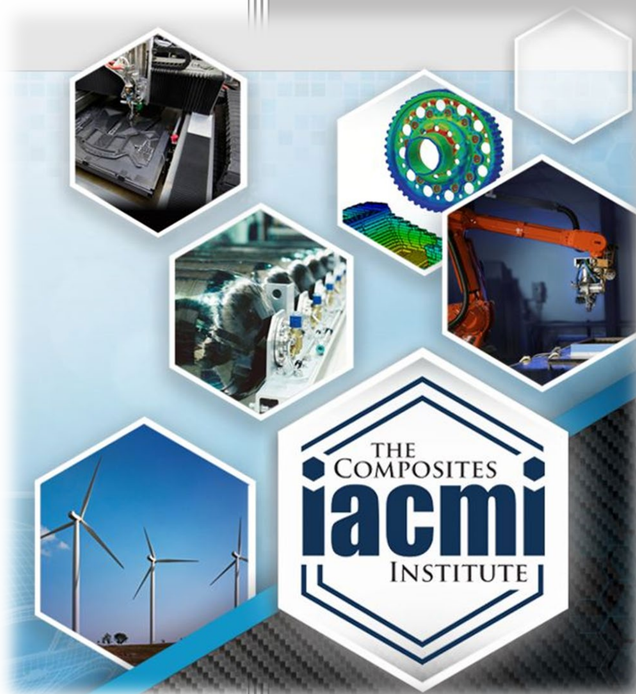
IACMI/R0001-2019/3.15

Carbon Fiber Reinforced Polyolefin Body Panels



Authors:
Megan Shewey, Ford
Patti Tibbenham, Ford
Dan Houston, MSU

Date: 10/23/19

Final Technical Report
IACMI/R0001-2019/3.15

Approved for Public Release.
Distribution is Unlimited.

The Institute for iacmi Advanced Composites Manufacturing Innovation THE COMPOSITES INSTITUTE

U.S. DEPARTMENT OF ENERGY

DOCUMENT AVAILABILITY

Reports produced after January 1, 1996, are generally available free via US Department of Energy (DOE) SciTech Connect.

Website http://www.osti.gov/scitech/

Reports produced before January 1, 1996, may be purchased by members of the public from the following source:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone 703-605-6000 (1-800-553-6847)
TDD 703-487-4639
Fax 703-605-6900
E-mail info@ntis.gov
Website http://www.ntis.gov/help/ordermethods.aspx

Reports are available to DOE employees, DOE contractors, Energy Technology Data Exchange representatives, and International Nuclear Information System representatives from the following source:

Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831
Telephone 865-576-8401
Fax 865-576-5728
E-mail reports@osti.gov
Website http://www.osti.gov/contact.html

Carbon Fiber Reinforced Polyolefin Body Panels

Authors:

Megan Shewey, Ford, 1.313.845.1373, mshewey@ford.com
Patti Tibbenham, Ford, 1.313.322.7158, ptibbenh@ford.com
Dan Houston, MSU 1.313.204.4941 housto79@msu.edu

Names of other project team member organizations – Borealis

Date Published: (October, 2019)

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

Project Period:
(04/2018 – 05/2019)

Approved For Public Release

Table of Contents

List of Figures

List of Acronyms

PP – Polypropylene
rCF – Recycled carbon fiber
CF – Combined Ford
DOE – Department of Energy
IACMI – Institute for Advanced Composites Manufacturing Innovation
PA/PPE – Blend of polyamide and polyphenylene ether

Executive Summary

This project addresses an automotive industry desire for a cost-effective, lightweight material for body panels that offers mass reduction compared to steel and aluminum body panels, and a cost savings compared to incumbent polymer body panels. Inexpensive polypropylene (PP) combined with <10 weight % reclaimed/recycled carbon fiber (rCF) have the potential to meet both performance and affordability targets for lightweight, paintable vertical body panels. This project supports DOE and IACMI technical goals of reducing production cost of CF composites >25% in 5 years on a path to >50% in 10 years and demonstrating technologies for >80% recyclability or reuse of fiber reinforced composites in 5 years on a path to >95% in 10 years.

Alternative body panel materials must meet all fit and surface finish requirements, and match the appearance of metal body panels adjacent to them. The PP/rCF materials must maintain exterior dimensional requirements with a low co-efficient of thermal expansion, excellent paintability, and mechanical performance. Thermoplastic injection molding offers significant reduction in tooling costs as injection molding dies are typically less than half the cost of stamping dies.

This project utilized rCF compounded with special formulations of PPs to produce automotive components that meet requirements for fit, finish, mechanical performance, and paintability while offering significant mass savings over incumbent metal panels. It will also offer a cost savings versus other composite solutions. Fenders were molded at the IACMI – Corktown facility using an existing fender tool.

Ford Motor Company was the industry lead for this project and provided project management, testing, painting and adhesion testing, and developed the cost-model/business case. Ford engaged and aggregated cost share with Borealis who provided materials, technical support for process trials, and participated in coordination meetings. Vehicles Technology Area staff in Corktown assisted in project management, process trials, molded fenders, and benchmarked physical characteristics.

