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# Development of rCF Thermoplastic Non-woven Prepreg for Automotive Class A Body Panels via Compression Molding

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# Project 6.5 Development of rCF Thermoplastic Non-woven Prepreg for Automotive Class A Body Panels via Compression Molding

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CTE – Coefficient of Thermal Expansion
CF – Carbon Fiber
rCF – Reclaimed Carbon Fiber
PA - Polyamide

# 2. LIST OF FIGURES

# 3. EXECUTIVE SUMMARY

One of IACMI's stated goals is the recycling of composites into useful products. To achieve this, the institute plans to demonstrate recycling technologies at a sufficient scale to justify the investment risk for private industry commercialization. Success will mean the reduction of regulatory disposal risks, encouraging additional investment and will allow for the opening of new composite markets. This is a particular concern as failure to achieve this could mean the loss of US global competitiveness in the composites marketplace as US manufacturers become unable to meet increasing regulatory burdens surrounding composite waste disposal nor are able to compete with emerging, inexpensive recycled composites from Europe and Asia. IACMI is uniquely positioned to conquer this fundamental risk for industry by demonstrating economical recycling technologies which reduce environmental impact while creating circularity in manufacturing and producing new recycled composite intermediates and products. The core IACMI team has come to view the recycling problem along three dimensions, with the first leg of identifying of composite waste types and characterizing that waste to determine appropriate methods of recycling. Along the second leg is the science behind the materials used in advanced composites and how different recycling methods alter these materials innate mechanical performance. Along the third leg is the building of relationships with key industrial partners to procure composite waste streams and build new markets for recycled composite products.

In making carbon fiber economics circular, this project was explicitly concerned with developing the materials and process to manufacture a reclaimed carbon fiber (rCF) - polyamide (PA) composite automotive body panel with a painted Class A surface comparable to the incumbent steel technology. Additional project targets included cycle time for molding the part, mechanical performance and thickness tolerances. The approach to meet these targets and showcase technical feasibility was a combination of material formulation, composite layup, processing conditions and paint application.

The composite preform consisted of a comingled non-woven mat of reclaimed carbon fiber and polyamide fiber. Through compression molding, the polyamide fiber melts, forming the composite panel. To meet the cycle time target and achieve a high-quality surface finish, a rapid heating and cooling tool from RocTool was designed and built for the project. This tool was installed at Oak Ridge National Laboratory's Manufacturing Demonstration Facility. However, due to startup challenges and troubleshooting, much of the development work for the project occurred at RocTool's development facility in Charlotte, NC.

The key technical challenge was to mitigate differences in thermal expansion between the carbon fiber and polyamide resin. The temperature changes that the molded part experiences during forming and paint curing causes the surface topology to change. Some of this surface topology can be smoothed by the paint system, but to approach the Class A designation, the polyamide resin, composite stack, and molding protocol must all be optimized to produce a smooth part directly from the tool, then the paint system can further improve the surface finish. Class A was defined based on steel benchmark panels and measured shortwave and longwave values from a BYK Wavescan® tool. The target values for this study to achieve Class A were below 20 and 10 for the shortwave and longwave values, respectively. A rCF/PA composite was demonstrated to meet these benchmark values, and a pathway has also been identified to provide further improvement in surface quality and processability in the future.

The mechanical performance of the composite panels was characterized and compared with benchmark panels where cycle time and surface quality were not the target. Molded parts using the RocTool compression molding tool exhibited slightly lower mechanical performance but still exceeded the target values. Furthermore, these parts also were produced within the targeted cycle time and had a high-quality surface finish. Additional characterization showed that these parts could be produced at a repeatable thickness within the allowable tolerance and it was identified that any significant variation in the molded parts came from variability in the incoming material.

The feasibility of creating a carbon fiber composite with an automotive Class A surface, suitable for high volume manufacturing, was established in this project. Areas for further optimization have been identified and would be tested in future work. A future study would focus on developing this technology further from a demonstration plaque tool to a real application to be defined with an automotive OEM.

