CAR
CENTER FOR AUTOMOTIVE RESEARCH

Assessing the Costs & Benefits of Effective Lightweighting Technologies

Prepared by:

Luke Deptula and Alaa Noah

Student Interns

Center for Automotive Research

With the Support of:

ALCOA FOUNDATION

July 2015

ACKNOWLEDGEMENTS

The Center for Automotive Research (CAR) would like to thank the Alcoa Foundation for providing the support and funding to make this study possible. For several years, CAR has engaged with student interns in a wide variety of research projects. The funding Alcoa Foundation provided was instrumental in assisting the authors of this study, Alaa Noah and Luke Deptula, to conduct the work necessary for this report. This paper is a continuation of research following a previous report and presentation given to SAE World Congress on the "Importance of Lightweight Closures," which discussed lightweight door case studies.

This study is the result of a group effort. Alaa Noah and Luke Deptula would like to thank their colleagues from CAR, who provided insight and expertise that greatly assisted the research. In particular, the authors would like to thank Mark Stevens for his support and guidance, as well as Dr. Jay Baron, President and CEO of CAR, for his comments, which greatly contributed to improving the manuscript.

About the Authors

Alaa Noah currently is a research assistant at CAR, in Ann Arbor, Michigan. He also attends Oakland University, pursuing his bachelor's degree in Electrical Engineering, with an anticipated graduation date of December 2016. Alaa's current projects at CAR are focused on lightweighting efforts in the automotive industry, application of new materials, and updates in manufacturing processes. Alaa has presented at the SAE 2015 World Congress.

Luke Deptula is a research assistant at CAR. He is pursuing his Bachelor's degree in Electric Transportation Technology from Wayne State University, with an Associate degree in Automotive Technology from Henry Ford Community College, and a Certificate in Electric Vehicle Development from Macomb Community College. At CAR, Luke is engaged in lightweighting research. He is passionate about transportation efficiency and annually participates in fuel efficiency competitions. These competitions have allowed him to regularly set new efficiency records in his personal vehicles and in 2015 his vehicle was awarded the most fuel efficient electric vehicle at the Green Grand Prix.

About CAR

The Center for Automotive Research is a non-profit organization based in Ann Arbor, Michigan. Its mission is to conduct research and analysis to educate, inform and advise stakeholders, policy makers, and the general public on critical issues facing the automotive industry, and the industries impact on the U.S. economy and society.

For more information, contact CAR at:
3005 Boardwalk Drive
Ann Arbor, Michigan 48108
734-662-1287
www.cargroup.org

TABLE OF CONTENTS

ABSTRACT

Over the next decade Corporate Average Fuel Economy (CAFE) regulations will increase the fuel economy with new model year (MY) cars and light trucks. The U.S. government finalized a regulation requiring vehicles average 54.5 miles per gallon (mpg) fuel economy for MY2025. Vehicle manufacturers recognize removing weight is a key approach to meeting these targets for fuel economy and emission reductions. Automakers are implementing incremental reductions in vehicle weight as part of their strategy to attain these fuel economy goals. The automotive industry continues to look for opportunities to reduce weight and cost while continually increasing performance and safety. Lightweighting technologies can enhance vehicle performance (e.g., fuel economy, acceleration, braking, and emissions). New materials are available to reduce weight; however, the incremental cost for the weight reduction can be prohibitive. This study encompasses the utilization of lightweight materials, as well as current and evolving manufacturing processes. In instances where reducing weight while achieving performance targets (e.g., dent resistance, stiffness, and crash-worthiness) is the goal, the key is to attain a lightweight assembly that assists in meeting the fuel economy targets through optimized part design or material substitution.

OVERVIEW

This report examines why lightweighting may be a viable solution and examines the cost of lightweight doors. The authors analyze the direct manufacturing cost by modeling the manufacturing processes of the door-in-white subsystem, including the inner and outer panels, hinge reinforcements, and intrusion beams, concluding with the joining of components into the subassembly, which can be installed in an automobile assembly plant body shop.

This project resulted in an extensive cost model. The cost model was validated through five case studies. A study of the lightweight door options is also included. This study includes breaking down the factors and costs of manufacturing lightweight doors, without consideration of the effect on mass decompounding or secondary weight savings. It evaluates which heuristics and published statements are supported, and which are challenged, by our research. It concludes with recommendations based on research and case studies where the results come out of the cost model.

