OPPORTUNITIES TO IMPROVE CARBON FIBER COMPOSITES FOR VEHICLE LIGHTWEIGHTING USING GRAPHENE ADDITIVES

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Abstract

Nearly one-fifth of all US emissions are produced by cars and trucks, making personal vehicles a major contributor of greenhouse gas emissions. To address this growing issue, the automotive industry is researching composites to reduce the weight of future vehicles which will lead to a decrease in emissions. Today, engineers are designing products to improve efficiency while maintaining strength in an attempt to reduce technology's environmental harm. Graphene has the potential to break the barrier between lightweight composites and metallic strength, and is a sustainable and affordable alternative to carbon fiber. The purpose of this study is to investigate the potential of graphene additives in carbon fiber body panels through manufacturing of a proof of concept hood for the 2016 Chevrolet Camaro. In order to develop the novel hood, which uses an advanced graphene infused carbon fiber, different amounts of graphene additive were investigated to determine the optimum performance. The developed hood, which is fabricated to precisely fit the Camaro and withstand Federal Motor Vehicle Safety Standards (FMVSS), will open the door to graphene-based automotive products, which could eventually impact material use across the globe. The results from this study will spark a new generation of automotive breakthroughs by using a new additive to decrease the weight of vehicles without sacrificing performance. This will help the automotive industry reach future goals of increasing fuel economy and decreasing greenhouse gas emissions without drastically increasing costs.

Introduction and Background

Lightweight composites, in particular carbon fiber based composites, in vehicles have the potential to improve fuel economy and reduce carbon dioxide emissions as metal replacements.[1],[2] A 10% decrease in vehicle weight corresponds to a 7% improvement in fuel economy;[3] a 1 kg decrease in vehicle weight corresponds to a 20 kg reduction in carbon dioxide emissions.[4] The body of an automobile accounts for approximately 40% of its total weight. Carbon fiber composites are about 40% lighter than their aluminum counterparts and are about 65% lighter than their steel counterparts.[5] Currently, many auto OEMs (e.g. Volkswagen[6]) are exploring carbon fiber reinforced plastics for use in exterior body panels in an effort to reduce overall vehicle weight by replacing metal parts with lightweight composites.

Demand for carbon fiber stems in part from the automotive industry and carbon fiber is incorporated in luxury and high performance vehicles.[7] However, carbon fiber costs 2-10 times more per part than its steel counterpart[5] creating a barrier to entry in the mass automotive market, as purchases/materials costs account for 77% of the revenue for the automotive manufacturing industry.[8] Specifically, substitutes such as steel and aluminum are threats to profitability for carbon fiber uses in passenger vehicles. Not only are steel and aluminum more affordable, they are easier to recycle and pose a more economical pathway to waste management for the auto industry. In spite of this, approximately 19% of the carbon fiber manufacturing industry revenue is from industrial and automotive markets.[7,a] In order to overcome the barrier of affordability (and potentially recyclability/reusability), the addition, supplementation or substitution of carbon fiber with its close cousin, graphene, is explored.

Graphene is a carbon-based material that has high strength, and can be added to plastics, providing increased strength to the composite compared to the baseline plastic.[9],[10] In this use, graphene provides increased performance to a lightweight material, in a similar way as carbon fiber does. Graphene is less expensive than carbon fiber and has the potential to add performance properties without significant added expense, setting it up to supplement or replace carbon fiber in the average passenger vehicle. Moreover, graphene is one of the strongest materials, is an affordable additive, and has the potential to expand the importance of thermoset and thermoplastic composites in passenger vehicles, light trucks, and other ground transportation applications. Enhancing carbon fiber parts by supplementing with graphene will positively impact vehicle lightweighting in large area components such as exterior body panels.

Graphene has been explored as both an interior[11] and exterior body panel additive in the past 5 years.[12],[13],[14],[15],[16],[17] However, most exterior body panel parts have been made exclusively for high performance automobiles and do not meet expectations of mass market automobiles (especially perceived costs). The issues surrounding graphene composites for automotive technologies are proof of viability which is a result of a very limited access to graphene composites that are consistent, are in a form that is viable for industrial/automotive use (such as pellets, sheet, filament, etc.) and are not embrittled. Moreover, graphene faces a significant barrier to entry as it is a new material and compounders, tier 1 suppliers and auto OEMs have limited experience handling the material.