# 4. INTRODUCTION

Reducing the weight of vehicles is a desired approach to improve fuel economy or extend the range of electric vehicles. Composite materials are a solution that can reduce the weight of a particular part with the potential benefits of corrosion resistance and part consolidation when compared to traditional steel construction. The use of carbon fiber as a reinforcing material in the composite offers superior strength to weight properties when compared to glass reinforced resins. For parts that are not easily visible on the automobile, carbon fiber has been used with thermoplastic and thermosetting resins. However, it has been a challenge to produce painted body panels for high volume vehicles from carbon fiber composites that can achieve a similar high-quality surface appearance (Class A) as the incumbent steel technology.

The high-volume vehicle market imposes some constraints that must be considered when determining if a new technology can fit within an existing manufacturing environment. The incumbent steel body panel is an established technology with a well-known manufacturing process. In order for a composite material to be of interest, there has to be additional benefits without majorly sacrificing cost or time for production. An advantage that composite materials often have is the ability to consolidate multiple steel parts in to one composite part, thus minimizing the manufacturing complexity and compensating for any gain in cycle time to produce the part. When attached to the vehicle, the composite panel must be able to integrate with the surrounding components without changing shape or performance significantly when subjected to a variety of environmental conditions. Lastly, the painting process for high volume vehicles involves a series of application and curing steps at elevated temperatures that the composite panel must withstand in order to be considered for adoption.

This project aims to show that a painted Class A carbon fiber / thermoplastic composite is feasible and that the technological pathway is suitable for high volume manufacturing. In addition to the Class A target, there were key process and material targets that were identified, which include: process cycle time at a specified part thickness, tensile modulus and strength performance, and a minimum thickness variance at the targeted thickness. To achieve these targets, the solution must encompass a combination of the appropriate material chemistry and processing conditions.

# 5. BACKGROUND

The Class A designation for automotive body panels is a general term used to describe a part's surface topography meeting a certain level of flatness. A qualitative representation of the surface quality is the clarity to which a reflected image is visible on the part's surface. A part with a Class A surface will be more mirror-like with highly defined edges in reflection, while a part with greater topological changes will make the reflected images look distorted and hazy. Quantitatively, this topology can be captured with a BYK Wavescan® tool. The tool measures the surface features from 0.1 to 30 mm in size, collects them in to 5 bins (Wa-We) and provides an index number for each bin. The values for the bins must be below a certain criterion to meet the Class A designation. These criteria differ between OEM, panel location (horizontal or vertical), vehicle class, and color. For the purposes of presenting the work here, the common designation of shortwave (0.3-1.2 mm) and longwave (1.2-12 mm) values are used to describe the surface quality [1].

Replacing a steel body panel with a polymer composite offers a number of challenges that must be overcome. Polymers on their own typically do not meet the needed mechanical properties for body panel applications and may have a high coefficient of thermal expansion (CTE) that inhibits their ability to cleanly mate to steel surfaces which have a much lower CTE. Thermosetting materials can have a lower CTE than thermoplastics because of cross-linking and have been used for body panel applications [2]. A shortcoming of thermoset composite parts has been with surface imperfections that can form during molding and their cross-linking makes the parts a greater challenge to recycle. For thermoplastic materials, sub-micron scale fillers (mineral fillers for example) can be added to reduce the overall CTE, however a separate structure must still support the visible body panel [3,4]. Fiber reinforced composites may allow for this underlying structure to be removed, further reducing the weight of the vehicle. However, the thermal expansion of the reinforcing fiber can differ greatly from the resin, which influences surface quality. Carbon fibers for example, have a CTE that is at least an order of magnitude lower than typical polyamides.

Painting of high-volume automotive body panels relies on a bake sequence to cure the paint system within a timeframe that is deemed acceptable. Temperatures during the bake process can reach up to 120°C. For carbon fiber reinforced polymers, the surface topology of the part will change during the bake cycle because of the mismatch in CTE. The paint system is capable of filling and leveling the topology that is created while the paint is uncured and still fluid. When the part cools back to room temperature, the composite substrate topology again changes, but the paint system has now cured and cannot flow to level this new topology. This results in an uneven surface and in some cases the underlying traces of carbon fiber can be seen in the paint.

This work is concerned with demonstrating the feasibility of producing a Class A body panel from polyamide and reclaimed carbon fiber using a compression molding process. A RocTool equipped compression molding tool was chosen based on its proven ability to produce a high-quality surface finish in a rapid cycle time. It is the intent of the project to establish the RocTool processing cell at Oak Ridge National Lab's Manufacturing Demonstration Facility. The materials, composite layup, process and processing sequence were developed during the course of this project to meet targets for mechanical properties, cycle time and surface quality.