COST MODEL METHODOLOGY

This paper investigates the application of manufacturing techniques to optimize the time and cost of manufacturing a few critical components of automobile doors. The entire manufacturing process is considered, including all the stages of development in the manufacturing of a vehicle door. Lightweighting is typically accomplished by downsizing, integrating parts and functions, substituting materials, or through a combination of these methods. Lightweighting reduces vehicle mass in order to improve fuel economy and vehicle performance.

This report focuses on the approach used to determine the relative costs of lightweighting automotive closures. The method chosen is a direct manufacturing cost (DMC) method where labor, tooling, materials, and processing have the greatest effect on component cost. Investment costs for equipment and automation are examined but do not directly contribute to part cost estimations for the DMC. These investments will be recovered in profits when the component price is determined. For simplification, the focus of this model is limited to the four main components of a door to help simplify the understanding of the processes.

We found that four parts of the door-in-white (DIW) account for 80 percent of its weight. These four parts include the outer panel, inner panel, hinge reinforcement, and side impact beam. While each company has its own approach to door design, most all companies have similar components in the doors.

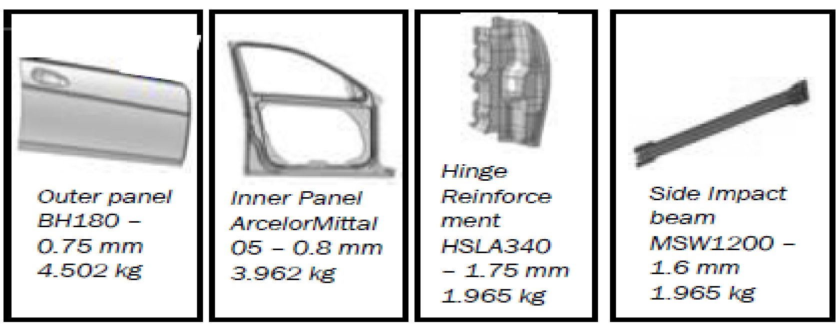

Figure 1: Majority of Door Weight in Four Parts

Source: Schurter Paul, Tim Lim, and Mansour Mirdamadi. "The SynergyTM Door – A New Approach to Lightweight Steel Doors." ArcelorMittal & Dow Automotive & AutoSteel.org. 2014.

Automotive door manufacturing is described with three major costs. The first cost is the material cost, the second is the cost of making the parts, and the third is the cost to assemble the parts. The cost model includes these three sections to determine the final cost.

Input Table

This study uses an input table to enter the data into the cost model. This table requires a determination of process requirements, equipment, and cycle times necessary to form the part. These requirements are combined with operational conditions for the plant (e.g., number of shifts and downtime) and costs (e.g., raw material price and labor wage) to calculate the unit cost of the input part. The cost model is designed to be predictive, which is useful in comparing novel technologies or design concepts that have not yet become standard for a company. These input table variables are considered factors that may lead to an increase or decrease in the cost. Variables include the material price, weight, annual production volume, number of shifts, equipment cost, and tools. They can be easily modified to update assumptions and achieve a more accurate output. In some plants, a few manufacturing processes can produce up to 10 different pieces at the same time, making it difficult to estimate changes in cost for some processes.

Table 1: General Input Assumptions

Metals production volume	200,000	parts/year
Composite production volume	35,000	parts/year
Working days per year	313	days/year
Wage (including benefits)	18.00	$/hour
Equipment life	30	year
Cadence	5	years
Number of shifts	2	per day
Overhead rate	$500	$/hour

Source: CAR 2015

A variety of general inputs, as shown in Table 1, are used to create our cost model. These inputs can easily be changed to test different scenarios and their influence on the final cost. The following sections detail the basic steps to manufacture parts and assemble them.

Material Cost

Material is an important cost factor in manufacturing. Some materials can be purchased in the direct size and quantity of the final part, often referred to as purchased part material. Many materials used in part manufacturing are often purchased in bulk quantities. Some materials will be purchased as loose bulk quantities later brought together to form the parts, as with injection molding. Other materials purchased in bulk are condensed into sheets for final processing, as with sheet molded compounds.