Currently, graphene accounts for approximately $9.5M of the $1.9B carbon fiber industry.[7] About $353.4M of carbon fiber is used for automotive and industrial segments. By offering performance substitutes at a more affordable price, graphene has the potential to outpace carbon fiber in the $26.993B segment of plastics parts for automotive technologies. Demonstrating the feasibility of new lightweight automotive composites will enable the automotive industry to improve fuel economy and reduce greenhouse gas emissions and meet the Corporate Average Fuel Economy (CAFE) by 2025. We anticipate the new lightweight graphene composite for automotive technologies will result a substantial increase in the size of the graphene market and will increase cost effectiveness of lightweight metal substitute components and potential for growth in the automotive industry.

This paper describes the systematic study of a proof-of-concept hood for the 2016 model year Chevy Camaro that reduces the weight of the hood and maintains adequate mechanical performance while complying with other subsystems of the vehicle. Results of this work provide benefits to the automotive industry of demonstrating weight, performance, finish and affordability targets through proof of technical feasibility of a lightweight, cost effective composite hood that complies with FMVSS requirements.

[a] *Aerospace accounts for the largest buyer of carbon fiber in the U.S. demonstrating the lucrative nature of carbon fiber in markets with higher margins and which are more amenable to high performance materials that have higher prices.*

Goals and Targets of Prototype Hood

An ideal lightweight hood would contain materials that meet specific constraints:

- Affordable and Market Ready – Reproducible and compatible with current OEM product development processes
- Complies with approved automotive production development process: product and manufacturing concept development
- Lightweight and Structurally Sound – Strength, Stiffness comparable to Aluminum Hoods, Feasible in Crash Test, Unembrittled
- Class A Surface Finish

For the purposes of proving the concept of a graphene enhanced carbon fiber hood, the constraints placed on the proof of concept hood are more limited, but effective in demonstrating the concept.

- Must reduce weight of the hood body by 50%
- Must increase costs by no more than 500%
- Must meet or exceed structural performance – crumpling, stiffness, dent resistance
- Must meet or exceed baseline crash performance – and must meet Federal Motor Vehicle Safety Standards
- Must not catastrophically fail under crash test simulations
- Must latch and hinge using the original system

For reference, aftermarket carbon fiber hoods are available to consumers. 2016 model year Chevy Camaro carbon fiber hoods range in price from $959 - $1,400.[18] Major players in the aftermarket space include Anderson Composites,[19] VIS Racing,[20] and Carbon Creations.[21] These three major players all cater to racing consumers who are looking to lightweight and improve performance of their vehicles.

Optimization of Graphene Additive to Improve Carbon Fiber Composites

In order to determine the optimal amount of graphene used in the resin, ASTM[b] tensile tests were performed on test specimens with different quantities of graphene (Table I). The graphene was added to the resin using a proprietary method and panels were fabricated by vacuum forming. Test specimens were cut from the panels using water jet and were tested unconditioned with unknown moisture content. Testing was performed using a MTS 809, 250 kN axal torsional machine with a test rate of 0.00065 inches per second in displacement control.

[b] *D3039/D3039M – 14 (Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials)*

Table I: Test Specimen Information

Panel Area	92,903.04 mm^2
Test Specimen Area	2,580.64 mm^2
Test Specimen Area in Gauge Section	30.73 mm^2
Graphene % by Weight	0%. 0.1%, 0.5%, 1%

The ultimate strength of the 0.1 wt% graphene enhanced carbon fiber test specimens was found to be statistically higher than that of the control test specimens. Higher weight percentages of graphene were not found to statistically enhance the structural performance of the carbon fiber composites. The optimal 0.1 weight % graphene is consistent with findings from previous exterior part development and was chosen as the final amount of graphene additive for the prototype hood.