Over 450 plaques were molded with two different gating systems to look at processing conditions and specimens were excised for mechanical testing. Plaques were also used for paint trials, surface analysis, and dimensional analysis. Subsequently, over 200 fenders were molded at IACMI – Corktown. These fenders were used for paint trials, surface analysis, and dimensional analysis. The PP/rCF systems met all of the requirements except for paint appearance. Additional development of paint primer and top coat is necessary to fulfill automotive OEM paint surface requirements.

Introduction

This technology combines inexpensive formulation of PP and rCF to reduce weight of current thermoplastic fender technologies. The PP/rCF material was successfully molded into fenders at the IACMI – Corktown SURF facility. Should these light weight fenders be incorporated onto a production vehicle, they would reduce greenhouse gas emissions and utilize recycled carbon fiber in a secondary automotive application. Current cost modeling indicates a piece cost reduction versus current production material.

Outlined below are the steps that would be necessary to develop a commercialization plan:

- Meet all OEM part requirements for exterior body panels
- Meet all OEM material specifications for exterior body panels
- Selection of Tier 1 molder; business plan, assurance of ability to deliver quality parts to OEM assembly plant
- Meet volume requirements, raw material availability and quality
    - Large quantities of quality, recycled carbon fiber
    - Inherent risk in recycled carbon fiber feed streams

Background

Based on previous research and development work at Ford on carbon fiber reinforced thermoplastics, it has been established that the critical fiber length must be at least 100 microns long in the final molded part. If the fibers are shorter than that, the fibers will not provide significant reinforcement. In another study, Ford looked at the effects of processing on retained fiber length. The outcome of this study was that general purpose screws and high shear screws break the fibers leaving a small retained fiber length. However, molding with a low shear screw caused less damage to the fibers and allowed for a greater retained fiber length, thus increasing the mechanical properties. Due to these studies, a low shear screw was used for injection molding operations at the IACMI – Corktown facility. There is minimal published work that has been done in this technical area.

Milestone 3.15.2.1 was to produce ≥ 100 test plaques (4”x12”) of selected materials for characterization.

Plaques were molded on a 200 ton injection molding machine at American Test Plaque (ATP). ATP was chosen as the molder because the plaque tool used for this project is stored there and IACMI – Corktown only has a 3000 ton injection molding machine.

Milestone 3.15.2.2 – Identify rCF and PP materials and appropriate fiber concentration such that compounded materials translate to molded specimens of density 1.2 g/cm^3 and tensile modulus of ≥ 3.0 GPa.

Tensile specimens were excised from molded plaques and tested. Both material formulations exceed the tensile modulus requirement. Both materials also had a density under 1.0 g/cm3.

Milestone 3.15.3.1 – Validate molded PP/rCF fenders meet or exceed Ford’s global standards for paintability and surface quality.

Molded fenders did not meet Ford's global standards for paintability and surface quality. They did come close, and with more development of paint and primer technology, could meet the standards.

Milestone 3.15.4.1 – Provide proprietary letter report assessing the business case for PP/rCF for vertical body panels using the fender as a test case.

This was completed by Ford and is proprietary information.

Listed below are the qualifications and experience of the project team members:

IACMI
- Greg Thorpe - 30 years injection molding experience
- Dan Houston - 38 years of composite materials processing and material characterization experience
- 3000 ton Cincinnati Milacron injection molding machine and low shear screw capability
- Saturn fender tool

Ford
- Patti Tibbenham - 25-30 years of injection molding thermoplastics experience with an emphasis on thermoplastic fender development
- Megan Shewey – 3 years of carbon fiber reinforced composites processing and material characterization
- Financial support

Borealis
- Material supplier

Results and Discussion

Plaque Molding – American Test Plaque

Milestone 3.15.2.1 – Produce ≥ 100 test plaques (4"x12") of selected materials for characterization.

As part of the first milestone, plaques were molded at American Test Plaque in Livonia, MI on a 200T injection molding machine. The goals of this molding trial were to develop processing parameters for the two materials and to produce at least 100 plaques of the selected materials for characterization. This milestone was met in May 2018. In total, over 450 plaques were molded with two different gating systems to simulate both random (corner gate) and oriented (edge gate) flow. The plaques can be seen below in Figure 1 and the gating system in Figure 2.

Figure 1: Molded plaques – PP/rCF06, PP/rCF10, PA/PPE

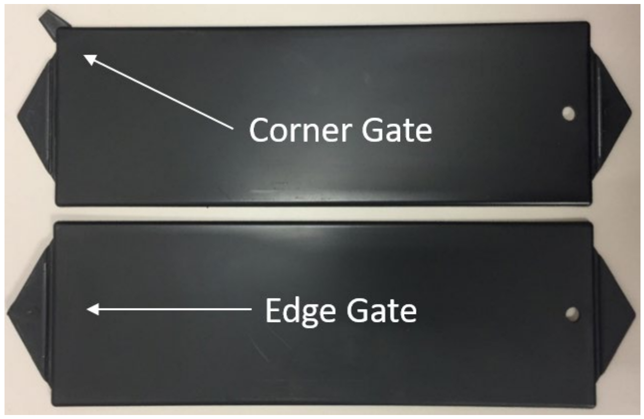


Figure 2: Gating system

Milestone 3.15.2.2 – Identify rCF and PO materials and appropriate fiber concentration such that compounded materials translate to molded specimens of density 1.2 g/cm^3 and tensile modulus of ≥ 3.0 GPa.