# 6. RESULTS AND DISCUSSION

A compression molding tool incorporating the rapid heating and cooling RocTool technology was designed for the project and set for installation at Oak Ridge National Lab. The tool cavity geometry was a flat plaque measuring 450 x 450 mm and could be varied from 1-4 mm in thickness with adjustable stops. The tool consisted of a highly polished surface that would contact the composite preform and impart the smooth surface on the molded composite. The opposing surface (B-side) was polished to less of a degree and contained ribs on a portion of the tool to investigate the effect of backing structures on the part surface quality. However, this was not investigated during the course of the project. The tool and molding cell are shown in Figure 1. The RocTool equipment was demonstrated to produce parts at ORNL but equipment faults prevented development on this tool. Troubleshooting continued throughout the course of the project, with the material trials and process development occurring at RocTool's development facility in Charlotte, NC on an equally capable tool.

Figure 1. Drawing of the RocTool compression molding tooling (top left), B-side of the tool undergoing temperature mapping with thermocouples (top right), induction generators and control system (bottom left), and the press utilized at Oak Ridge National Laboratory

Resins for the composite were iteratively developed by BASF based on Ultramid® polyamide. The composite preform was a comingled non-woven mat consisting of chopped polyamide and reclaimed carbon fiber. The formulation of the resin and composite layup were such that the final part can be molded from non-woven preform to composite plaque in one processing step. At this point the resin and composite composition are considered proprietary and will not be discussed further.

Molded composite panels were supplied to BASF for painting and surface quality measurements. The longwave and shortwave surface quality values are shown in Figure 2 for the painted composite panels and painted cold rolled steel benchmark panels. The shortwave and longwave values for the steel panels was within 30 and 10, respectively, which became the project benchmarks because these panels were painted at the same time as the composite panels and subjected to the same curing environment on the lab-scale. Ideally, the shortwave value should be below 20 for the Class A designation.

Polyamide was molded without carbon fiber to confirm that a Class A painted surface could be produced from the tool. However, a painted Class A surface was not always the case because the chosen resin must be accompanied by the appropriate processing conditions to impart the desired part quality. Extreme examples of this might include incomplete consolidation or processing conditions causing resin degradation which will negatively impact the resin's ability to have a smooth surface from the tool.

During the molding trials, there were composite panels produced that would knowingly not meet the project targets, but were important to understand the relationship between materials, composite layup, processing and surface quality. One of these tests was to make surface quality measurements on the painted part at room temperature and near the bake temperature. The shortwave and longwave values improved by 30-40%; however, it is unrealistic to keep an automotive body panel at such a high temperature in its end-use application. This test was to confirm that the difference between thermal expansion coefficients of the carbon fiber and resin were responsible for the surface roughness even when no carbon fiber traces were visible through the paint layer.

The intended composite panels produced in the initial trials exhibited shortwave and longwave values above 50 which was a result of the resin, composite layup and processing conditions not being well understood and optimized. In some cases, the shortwave and longwave values were not measurable with the BYK Wavescan® tool. With refinement in materials and process understanding, the surface quality began to approach the steel benchmarks. The summary in Figure 2 shows a broad range of surface qualities measured on the composite panel which can be a result of many factors. Each of the manufacturing steps to make the composite build upon the previous step and any large deviation that may occur along the way can negatively impact the final surface quality. One example of this occurred in a later molding trial where high-quality parts were obtained directly from the tool but after painting, the shortwave values were on average higher for these composite panels and steel control than any of the other trials. Despite this occurrence, shortwave values below 30 (and more importantly, below 20) can be achieved consistently without any visible traces of carbon fiber on the painted surface. Reducing the longwave values appeared to be a greater challenge, but it was demonstrated that a carbon fiber composite could be produced with a longwave value lower than 10. The composite panel that exhibited the best surface quality and met the surface quality targets, had short- and longwave values of 11.4 and 9.5, respectively.

