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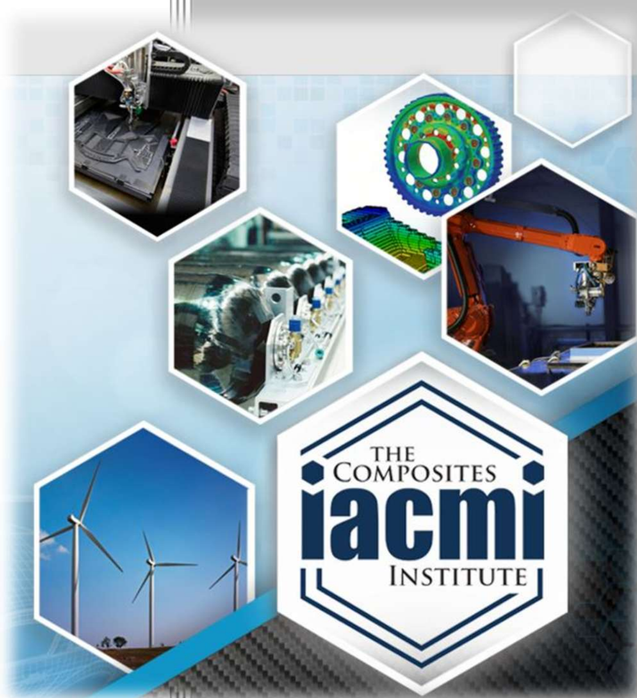
# Reclaimed Carbon Fiber Reinforced Automotive Part Using 3-DEP® Preforming Technology on Additive Manufacturing Tool Made with Reclaimed Carbon Fibers

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# Reclaimed Carbon Fiber Reinforced Automotive Part Using 3-DEP® Preforming Technology on Additive Manufacturing Tool Made with Reclaimed Carbon Fibers

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## 1.1 List of Acronyms

3-DEP® - three dimensional engineered preforming process
ABS - Acrylonitrile Butadiene Styrene
BAAM - Big Area Additive Manufacturing
CCI - Carbon Conversion Inc.
Ft-lb/in – foot pounds per inch
g/cc – grams per cubic inch
MIT - Materials Innovation Tehcnologies, LLC
IACMI - Advanced Composite Manufacturing Innovation
PC - polycarbonate
PPAP - Production Part Approval Process
PSI – Pounds per Square Inch
rCF – recycled carbon fibers
UTK - University of Tennessee Knoxville

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None

# 2 EXECUTIVE SUMMARY

The project focused on how well tools designed and built using reclaimed carbon fiber on the Big Area Additive Manufacturing (BAAM) can be used to manufacture preforms made with reclaimed carbon fibers. The project supported multiple Institute for Advanced Composite Manufacturing Innovation (IACMI) goals:

- Enables the use of recycled carbon fibers in two areas:
    - Tooling material compounded with reclaimed carbon fiber.
    - Preforms made with recycled carbon fiber (rCF).
- Lowers manufacturing costs by producing low cost 3-DEP® preform tooling.
- Reduces manufacturing cycle time with quick additive manufacturing techniques.
- Produces lightweight automotive components that will increase fuel economy which will in turn reduce greenhouse gas emissions.

The project demonstrated a tool made from reclaimed carbon fibers, gathered technical data that will guide optimization of tooling materials, evaluated preforms made with the BAAM printed tool, and developed cost evaluations.

This project has been a total success. First the project demonstrated that reclaimed carbon fiber can be compounded and successfully printed in the BAAM equipment. Second preforms were successfully made from reclaimed carbon fiber using a reclaimed fiber printed tool. Third the team successfully printed a molding tool out of reclaimed carbon fiber. Fourth the project went beyond the scope of this phase I project in 3 areas:
(1)- Techmer PM compounded rCF in 2 resin systems instead of just one system
(2)- Local Motors evaluated and collected data that will support their IACMI 3.6 project (Robert Bedsole, 2017) .
(3)- University of Tennessee Knoxville (UTK) molded a part using the reclaimed preform on a molding tool made from printed reclaim fiber.

# 3 INTRODUCTION

The three dimensional engineered preforming (3-DEP®), wet-laid, net-shape nonwoven preform process has been demonstrated to be a viable method for making preforms from discontinuous recycled carbon fiber (rCF). (Janney, 2009) Preforms up to 6 x 6 feet can be produced on the Carbon Conversion Inc. (CCI) production-scale 3-DEP® machine. At the time of this project CCI was part of Materials Innovation Tehcnologies, LLC (MIT). These preforms have been used to mold semi-structural parts for automotive applications such as the upper plenum for the Corvette, Figure 1. These parts have passed Production Part Approval Process (PPAP) trials for Chevrolet.


