represents tens or hundreds of thousands of new vehicles being manufactured, all heavily reliant on composites to meet weight and performance requirements. This fleet size places the manufacturing, in terms of volume, somewhere between aerospace and automotive. This is a somewhat awkward position that outstrips the capabilities of conventional autoclave processing, typical of aerospace manufacturing, but does not necessarily rise to the level of investment needed for full-rate automotive production lines. In addition, the part quality must meet that of aerospace standards, further reducing the opportunity to pull automotive processes into this market.

The RapidClave® is uniquely positioned to address this gap in production capability, allowing for the production of aerospace-quality composite structures at a rate previously not possible. This investigation has laid the groundwork for its adoption.

7. CONCLUSIONS

Cycle Time

A technical goal of the project was to reduce cycle time by 50%. The one-tool time for RapidClave® processing was 29.5 minutes, a 75% reduction compared to the spray-up process.

Manufacturing Costs

The technical goal of the project were to reduce tooling cost by 50%. Although it was not possible to reduce the cost of spray-up tooling, the overall production cost of the new door panels show a comparable, if not lower, cost as compared to the spray-up panels. Given the faster cycle time of the RapidClave®, six toolsets would be required to meet a potential production rate using spray-up tooling. For higher production rates and quality, it is more likely compression-molded sheet molding compound would be considered. Compression molding tooling has been shown to be 80-90% more expensive than RapidClave® tooling under related IACMI projects [4].

Performance

Although not a technical goal at the conception of this program, an increase in performance became a goal of the program as it evolved. Tensile strength and stiffness increased by 70% and 49%, respectively. Flexural strength and stiffness increased 122% and 80%, respectively, even in a thinner laminate.

Dimensional Consistency and Surface Quality

The door panel molded in the autoclave and the door panel molded in the RapidClave® were reviewed by O’Gara. O’Gara was very satisfied with the consistency of the part thickness. O’Gara also liked how stiff the part was even though it was thinner than the original part. O’Gara reported that the surface quality was sufficient for the application.

In conclusion, this program successfully showed that MultiMat reinforcement, Hexion snap-cure epoxy, and RapidClave® processing could create laminates far exceeding the mechanical performance of the spray-up baseline. In addition, this could be done at little to no effect on cost and cycle time, which is the real innovation of this program.

8. RECOMMENDATIONS

Technical Recommendations

It is recommended that more capable resin mixing equipment be used in the future. Specifically, a mixing system that does not introduce air into the mixed resin is recommended. Other resin forms should also be explored. The current system is a hot melt, making it applicable to prepreg conversion. The same resin is available in an infusion grade, which should also be explored for other infusion methods beyond RFI.

Recommended Commercialization Paths

O’Gara is evaluating the technology demonstrated in this project for some of their current production. Additionally, there are new products O’Gara is pursuing which require higher production rates than their current products. O’Gara has identified these new products as good candidates for the RapidClave® technology. The cost advantages demonstrated by this project would then lead to significant economic development.

Follow Up Research and Development

The parts considered in this project were limited in size and were relatively flat. This size and shape limitation was required due to the space limitations of the current RapidClave®, which is limited to approximately 36” x 72” x 6”. It is recommended that a larger RapidClave® be procured to manufacture larger parts such as small aircraft fuselages. In addition, a more thorough investigation of properties should be done to evaluate the snap-cure resin for this aerospace applications.

9. REFERENCES

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