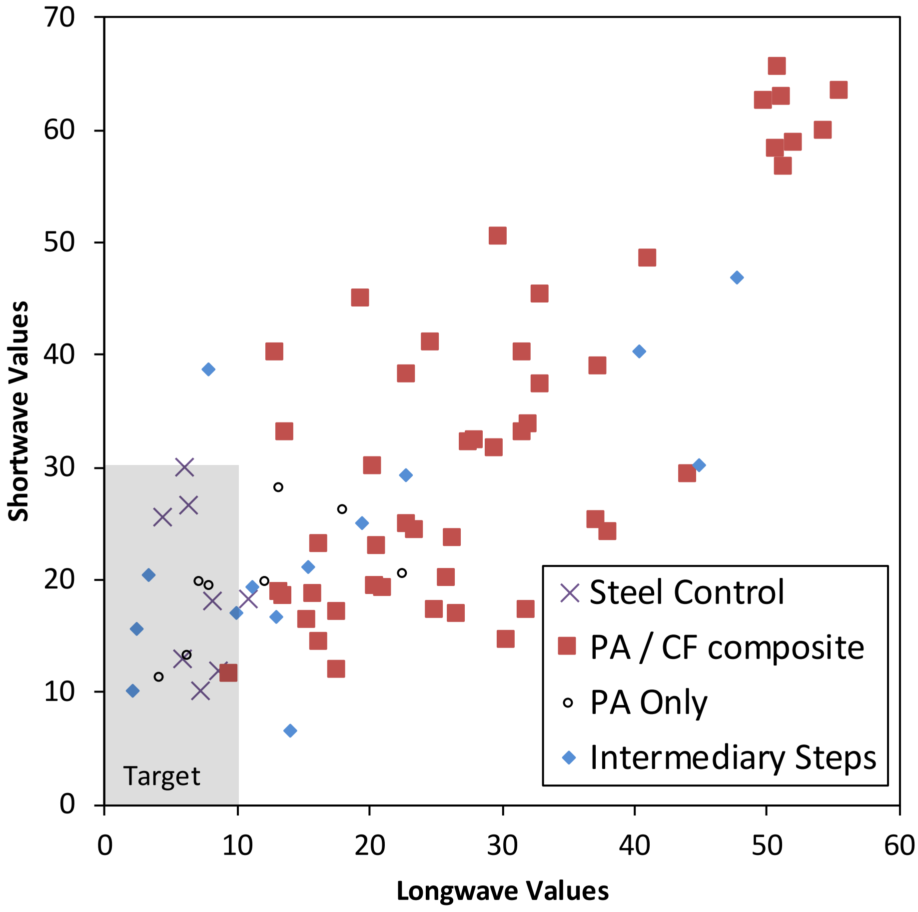

Figure 2: Measured shortwave and longwave values of thermoplastic panels with and without carbon fiber and steel benchmark panels.

In addition to surface quality, the composite panels must meet a target tensile modulus and strength performance criteria. The results are shown in Figure 3. Initial screening and benchmark tests were performed on the non-woven material to make sure that the composite formulation was capable of meeting the targets, independent of surface quality and cycle time. The material was demonstrated on a demonstration tool on loan from RocTool while the project tooling was being manufactured. A standard compression molding process was also used at the University of Tennessee, Knoxville and the parts were tested both at BASF and UTK to ensure that there were no significant differences in results between testing facilities.

The mechanical performance of parts tailored to meet all the project surface quality and cycle time targets had diminished performance. This was a result of changes in the resin, composite layup and likely the degree of consolidation. With a reduction in cycle time, there is a risk that the parts may not be fully consolidated or may lose full consolidation if the demolding temperature is too high, for example. There is also a limit to how much heat can be applied to the resin before degradation occurs, which can result in a loss of properties as well. Determining the proper processing protocol was an important step to achieving the project targets. The surface quality targets were the primary focus once it was established in the benchmarking trials that the composite material was in range of the mechanical targets. Once the process and materials allowed for a high-quality surface finish, then incremental optimization in the materials and process allowed for the molded composite panel to exceed the mechanical performance targets.