The next milestone was to verify molded plaques met or exceeded density targets and mechanical property targets. The density target was less than or equal to 1.2 g/cm^3 and the tensile modulus target was greater than or equal to 3.0 GPa. The density was calculated via the rule of mixtures formula, shown in the equation below, where ρ_c is the density of the composite, ρ_m is the density of the matrix, v_m is the volume of the matrix, ρ_f is the density of the fiber, and v_f is the volume of the fiber.

$$\rho_c = \rho_m v_m + \rho_f v_f$$

The results for the rCF06 and rCF10 formulations were both superior to the target values with the density of rCF06 being 0.932 g/cm^3 and the density of rCF10 being 0.951 g/cm^3.

ASTM E8 sub-size tensile specimens were excised from the plaques in the direction of flow via water-jet. They were subsequently tested on an Instron load frame at the rate of 5mm/min while utilizing a 25mm extensometer. Figure 3 below shows the results for the rCF06 formulation for both the corner and edge gated plaques. The average tensile strength for the corner gate was 40.5 MPa and the average tensile strength for the edge gate was 40.2 MPa. The average tensile modulus for the corner gate was 6.18 GPa and the average tensile modulus for the edge gate was 6.20 GPa. For the rCF06 formulation the gating system did not have an effect on the tensile properties.

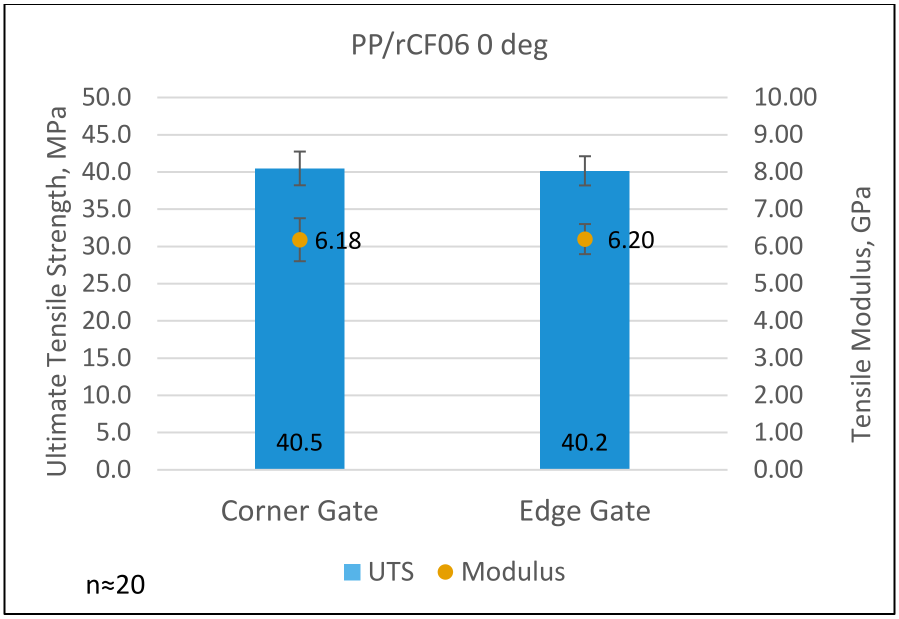


Figure 3: Tensile properties of PP/rCF06

Figure 4 below shows the results for the rCF10 formulation for both the corner and edge gated plaques. The average tensile strength for the corner gate was 30.5 MPa and the average tensile strength for the edge gate was 30.8 MPa. The average tensile modulus for the corner gate was 5.50 GPa and the average tensile modulus for the edge gate was 5.53 GPa. For the rCF10 formulation the gating system did not have an effect on the tensile properties.

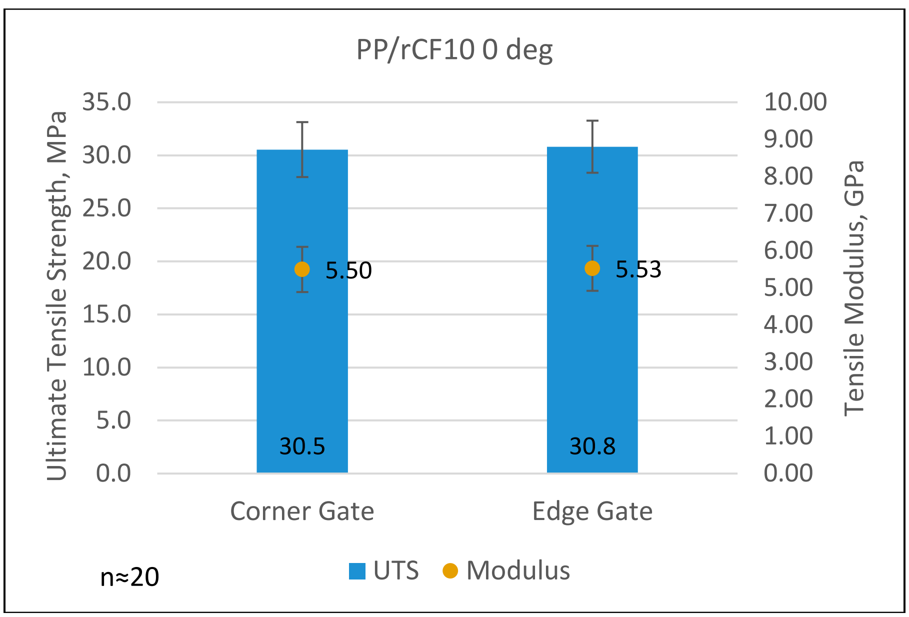


Figure 4: Tensile properties of PP/rCF10

The rCF06 formulation had superior tensile properties to the rCF10 formulation. This can be attributed to differences in the base polymer system of the two formulations. Borealis previously designed the rCF10 formulation for a mold in color application while the rCF06 formulation was developed for a different application. However, both formulations exceeded the tensile modulus requirement of 3.0 GPa.