Materials purchased at a direct quantity and size of the part would be ideal and make cost estimation of materials used for parts easy because they may be purchased at the exact amount required per part. When considering purchased part material, where the component parts are already in their final form, only additional assembly costs apply. Manufacturers most often choose to buy material in bulk, so they keep the control of their products and technology in house.

Materials purchased in large loose bulk quantities have costs that are divided amongst the amount of parts they produce to determine individual material per part cost. All loose bulk materials will require additional costs to form and assemble each part. Some loose bulk materials may have additional cost to condense and create the final material, before final forming to the appropriate dimensions. This is an additional process cost is not acquired to manufacturers who build assemblies by manufacturing parts with materials that are bulk condensed materials or purchased parts materials.

Materials purchased in condensed bulk quantities can be in the form sheets or coils or even fabric type materials on rolls. They have a large surface area, and condensed materials will have to have the parts shape or blank cut out from the bulk of the material. This process cost is affected by the volume, speed of the equipment, and material which determines what equipment will be used.

Material cost is summarized by the purchased cost, whether in bulk loose or condensed into sheets or coils, with the appropriate processing cost to prepare the material for forming. The cost model allows the estimator to select from the list of options differentiating between inner panels, outer panels, and reinforcements. A variety of material types are included along with different processes for forming the material. Moving between these selections affects the cost of the operation. Material cost is shown in Figure 3.

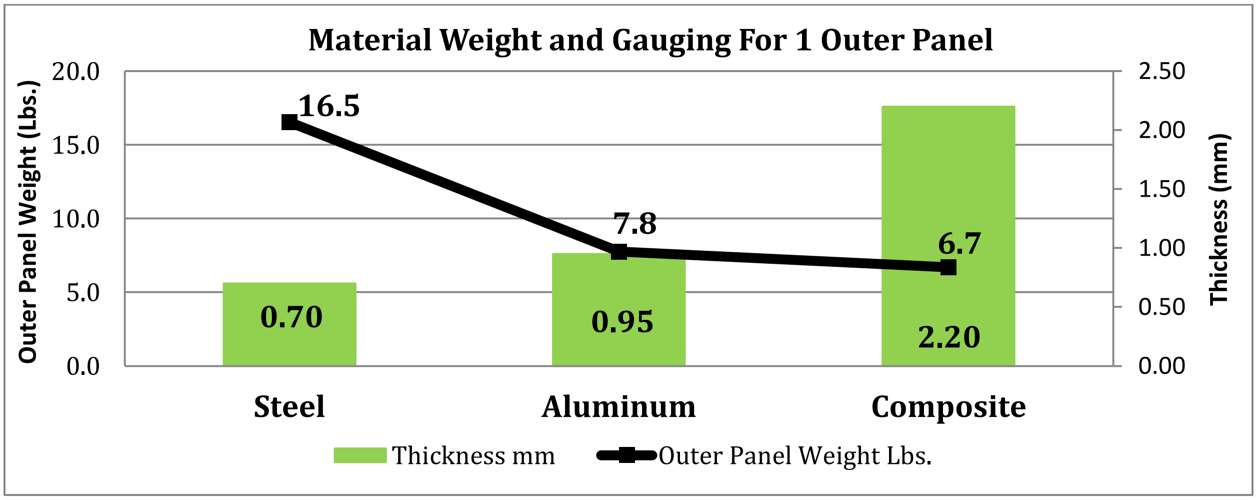

Figure 2: Material Weight and Thickness

Source: CAR 2015

The materials used in the model have various thicknesses based on material strength and stiffness to account for a more uniform part performance. The steel outer panel in the model uses 0.7mm thick material. The aluminum outer panel uses 0.95mm thick material. The composite panel uses a 2.2mm thick material. Although the material thickness is considerably different, the individual part weight decreases by about 53 percent when switching from steel to aluminum. Likewise, the composite part is nearly 14 percent lighter than the aluminum part, even though it is thicker. Material cost assumptions include: mild steel $0.38/lb.,[1] aluminum 6000 series $1.65/lb.,[2] and composite $2.88/lb. having 0.047 lb./in^3 density.

Composites are diverse and have a broad range of prices ($2.50-4.00/lb.). The composition of a composite may include glass fibers; sheet molded compounds; thermosets; thermoplastics; and carbon fiber with short, medium, or long fibers, at a wide variety of thicknesses.