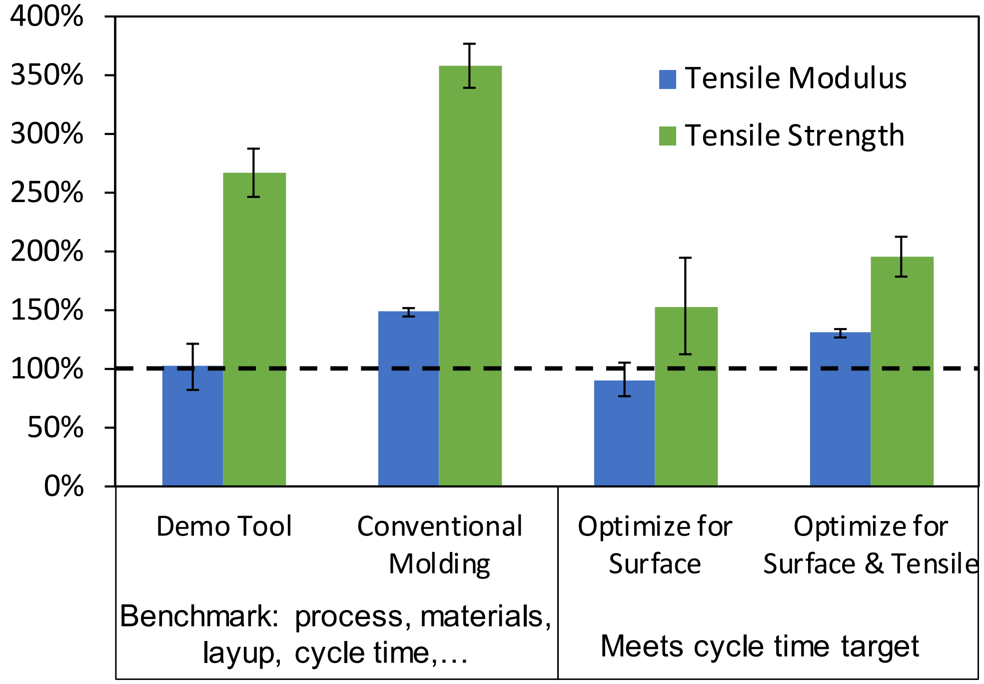

Figure 3: Mechanical performance results of select carbon fiber / polyamide composite panels

The last milestone was to maintain a thickness variation of less than 6.5% of the target thickness. Thickness data is shown in Figure 4 for a variety of samples and processing conditions. The thickness of a part was determined by the amount of material in the mold and the shim thickness which limits the degree to which the mold can close. The tooling has a positive cavity design which is intended to keep material within the mold cavity and limit flash. As a result, if more material was in the mold cavity than what was allowable by the shim limits, then the part would be thicker than the intended thickness. Parts that were less than the shim thickness were believed to be a result of shrinkage and entrapped air. The thickness variations within each part were quite small when compared at different locations. Larger variance was observed between different parts. The part-to-part variances were traced to thickness or areal density variations with the incoming materials that encompassed the composite layup. Much of this variability was a result of processes that were not optimized while developing and screening different formulations. For the most part, the data in Figure 4, would be acceptable; however, it is expected that this variability will be reduced now that the upstream processes are better optimized.