Milestone 3.15.3.1 – Validate molded PP/rCF fenders meet or exceed Ford's global standards for paintability and surface quality.

Before molding and painting fenders, PA/PPE and rCF10 plaques were used for paint trials and were painted at PPG's facility in Flint, MI. The rCF06 plaques warped during processing and were not able to be painted. First, plaques were flame treated to activate the surface energy. Then, an adhesion promoter was used on half of the plaques to evaluate if it enhanced appearance. Next, the plaques were primed with PPG's experimental primer developed for carbon fiber and polyolefin based systems. Finally, the plaques were painted with a black basecoat and a clear coat. Wavescan data was taken on the plaques after they were dried in the oven.

Figure 5 below shows the wavescan data. The red line is the target Combined Ford (CF) number. The rCF10 formulation fell short of the target for both the Flame + AdPro and the Flame treated plaques. The PA/PPE was at or near the target for both the Flame + AdPro and Flame. Overall, flame treated plaques resulted in better wavescan values compared to flame treatment plus an adhesion promoter.

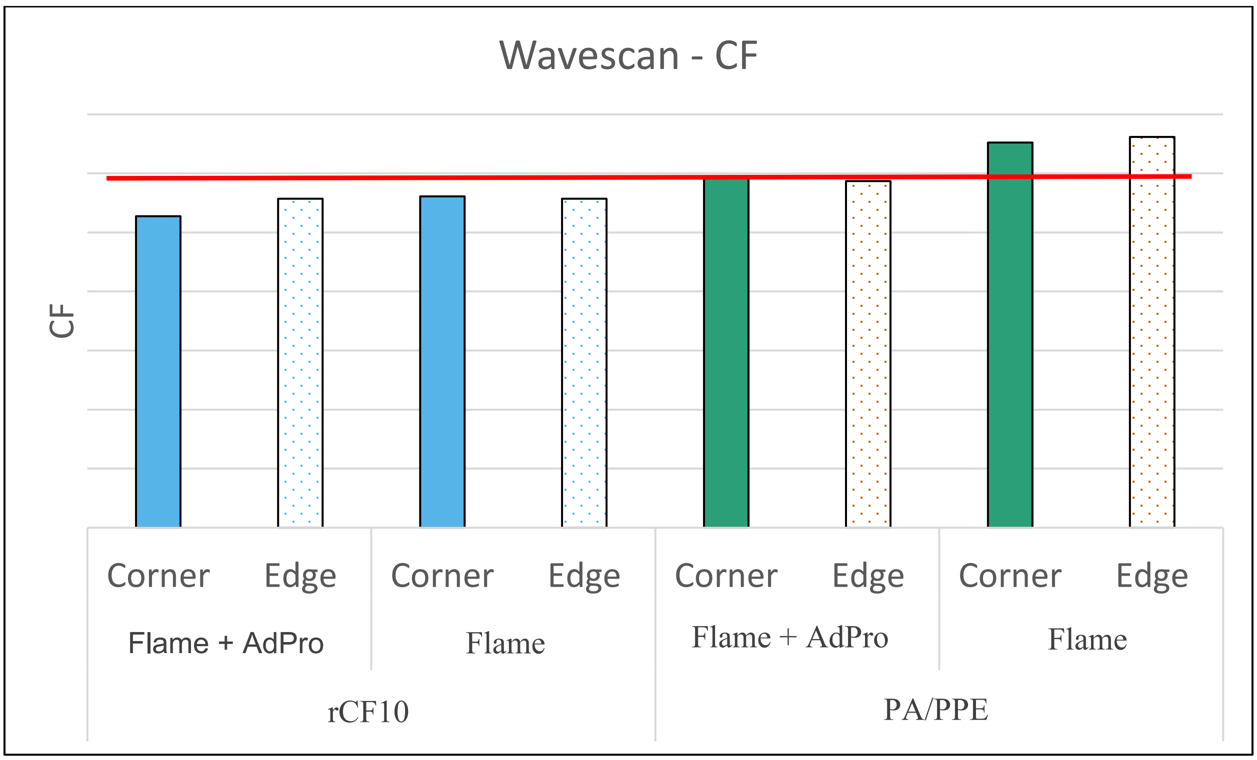


Figure 5: Wavescan results

Fender Molding – IACMI

Fenders were molded at IACMI – Corktown on the 3000T Cincinnati Milacron injection molding machine and utilized the refurbished Saturn fender tool. The goals of this molding trial were to verify processing parameters for the two materials on the fender tool, to completely fill the part with a cycle time of ≤ 90sec, and to produce at least 25 fenders of the selected materials. These goals were met and the fenders were subsequently used for paint appearance trials and dimensional capability analysis. The molding equipment at IACMI – Corktown is shown in Figure 6 - Figure 9 below.