*Figure 1. Upper plenum for C7 Corvette. The recycled carbon fiber preform was made using the CCI large 3-DEP® machine. The composite part was molded by the Molded Fiber Glass Company (Ashtabula, OH) using liquid compression molding in a matched metal tool.*

One of the challenges to using the 3-DEP® technology in automotive production is the cost and the time required to make the tooling for forming the preforms. Large preform tools such as those for the Corvette upper and lower plenum cost about $65,000 and took 16 weeks to design, build, and install. This high expense and long design/build time means that it is very expensive to conduct iterative development projects. The starting preform tool typically is the only preform tool fabricated for a project, which means that even if new knowledge is generated, it is difficult to implement that knowledge into the project.

Using the ORNL Big Area Additive Manufacturing (BAAM) machine to make tooling for the large 3-DEP® machine has the potential to drastically reduce the time to make tooling and to reduce the cost of tooling. BAAM manufacturing of tooling is therefore an "enabling" technology for the deployment of the discontinuous recycled carbon fiber (rCF) preforms made using the large 3-DEP® process. Furthermore, the thermoplastic compound used to build the 3-DEP® tooling on the BAAM could be reinforced with rCF; CCI is a commercial supplier of rCF to several industrial injection molding compounders.

The project focused on how well tools designed and built on the BAAM can be used to manufacture preforms on the large 3-DEP® machine, and how well those preforms can be molded and incorporated into an automotive production system. The design/fabrication of the 3-DEP® tools focused mainly on the "structure and surface" of the tool. This aspect of tool fabrication is not discussed herein since CCI retained proprietary details of the process. The project was built around one automotive part (Corvette front lower wheelhouse support).

# 4 BACKGROUND

The 3-DEP® has been developed under a DOE Phase I, II and III SBIR grant (Janney, 2009). The pilot scale 3-DEP® machine is shown in Figure 2. This innovative technology has proven to be an effective enabling preform process with the following benefits:

- There is virtually zero scrap material produced by forming a complex, net shaped preform. This has a dramatic cost benefit when using expensive carbon fibers as the reinforcing material.
- The cycle times for producing large, complex shaped preforms with the 3-DEP® process has been demonstrated to be 2 minutes or less. This would match the high volume cycle times needed for automotive composite molding cycle times.
- The coefficient of variability within a complex shaped preform and from preform to preform has been demonstrated to be less than 5%. This guarantees a uniform, consistent preform which will deliver uniform, consistent properties within the composite component.
- The 3-DEP® process has been effective using "reclaimed" carbon fibers as the reinforcing material significantly reducing preform costs.

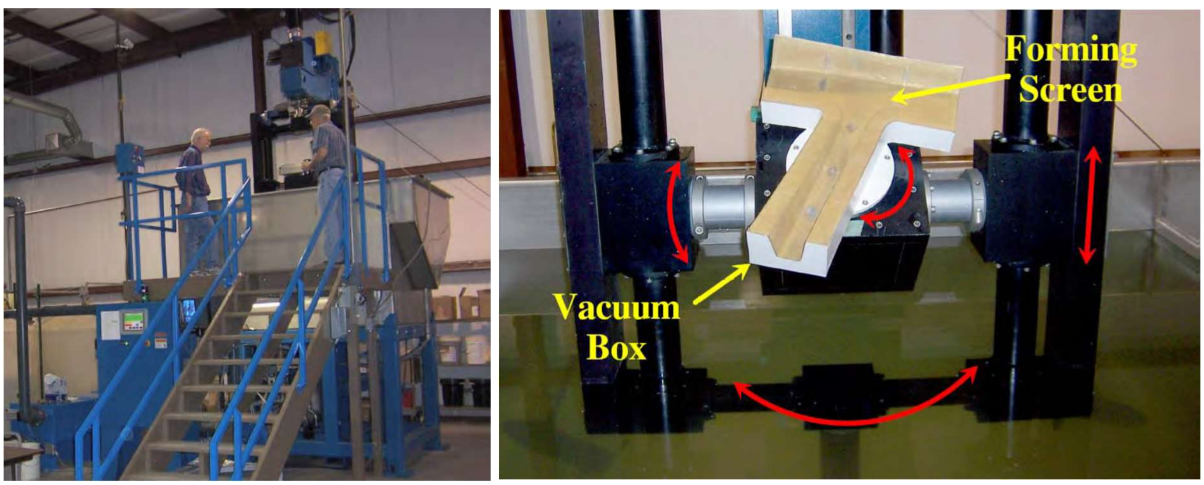

*Figure 2. (A) Overview of the 20-foot tall, pilot-scale 3-DEP®machine. (B) Detail of the forming head of the 3-DEP®machine*

# 5 RESULTS AND DISCUSSION

The project was broken up into four tasks. The first was to compound thermoplastics materials with the rCF. The second was printing a preforming tool using the BAAM printer. The third was making preforms on the tool. The fourth was producing parts using the preforms. The following describes the work done in each task in more detail.