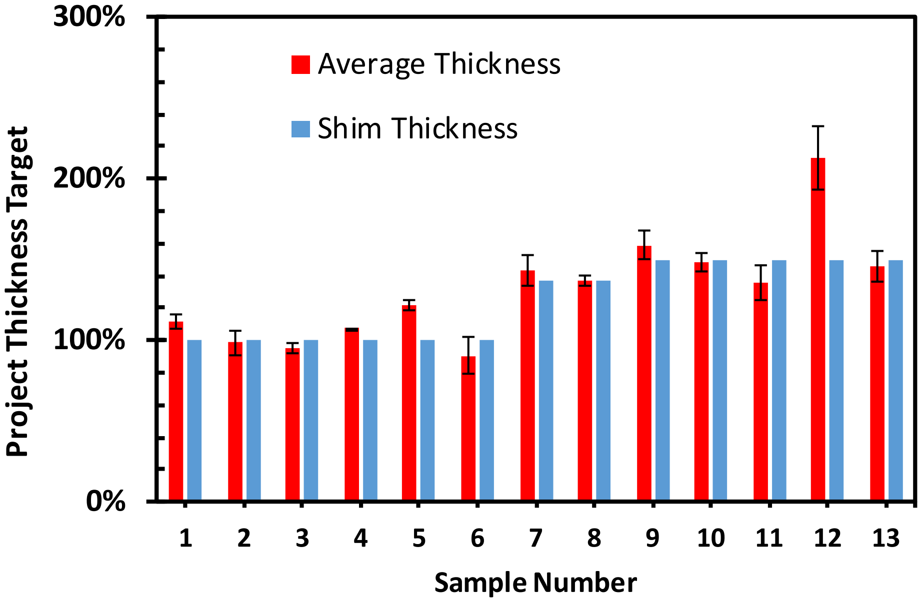

Figure 4: Thickness measurements per part in reference to the target thickness defined by shim thickness

The carbon fiber composite panel meeting the Class A criteria is shown in Figure 5 next to a painted steel panel that was painted concurrently. A qualitative assessment of the surface finish can be made by the clarity of the reflected images of a ceiling light fixture. As the values for shortwave and longwave decrease the edges of the reflected image become more defined. However, this is still quite subjective and the assessment of surface quality should be in reference to the measured shortwave and longwave values previously discussed in Figure 2.