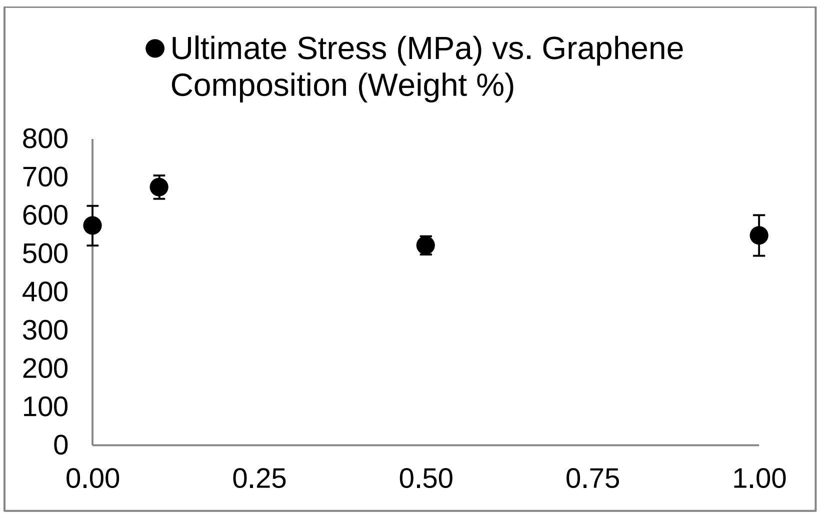

Figure 1: Ultimate Stress of Test Specimens with Varying Graphene Compositions.

Table II: Test Specimen Results

	Test Specimen Group 1	Test Specimen Group 2	Test Specimen Group 3	Test Specimen Group 4
Weight % Graphene	0%	0.1%	0.5%	1%
Number of Test Specimens	3	5	5	5
Average Ultimate Stress (MPa)	573.6	674.2	521.6	547.6
Standard Deviation	51.8	30.3	23.8	52.9
Coefficient of Variation	9.04	4.51	4.57	9.68
% Change Compared to Control	0	17.5	-9.06	-4.54

Scaling of Approach to Produce Graphene-Enhanced Carbon Fiber Hood Prototype

To prove the concept of using graphene enhanced carbon fiber composites for mass production consumer vehicles, a prototype hood was created using a mold. The mold was formed using fiberglass and resin and a 2016 model year Chevy Camaro SS hood. Two fiberglass molds were formed to represent the top panel and bottom panel of the hood. The prototype hood was made in two pieces using vacuum forming with the two molds. Materials.[c]

[c] *In total, three prototype hoods were fabricated, two were used for destructive crash testing and one was attached to a 2016 model year Chevy Camaro and presented to GM through the EcoCar3 competition.*

Figure 2: Picture of the mold (left) and of the vacuum forming process (right) used to make the prototype hood.

A major consideration in the design of the prototype hood was incorporating the latch and hinge hardware so that it complies with GM's requirement that it does not fail during crash testing. The latch and hinge hardware was attached to the bottom hood using a two-part polyurethane epoxy specifically designed for adhering metal to carbon fiber. In addition, the top and bottom panels of the hood were epoxied to bond the two carbon fiber surfaces together.

Table III: Hood Panel Structure

	Top Panel	**Bottom Panel**
Dimensions	2.32 mm thick	1.21 mm thick
Graphene % by Weight	0.1 %	0.1 %
Sandwich Structure	200 gram Carbon Fiber Mat Core Material 200 gram Carbon Fiber Mat Graphene Infused Resin	200 gram Carbon Fiber Mat 650 gram Carbon Fiber Mat Graphene Infused Resin

Figure 3: Picture of the student team with the unfinished prototype hood fitted on the 2016 model year Chevy Camaro (left) and picture of the final finished hood (left).

Determination of Feasibility of Prototype Hood

In order to demonstrate that the prototype hood is crashworthy, destructive testing was performed to determine compliance with Federal Motor Vehicle Safety Standards. The prototype hood was subjected to an applied force of 140 lbs using a frame built to simulate a 30 mph crash.

Table IV: Destructive Testing Requirements and Results

	Testing Requirements	**Testing Results**
Latch and Hinge Security	Must Stay Intact	Latch and hinges stayed connected to the hood
FMVSS 212 **Windshield Retention Simulation**	Hood must crumple	Hood deformed with no shattering
FMVSS 219 **Windshield Intrusion Simulation**	Failure away from Latch and Hinge System	Failure occurred away from the latch and hinge in the expected failure regions of the original SS hood
Simulated Speed	48 km/h Or 29.8258 mph	30 mph
Safety Factor	1.5	1.75

During the Year 3 EcoCAR3 competition,[22] the graphene hood was presented as part of the University of Alabama Camaro to General Motors (GM), Argonne National Laboratories, and the Department of Energy (DOE). In attendance were, Marry Barra, GM CEO, Mark Ruess, GM executive vice president, Global Product Development, Purchasing and Supply Chain, and Michael Berube, Director of Vehicle Technologies Office, DOE. Judges commented on the quality of the POC hood and were excited about its future impacts on the automotive industry.