[1] Metalprices.com / AK STEEL price book
[2] Aluminum 6000 series pricing derived from London metals exchange / Alibaba

Forming Cost

During the forming process there are various aspects related to stamping of three-dimensional shaped panels from blanks. Variables such as material, dimensions, volume, equipment type, automation, labor, number of dies, and overhead rates are important inputs into calculating the cost of stamping. Various materials with different strengths are also inputs that contribute to making a more accurate cost estimate.

The number of forming stations required is another major input into the estimate. This could vary from a single press to a press line with multiple stations or individual presses. In order to form a complex part such as a door inner panel, there are several operations (or stations) required.

For sheet metal parts, the process includes forming, trimming, pierces, flanging, and possibly a restrike to correct for any variations from material spring back. It is typical to see a sheet metal press line with four to five dies required to fabricate a door inner panel.

The basic forming of plastics includes adding thermoset plastic granules into a split mold or upper and lower dies. The dies are heated and compress the plastic. It is then cooled to return to a solid before the part is extracted from the dies.

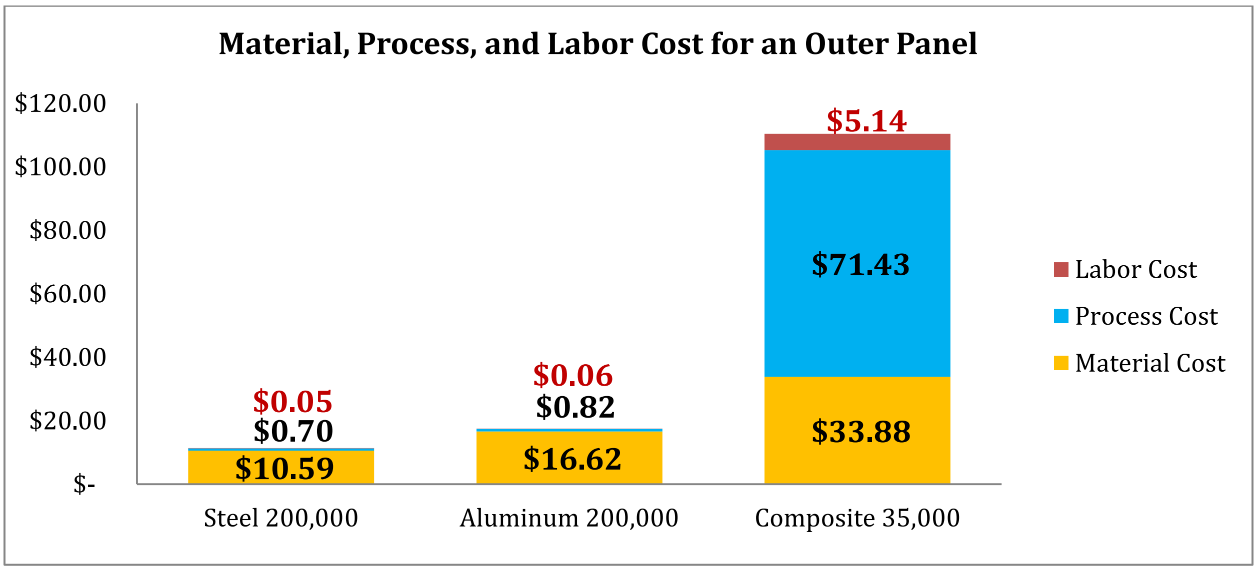

Figure 3: Breakdown of Forming Cost with Various Materials (Material, Process, and Labor Costs)
Source: CAR 2015

Figure 3 shows how cost to form a panel changes based on the material and process used. The first option represents a steel outer door panel stamped on a tandem press line. The second shows a door stamped from aluminum on a tandem press line, while the third option indicates a generic composite outer made using compression molding process.

Assumptions are based on $18 per hour labor rate with two workers per shift, production volumes of 200,000 units for sheet metals, and 35,000 units for composites. Overhead rates including heat, power, lighting, tax, depreciation, and amortization rate are set to $500 per hour with an 85 percent uptime.