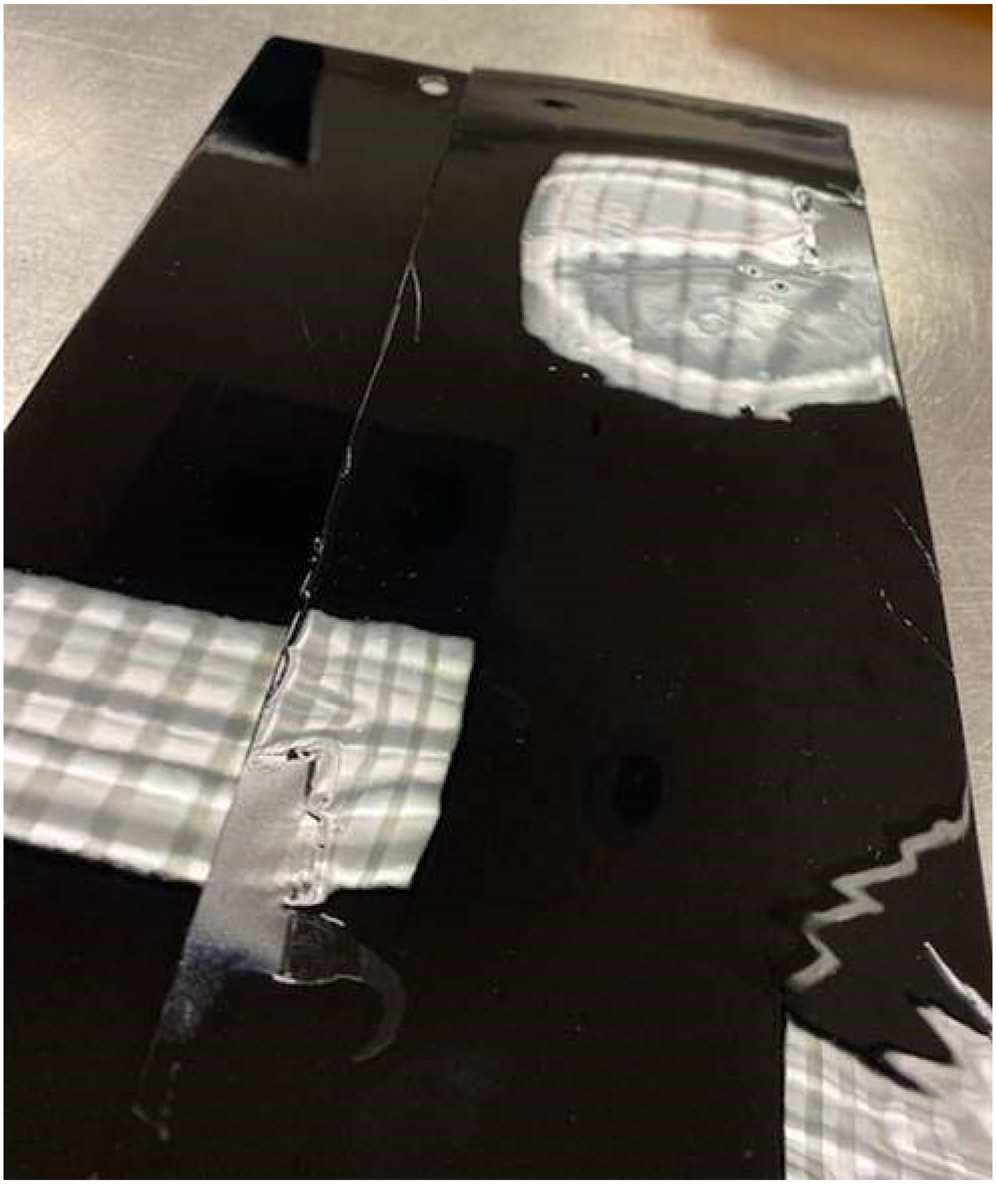

Figure 5: Comparison of a painted steel benchmark panel (left) and the carbon fiber composite panel meeting the Class A target (SW<20, LW<10) (right)

## 7. BENEFITS ASSESSMENT

There are at least four favorable energy and environmental aspects that should be noted at this stage of the technology development, yet others may arise as this technology becomes implemented:

1. Metal replacement in automotive body panels by a lower weight carbon fiber / polyamide composite
2. The use of polyamide thermoplastic in the composite allows for ease of recycling at the end of vehicle life in to carbon fiber molding compounds
3. The use of recycled carbon fiber in the non-woven composite reduces the amount of carbon fiber

entering landfills and the energy to reclaim carbon fiber is significantly less than the conversion of textile fibers in to carbon fiber.

4. The use of RocTool induction heating tooling has the potential for reduced energy consumption per part compared to other heating technologies because the tool design allows for less thermal mass that must be heated [5].

# 8. COMMERCIALIZATION

Most of the commercial composites-based Class A automotive body panels are made using thermoset resins technology which is not suitable for mass production of automotive parts and difficult to recycle. Results from this project show that the proof of concept for a thermoplastic - rCF class A composite parts has been established. An automotive class A thermoplastic structural part using rCF based non-woven composites is an important technical milestone that will ultimately bring the production cost and cycle time to an acceptable level for high volumes manufacturing. Suppliers of reclaimed carbon fiber indicate that the cost of rCF for this application could be 50% less than industrial grade virgin carbon fiber. The reduced cycle time and material costs are key drivers that will allow for partnership with an OEM in a follow-up project targeting a specific automotive part. The business case will then be built around the production of the identified part based on the manufacturing and commercial requirements of the OEM.

# 9. ACCOMPLISHMENTS

i) Patent application in progress

ii) Presentation at IACMI Summer Members Meeting, Denver Co, July 24-25, 2019. *Cieslinski M*.; Bouguettaya, M; Ginder, R.; Ozcan, S.; Vaidya, U. “Development of rCF Thermoplastic Non-woven Prepreg for Automotive Class A Body Panels via Compression Molding”

# 10. CONCLUSIONS

This project has shown that it is possible to mitigate the thermal expansion mismatch between carbon fiber and thermoplastic resin through the development of materials and process to the point that it appears feasible to produce a painted body panel with a Class A surface. Key project targets for cycle time, mechanical properties and part variance were met during the course of the project and it is believed that there is further opportunity for optimization. The processing protocol for the RocTool system was well understood and required only minor changes based on changes in the composite layup. For surface quality, the shortwave and longwave values determined by the BYK Wavescan® tool were within the general Class A designation, and it is believed that these values can be improved with further refinement.

# 11. RECOMMENDATIONS

This project successfully developed a new processing technology and demonstrated the technical feasibility to produce a painted Class A surface on a reclaimed carbon fiber / polyamide composite. The next steps involve refining the technology further and implementing it in to a real part. An initial series of next steps have been identified to improve the proprietary resin and composite to further reduce the values measured by the BYK Wavescan® tool and improve processability. Once this is achieved, any further development and characterization of the material and composite layup would be specific to the targeted body panel and would need to be specified by an OEM partner. The molding protocol established on the RocTool system will also need to be transferred from the demonstration plaque tool to the tool with a real part geometry. The ease of this transition will depend on the mold design and part geometry. It is always of interest to make parts on an existing tooling technology to benchmark with the RocTool process. It is the intention of the project team to continue the development of this technology and address the above items within a second phase of this project.

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