Figure 6: 3000T Cincinnati Milacron Injection Molding Machine

Figure 7: Dryer

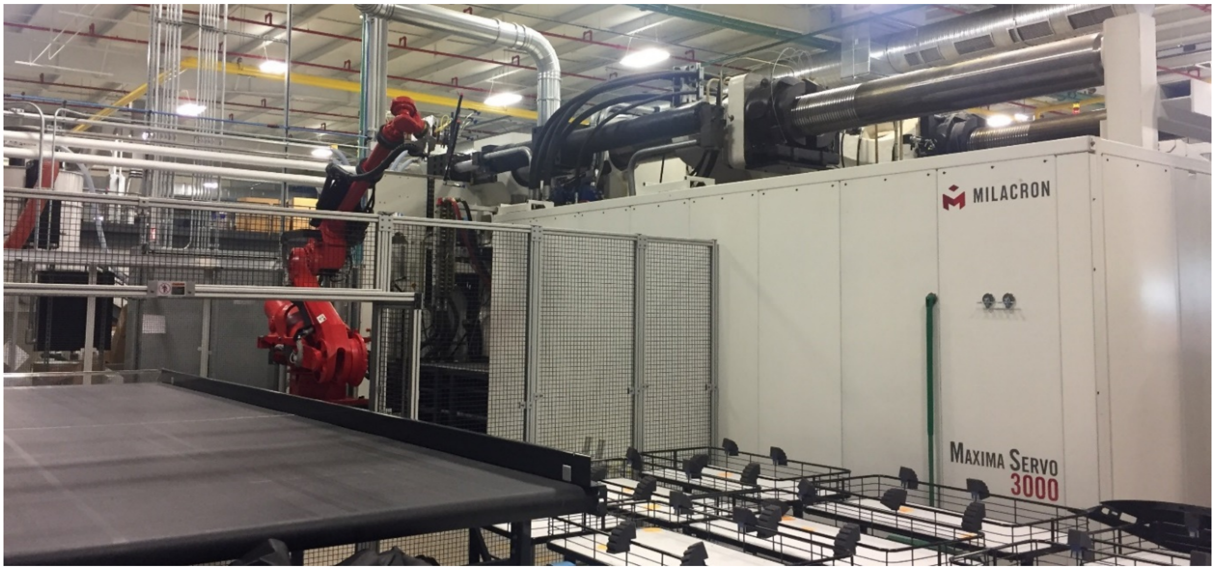


Figure 8: Robot arm, conveyor belt, and cooling racks

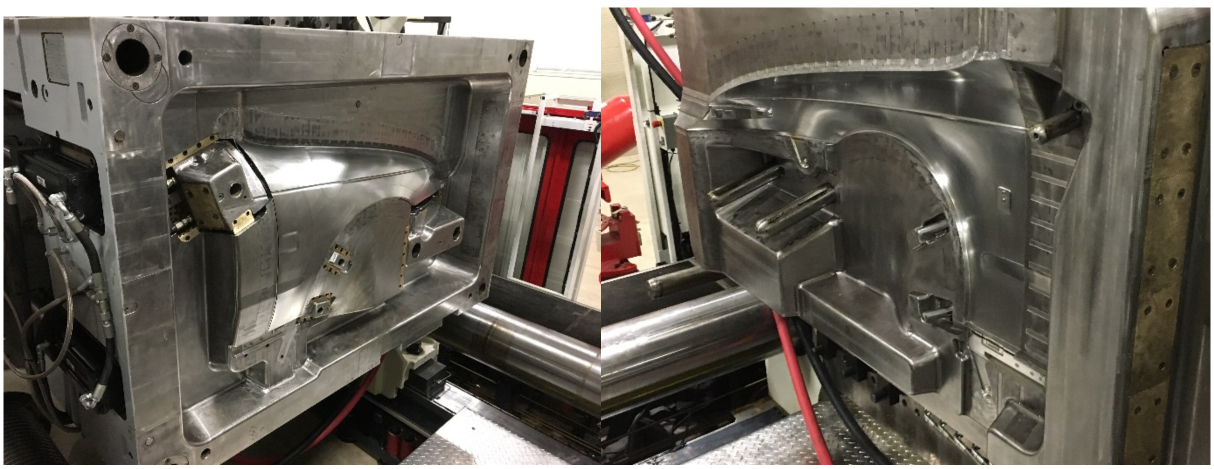


Figure 9: Fender tool

Fender Paint Trial – PPG

Fenders from the molding trial at IACMI were put in bags to protect the surface, packaged in boxes, and shipped to PPG - Flint to be painted. For this trial, the fenders were flame treated, primed, painted with a black base coat, and a clear top coat. Adhesion promoters were not used during this trial due to the poor results obtained from the plaque paint trial. PPG's developmental primer (denoted in the figures below as primer) was used again as well as an RPP primer commonly used on SMC. Horizontal and vertical wavescan were measured. The results are shown in Figure 10 and Figure 11 below. The results from the plaques are also included for reference. The AdPro column denoted the plaques that were flame treated with the addition of an adhesion promoter, primed with PPG's experimental primer, painted with a black basecoat and a clear top coat.