## 5.1 Reclaimed Carbon Fiber Compounded

Reclaimed carbon fiber was obtained from CCI. Techmer PM compounded the rCF into polycarbonate (PC) at three loading levels 20%, 30% and 40% by weight (wt). Techmer PM also compounded the rCF into Acrylonitrile Butadiene Styrene (ABS) at three loading levels 20%, 30% and 40% by wt. Samples were made by injection molding and tested. The results are presented in Table 1.

*Table 1. Mechanical Properties of Compounded rCF*

| | Test Method | Units | 20% in PC | 30% in PC | 40% in PC | 20% in ABS | 30% in ABS | 40% in ABS |
|---|---|---|---|---|---|---|---|---|
| Tensile Strength @ yield | ASTM D638 | KSI | 18.59 | 21.24 | 19.47 | 15.66 | 16.84 | 17.6 |
| Tensile Elonation @ break | ASTM D638 | % | 3.2 | 2.2 | 1.1 | 1.4 | 1.1 | 1.1 |
| Notched Izod Impact | ASTM D256 | ft-lb/in | 2.1 | 1.9 | 1.6 | 1.1 | 1.0 | 1.1 |
| Flexural Strength | ASTM D790 | KSI | 29.4 | 33.1 | 34.0 | 23.2 | 25.5 | 28.9 |
| Flexural Modulus | ASTM D790 | MSI | 1.59 | 2.55 | 3.20 | 1.63 | 2.70 | 3.58 |
| Surface Resistivity | ASTM D257 | log Ohms/square | 5.1 | 4.6 | 4.3 | 5.0 | 3.6 | 3.5 |
| Carbon Fiber content | Techmer PM method | % | - | - | - | 12.9 | 22.5 | 37.4 |
| Bulk Density | Techmer PM method | g/cc | 0.61 | 0.48 | 0.4 | 0.56 | 0.55 | 0.39 |

## 5.2 Design and Print Upper Wheelhouse Support Tool

A legacy discontinuous fiber wet lay preform metal tool was provided to ORNL by partner company Materials Innovation Tech LLC. The overall goal of ORNL's portion of work on this project was to determine a method to rapidly reproduce a viable additively manufactured tool for performance comparison against the legacy tool with no associated CAD file. In order to obtain a usable digital file of the legacy tool it was scanned using a FARO laser arm to obtain a digital point cloud representing the tool. This point cloud was then used to generate a 3D dimensional digital file seen in Figure 3 below.

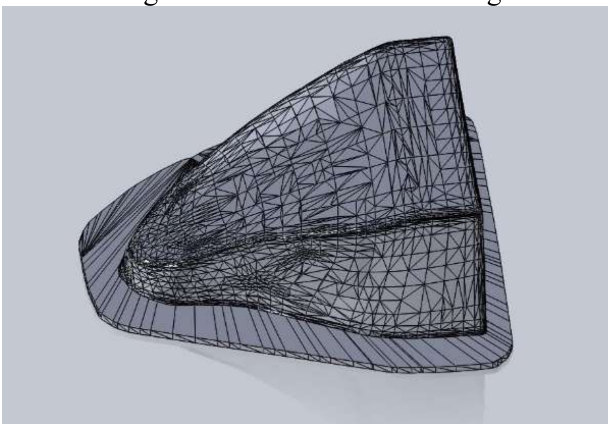

*Figure 3– 3D CAD mode of legacy tool*

This file format was necessary in order to additively manufacture the tool. Due to the size of the tool, approximately 13x9x6 inch, the Fortus 450MC machine made by Stratasys was selected. Acrylonitrile Butadiene Styrene was selected as the candidate material for comparison to the legacy tool. The new additive manufactured polymer tool was printed hollow with a ¼ inch uniform wall thickness to allow post additive manufacturing drilling of holes to pull water through during the wet lay preforming process. The additive manufactured mold can be seen during the process of building in Figure 4 below. After manufacturing the new polymer tool, it was provided to Materials Innovation Tech LLC along with the legacy tool for comparison.