Steel is formed at a speed limited by the press; we selected 14 strokes per minute or 714 parts per hour. Aluminum is set at 12 strokes per minute or 612 parts per hour. After interviewing manufacturers we found it was possible to run aluminum faster, but it could affect the part quality.

With sheet metal forming running one shift, steel stamping completes their job in the equivalent of 35 days. Aluminum stamping consumes the equivalent time of 41 days. While composite forming takes 313 days running two shifts, due to producing seven parts every hour, or having near an eight and a half minute cycle time (Proper lot-sizing spreads the production volume over the year as needed).

Table 2: Labor, Process, and Time Associated with Three Materials

steel	labor	($18*2)/714 = $0.05 per part
	process	$500/714 = $0.70 per part
	time	200000/714/8 hours per day = 35 days

aluminum	labor	($18*2)/612 = $0.06 per part
	process	$500/612 = $0.82 per part
	time	200000/612/8 hours per day = 41days

composite	labor	($18*2)/7 = $5.14 per part
	process	$500/7= $71.43 per part
	time	35,000/7/16 hours per day = 313days

Source: CAR 2015

Both steel and aluminum have nearly the same cost to form; this is because they use the same forming equipment in most cases. Forming the composite outer panel has a higher cycle time. This is not necessarily an ideal option as a cost effective manufacturing process at high volume production where it would require additional tooling.

During the forming process a part may lose some of its weight by getting trimmed. Blanks are the input to the stamping process and stamped sheet metals typically lose 30 percent (by volume) of the material as offal (excess metal, recoverable scrap material) during the manufacturing process. The recovered value from the offal is added back to reduce the final cost, because this model assumes a closed cycle recycling process between manufacture and material supplier for sheet metals. The scrap assumptions are: mild steel 170/240 $0.035/lb.,[3] aluminum 6000 series $0.995[4], and composite has no cost adjustment for value of scrap. The major cost of forming is based on the process. In sheet metals, this means that the type of press line and the numbers of dies have a large effect on the overhead rate charged to use the press line. The volume of production required affects which press line will be necessary to keep up with required production rates. Volume also affects the amount of automation and labor required to keep the process running at required production rates.

[3] Metalprices.com
[4] Metalprices.com aluminum-alloy-6061-scrap

Assembly

In assembly, parts are merged together to produce a car door in white. Here all the parts are combined through use of by welding, adhesives, mechanical fasteners, hemming, or some combination of these processes.

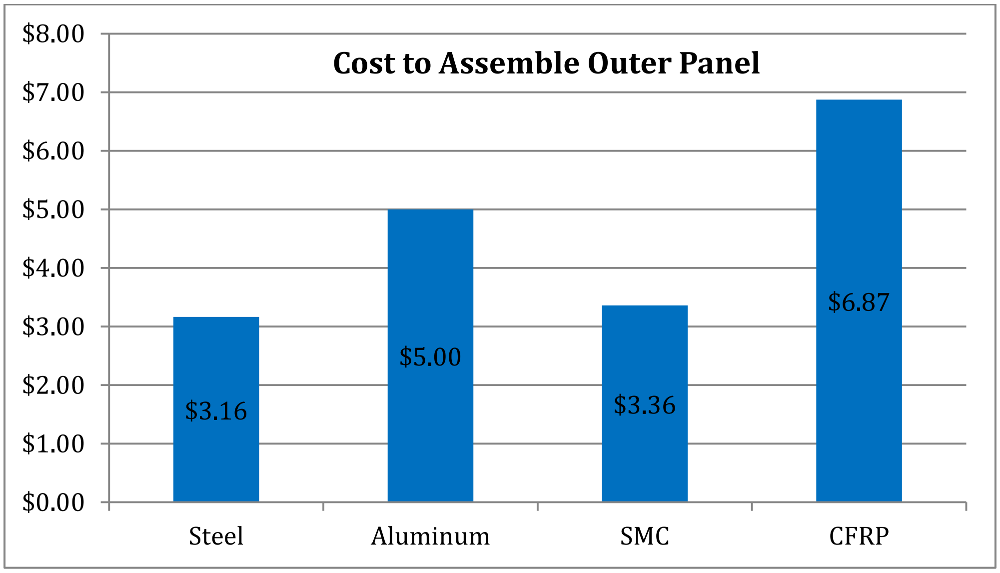

Figure 4: Cost of Assembly Process Using Different Material Options for Outer Panel Only
Source: CAR 2015

Figure 4 compares the costs to assembly outer panels made from steel, aluminum, sheet molding compound (SMC), and carbon fiber–reinforced polymer (CFRP). It shows that the highest cost to join outer panels is associated with CFRP material.