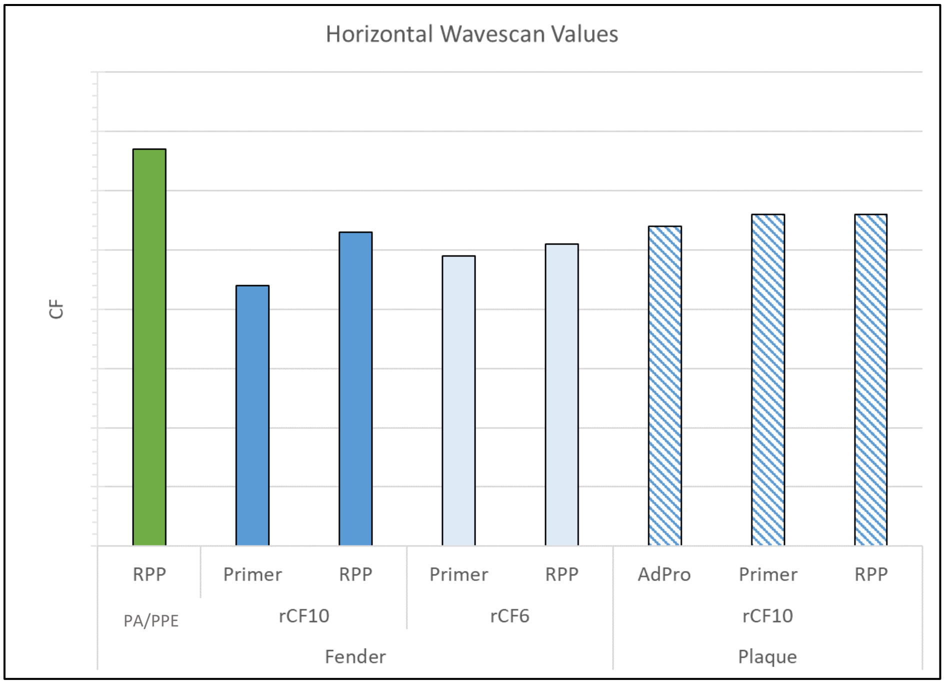


Figure 10: Horizontal wavescan values

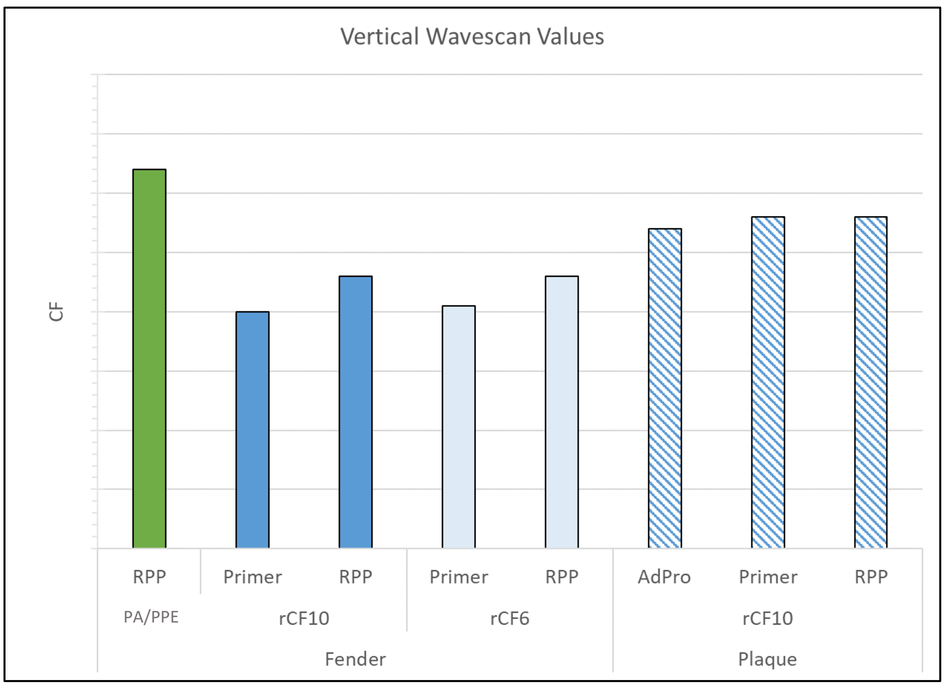


Figure 11: Vertical wavescan values

The paint appearance of the fenders was inferior to that of the plaques, and substantially lower than that of the PA/PPE fender. This was expected as the PA/PPE material is a production benchmark that meets paint requirements. Overall, the RPP primer yielded the best results.

Fender Dimensional Assessment – Standard Components Incorporated (SCI)
Scribe lines were incorporated in to the fender tool at IACMI. The resulting scribe lines on the molded part are on the interior side of the fender and are 300.00 mm in length. Figure 12 below shows approximately where the scribe lines are located on the fender. CMM measurements were taken on the scribe lines of the molded parts and the resulting scribe line lengths are shown in Figure 13. Figure 14 shows the measurement results as a percentage of how much the scribe lines shrank from 300.00 mm.