*Figure 4 – In process additive manufacturing of tool*

## 5.3 Preform From Printed Tool Evaluation

Materials Innovation Tech LLC used the additive preform tool to produce preforms from reclaimed carbon fiber.  Figure 5 shows photographs of the typical preform.  This shows that the architecture of the rCF preforms is a combination of individual fibers and some fiber bundles. The orientation distribution of the fibers in the preforms was not measured ; however, the distribution appears to be fairly random based on observations of many different areas in numerous preforms.

(A) (B)

*Figure 5. (A) Bottom view of Corvette front lower wheelhouse support 1-inch chopped carbon fiber preform. As-formed, no trimming was done. (B) Top view of Corvette support preform; 1-inch chopped carbon fiber preform. As-formed, no trimming was done.*

## 5.4 Parts Made from BAAM Tool

In addition to the preform tool, a vacuum resin infusion tool was made using additive manufacturing. This tool was made using the BAAM technology developed by ORNL in collaboration with Cincinnati Incorporated. In this process polycarbonate that had been melt compounded at 20 weight percent with recycled carbon fiber provided by Materials Innovation Tech LLC was used. This material processed well through the extruder at 280° C. After being manufactured the tool was coated with a vinyl ester tooling putty and sanded smooth. A recycled carbon fiber preform generated from the additive manufactured polymer tool was then infused on this tool with a West Systems epoxy resin to create a carbon fiber composite part.  The West System epoxy resin used was West 105 epoxy & West 206 hardener @ 5.36:1 ratio by weight. System is ambiently cured with full cure reached in 10-15 hrs.  After the part cured, it was trimmed to final shape. Figure 6 shows the process from additive manufacturing of the tool all the way to the final generated composite part.


*Figure 6– A) Additive manufacturing of infusion tool using BAAM technology, B) Finished mold next to recycled carbon fiber preform, C) recycled carbon fiber preform on tool prior to infusion, D) cured and trimmed carbon fiber composite part*

# 6 BENEFITS ASSESSMENT

Cost and manufacture time of preform tooling is a significant challenge to implementation of advanced processes such as 3-DEP®, which has been demonstrated as a viable method for making preforms from discontinuous recycled carbon fiber. The project showed that using the BAAM to create tooling for 3-DEP® can be cost-effective which will enable utilization of discontinuous rCF preforms made using 3-DEP®. The use of the BAAM decreased design-manufacture cycle time for CFRP components and increased use of recycled carbon fiber.

# 7 COMMERCIALIZATION

Based on interactions with potential customers, there is considerable customer pull for the benefits of carbon fiber-reinforced composites for transportation applications. The stiffness of the wheelhouse supports made from reclaimed fiber was similar to that for virgin fiber. Thus, it has been demonstrated that lower cost, reclaimed fiber is a viable candidate for use in automotive structural components. The project also showed that reclaimed carbon fiber can be used in the printing of preforming tooling using additive manufacturing.

MIT is ready to commercialize the technology, multiple revenue generation streams are envisioned:

- MIT will be a preform manufacturer supplying performs to molders.
- MIT will be a capital equipment supplier, supplying 3-DEP® machines to molders.
- MIT will be a licensor of technology allowing molders to utilize our 3-DEP® technology.
- MIT will be a molder of specialty advanced composite components.

# 8 ACCOMPLISHMENTS

The project successfully showed that rCF can be used to print a preforming tool on the BAAM. Preforms were made from the tool and molded into parts.

# 9 CONCLUSIONS

The project has shown preforming tools and molding tools can be printed on the BAAM using rCF. This technology with the use of the BAAM can decrease design-manufacture cycle time overcoming one of the barriers facing composite usage. The 3DEP process was shown to be able to use rCF which will allow a lower cost alternative for carbon fiber in composite parts.

# 10 RECOMMENDATIONS

The results of this project are encouraging. Further studies should be done to show that the rCF can be used in the BAAM to produce larger tooling. The use of the BAAM to produce lower cost tooling for the 3DEP preforming system is also encouraging. Continued development of this process will allow the use of rCF into automotive parts.

# 11 References

Janney, M. A. (2009). *Low Cost Carbon Fiber Composites for Lightweight Vehicle Parts.* Washington DC: US Department of Energy SBIR Phase-II Final Report DE-FG02-05ER84327.

Robert Bedsole, C. H. (2017). *BAAM Materials Development and Reinforcement with Advacned Composites.* Washington DC: Office of Scientific and Technical Information - US Department of Energy.

# 12 APPENDICES

None