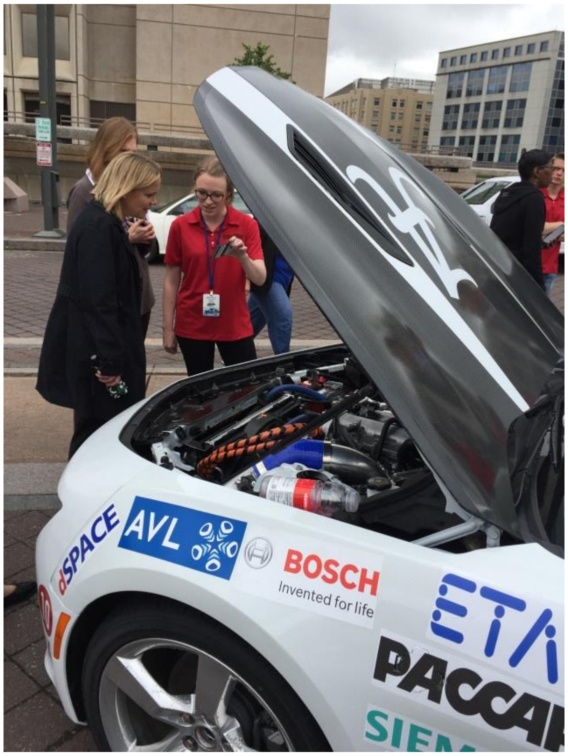

Figure 4: Hood presentation to DOE in Washington, D.C.

Future Outlook

A nine month research project demonstrates the potential of graphene additives to enhance carbon fiber exterior automotive panels, such as a hood. A new lightweight graphene enhanced carbon fiber composite has been proven as an effective material for a proof of concept automotive hood for the 2016 model year Chevy Camaro.

Table V: Hood Constraints and Results

Constraint	Target	0.1 wt% Graphene Enhanced Carbon Fiber Hood Result
Reduce weight of the hood body by 50%	Original Aluminum Hood: 22.1 pounds	11.1 pounds
Increase costs by no more than 500%	Original Aluminum Hood: $650	$1200
Meet or exceed structural performance	Carbon Fiber: 574 MPa	0.1% Graphene: 674 MPa
Meet or exceed baseline crash performance	Crumple away from latch/hinge system without shattering	✓
Latch and hinge using the original system	Conform to 2016 Model Year Chevy Camaro	✓

Lightweight, affordable graphene enhanced carbon fiber composites will reduce CO_2 emissions and improve fuel economy of mass produced vehicles. Introducing these revolutionary composites to the automotive market will bolster company growth and jobs. Furthermore, deploying lightweight graphene composites in exterior body panels for automotives and other vehicles (golf carts, scooters, etc.) has the potential to extend to the global consumer market. Our strategy is to partner with automotive OEMs (e.g. GM, BMW, Tesla, etc.) to phase the body panels into their product development process and eventually into their production line. We anticipate the new lightweight graphene composite for automotive technologies will result a substantial increase in the size of the graphene market

Acknowledgements

The authors and The University of Alabama thank the EcoCar3 competition, General Motors, Argonne National Lab, and the Department of Energy for financial support of the 2016 model year Chevy Camaro and technical advice and assistance. In addition, the authors wish to thank Paul Puzinauskas (faculty advisor), Mike Pope (faculty advisor), and Josh Stoddard (engineering manager) of the University of Alabama EcoCar3 Team for insights into the hood design and Jack Sisk of Technology Acceleration and Innovation Services for insights into the automotive production development process. Graphenics thanks Steve Vershaeve of RocTool, Lynn Venditti and Maria La Torre of Technical Fibre Products Inc., and Erin Harkins of Intertek for insightful conversations about the hood, in particular the manufacturability of future graphene enhanced automotive hoods. This work has been supported by Graphenics and generous contributions from the Reasoner family.

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