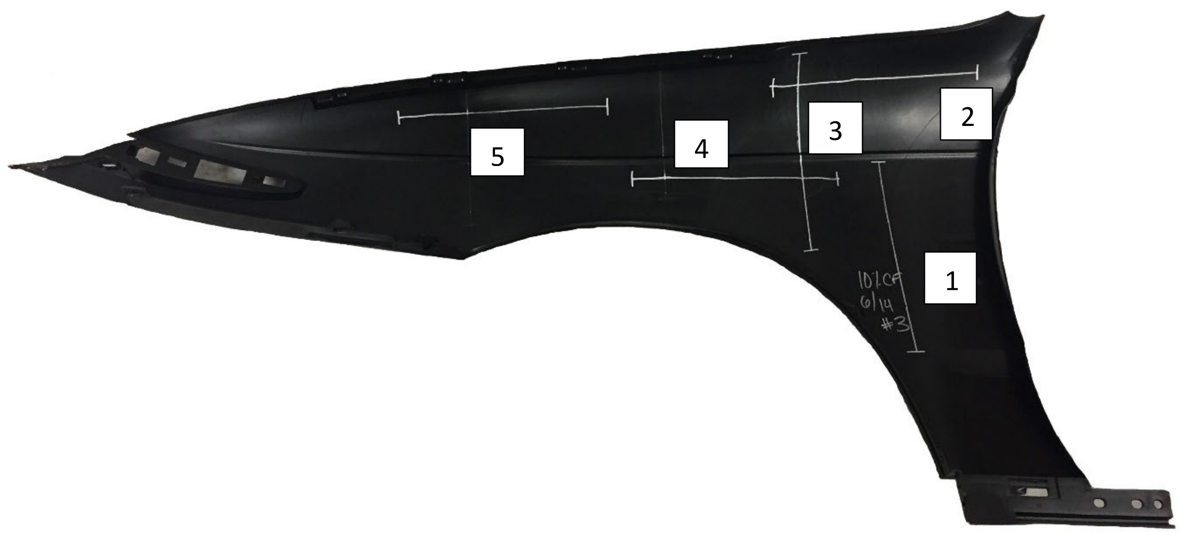


Figure 12: Approximate locations of scribe lines on the back side of the fender

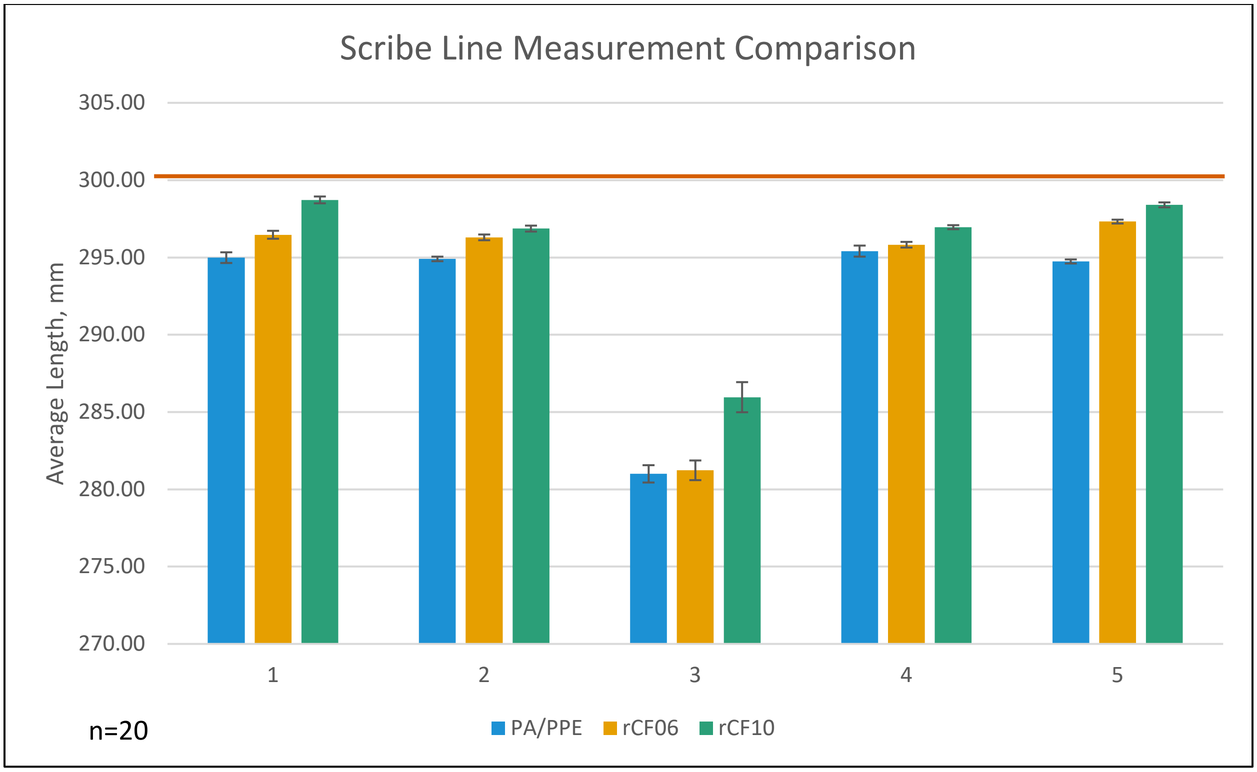


Figure 13: Scribe line measurements

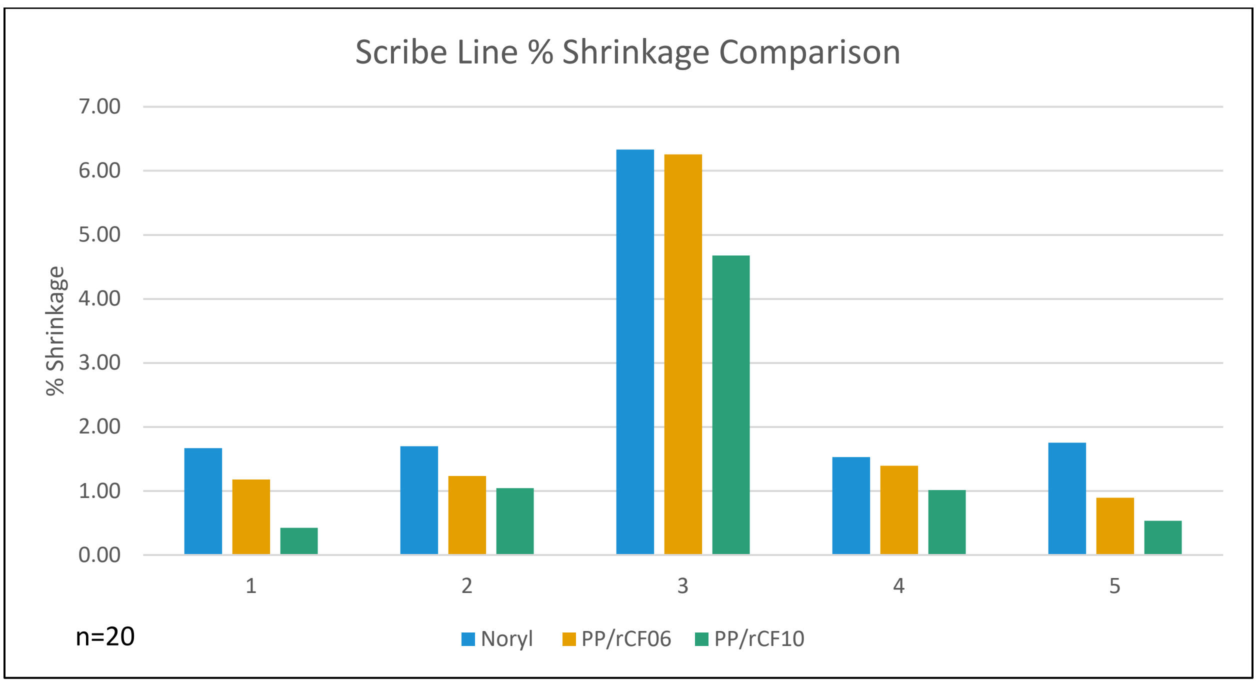


Figure 14: Scribe line % shrinkage

As expected, both rCF materials yield less shrink due to the carbon fiber adding stiffness to the material. Scribe line 3 on the vertical dog leg above the wheel had the most shrinkage. This is approximately where the two flow fronts meet and likely why this area had the most shrink.

Benefits Assessment

This technology combines inexpensive formulations of PP and rCF to reduce weight of current thermoplastic fender technologies. Should these light weight fenders be incorporated onto a production vehicle, they would reduce greenhouse gas emissions and utilize recycled carbon fiber in a secondary automotive application. Current cost modeling indicates a piece cost reduction versus current production material.

Commercialization

There is still much work to be done before commercialization of this product will be realized. As mentioned previously in the report, this technology will have to meet all OEM part requirements for exterior body panels including, but not limited to, paint appearance and adhesion, impact requirements, and CLTE requirements. In addition, if the material meets the requirements and the OEM decides to move forward with this technology, a Tier 1 molder will need to be identified. They