The cost of assembly increases or decreases depending on the number of assembly stations required. It also depends on the way the parts are attached together (e.g., welding, adhesives, fasteners, or hemming). The steel door design shown in the cost model has been welded several ways. First it was spot welded, and then it was laser welded at two different stations. Generally, spot welding is the most common, because it is inexpensive and it is a well-known proven technology. Laser welding is increasingly common, because not only is it more accurate and precise, but also because it works well with aluminum. The labor cost varies depending on the number of stations in the assembly process. More stations may require increased labor costs or increased overhead cost driven by increased use of automation. When the inner panel is combined with reinforcements and is about ready to merge with the outer panel, a robot applies a bead of adhesive to the edges of the outer panel. Once adhesive has been applied, the outer panel is joined to the inner panel. Typically a robotic roll hemming attachment moves around a stationary door and folds over a flange to join the assembly together. Next the assembly is moved to the induction heating or ultraviolet process to cure the adhesive inside the hemmed joint. The size of the door surface and the joining quality required on the sealed joint determine the amount of adhesives required and affect the cost of assembly. Each station has a number of robots that move the parts, and each station is different depending on its shape and purpose. The robots and stations are included in processing cost, because they are an investment.

RESULTS

The following model completes the cost estimation process for three example doors-in-white. All three designs have the same dimensions with the exception of material thickness. All doors are dimensioned to fit the same vehicle and share the same advanced high strength steel intrusion beam.

- The steel door has steel inner, outer, and steel reinforcements.
- The aluminum door has a 6000 series outer, 5000 series inner, and aluminum reinforcements.
- The composite door has a composite outer, aluminum 5000 series inner, and aluminum reinforcements.

The results of this cost model show the general trend of higher cost with decreasing door weight.

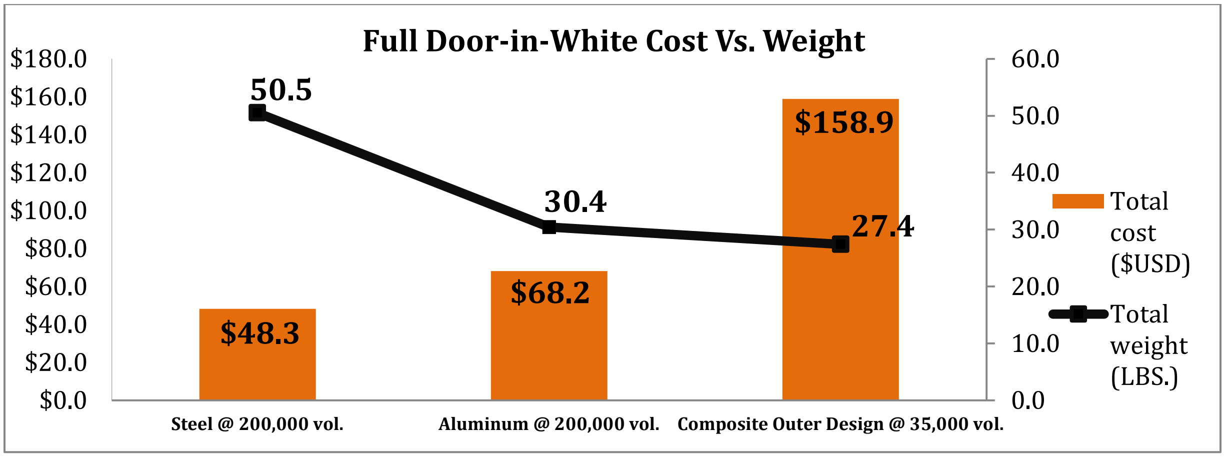

Figure 5: Final Results of Cost Model Include the Other Major Door Components

Source : CAR 2015

When processes used in manufacturing high volume panels have increased cycle times, the cost is greater because multiple tool sets would be necessary to keep production up to pace. According to the cost model at the high volume of 200,000 units, the aluminum design door is the most cost effective lightweighting solution available. As manufacturing processes improve cycle times and reduce cost, composite designs may become more competitive.