will need to provide a business plan and assurance of the ability to deliver quality parts to the OEM assembly plant. The material supplier must be able to meet volume requirements and provide large quantities of quality recycled carbon fiber. Directional cost information is provided in Figure 15 below. Both PP/rCF formulations are more cost effective than the PA/PPE incumbent material.

Fender Molding Comparison

	PP CF6% (p/u)	PP CF10% (p/u)	PA/PPE (p/u)	Comments (text)
Material Cost	49%	46%	X	
Manufacturing Cost	11%	11%	X	
Mark-up Cost	33%	33%	X	
	39%	37%	X	
Raw Mtrl Rate:	48%/kg	46%/kg	X	

OCE: 110708-CSW

Figure 15: Directional cost information

Conclusions

Both polypropylene/recycled carbon fiber materials were able to meet stiffness and density targets as well as surpass the benchmark material. However, neither the PP/rCF06 nor PP/rCF10 materials were able to meet paint appearance targets. Initial dimensional analysis of the materials point towards improved dimensional stability over the benchmark material. Initial cost estimates are favorable; however, if these materials require a unique primer solution to meet paint appearance targets, any benefits or cost savings may be negated.

Based on this initial project, PP/rCF material solutions seem promising. However, there is much more work to be done to determine if other targets can be achieved – most notably, paint appearance.

Recommendations

As stated previously, more R&D work and demonstration is needed.