CASE STUDIES

Five different door case studies have been used to validate this model. These cases were chosen to have an objective view encompassing a more comprehensive assortment of doors in a variety of materials, volumes, architecture, and manufacturing processes. Each case study provides details on the materials, volumes, and manufacturing processes used. This data was entered into the cost model and the resulting observations are evaluated.

Ford F-150

The 2015 Ford F-150 pickup is an aluminum intensive truck that is 700 lbs. lighter than its predecessor, which had a steel body.[5] The F-150 is made in two plants: Dearborn, Michigan and Kansas City, Missouri, with a combined capacity of 2,400 trucks a day. In 2014, Ford sold 753,000 F-series[6] and expects 850,000 units in 2015. Ford has made a large commitment to lightweighting by making significant changes to a high volume production vehicle like the F-150.

Figure 6: Ford F-150
Source: Ford 2015

The F-150 has an aluminum intensive body attached to a high strength steel frame. Detailed information on the driver's front door of the F-150 was input into the cost model. The previous F-150 model had a full frame conventionally designed door. The MY2015 door is a completely new design. The door is made using a 6000 series T81 aluminum outer panel, a 5000 series aluminum inner panel, with latch and hinge reinforcements also made from 5000 series aluminum. The intrusion beam is stamped from boron steel in a press hardened steel process, resulting in an extremely strong martensitic beam.

Since aluminum and steel share a similar manufacturing process for stamping, the difference in cost is primarily driven by differences in material and assembly costs. Assembly cost of the MY2015 door is increased due to use of fasteners and adhesives for aluminum, rather than the simple spot welds used for steel.

Ultimately the decision to remove weight from the F-150 allowed Ford to increase the work load and towing capacity of the truck while reducing fuel consumption under normal operating conditions. While

[5]Turkus, Brandon. "2015 Ford F-150 Shaves 700 Pounds, Adds 2.7-liter EcoBoost [w/video]." *Autoblog*. 13 Jan. 2014. Web.
[6]Williams, Mark. "Ford on Track to Sell 700,000 F-150s - PickupTrucks.com News." *Ford on Track to Sell 700,000 F-150s - PickupTrucks.com News*. Pickuptrucks.com, 25 Feb. 2015. Web.

the aluminum material tends to cost nearly three times that of steel, with a third of the weight, it may appear to be a cost neutral solution. Upon closer investigation, one would notice the aluminum material must be around 1.7 times thicker than steel to achieve similar performance and strength.

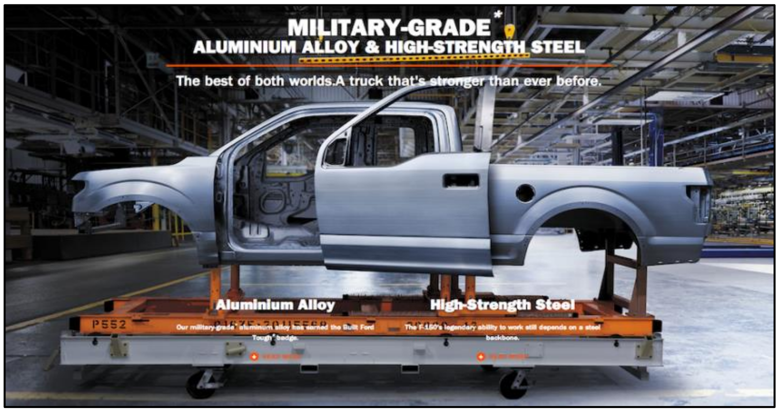

Figure 7: Ford F-150 2015 Truck Door and Body Produced Truck in its Class Featuring a High-Strength, Military-Grade, Aluminum-Alloy Body and Bed

Source: www.Ford.com /F-150

Figure 8: F-150 Inner Panel Made from All Aluminum

Source: Truck Trend 2015

BMW i3

The BMW i3 is the first consumer vehicle built with a carbon fiber intensive body structure. This electric vehicle was an all-new design and was built with weight reduction ideas being utilized to extend its driving range. The i3 is a low volume production vehicle made in Leipzig Germany. In 2014, 16,052 BMW i3 models were sold worldwide, and the vehicle should achieve similar sales levels in 2015.[7] The vehicle uses state of the art mixed materials, especially in the doors.

[7] Blanco, Sebastian. "BMW i3, I8 Sales Strong Enough to Reach Almost 17,800 in 2014." *Autoblog*. 16 Jan. 2015. Web.

Figure 9: BMW i3
Source: BMW 2015

The i3 has a carbon fiber passenger cell or life module, affixed by adhesives to high pressure aluminum die-castings for suspension mounts to connect it to the aluminum frame. The outer body is made primarily from SMC plastics, and hood and tailgate are made from carbon fiber. The roof is a class-A exterior surface, made out of scraps and recycled carbon fiber[8]. The i3 driver's door is a headerless door, also known as a half door or a door without a window surround. The rear door is a coach door; which is a reverse hinge mounted door with an integrated B pillar. The outer and inner door panels are made of SMC plastic. The inner framing of the door is made from aluminum extrusions and aluminum stamping that has been wire welded. The crash beam is press-hardened advanced high-strength steel. The hinge and latch reinforcements are made from aluminum extrusions and stampings.

Figure 10: BMW i3 Inner Panel Made for Aluminum and HSS Beam Reinforcement
Source: BMW Blog 2014

[8]Sloan, Jeff. "BMW Leipzig: The Epicenter of I3 Production : CompositesWorld." *BMW Leipzig: The Epicenter of I3 Production : CompositesWorld*. 31 May 2014. Web.

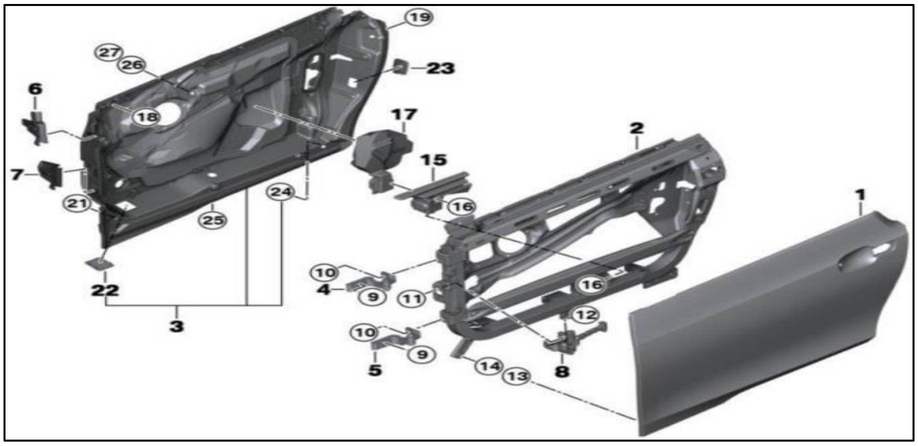

Figure 11: BMW i3 driver's door breakdown of parts
Source: BMW I-3 repair manual 2015

The i3 has a new non-conventional door in that its inner panel is not a structural load bearing component of the door. A conventional door has an inner panel that would normally have specific parts mounted to it: hinges, door latch, window regulator, speaker, and cross beam. The i3 has these mounted to the aluminum door inner framing, and covers the inner door with a SMC plastic. This slimmed down inner door structure gives the door almost all the strength it needs without plastic covering for the inner and outer panels. This is quite different from conventional doors which have integrated the inner and outer panels or covers joined to give a door structure its strength. Though it is commonly believed that carbon fiber cannot be formed as fast as steel in a press because the resin transfer molding (RTM) process for carbon fiber takes too much time to cure. This led to unnecessary assumptions that the processes used to manufacture a carbon fiber vehicle could not sustain high volume production. However, the i3's start to finish production time of 20 hours is the same as that of the Ford F-150. The i3 is a great example of how mixed material solutions with unconventional designs can reduce mass.

Chevrolet Corvette

The Corvette is a sports car manufactured by the Chevrolet division of General Motors (GM). The car has gone through seven generations of production since 1953. Since the beginning, Corvette has been known to utilize lightweight material innovations to increase the vehicle's performance. The first design utilized an all-fiberglass body, and every Corvette since has featured some form of a composite-material body. Originally fiberglass offered GM an economical way to manufacture the low-volume Corvette without the expense of metal-stamping dies. Materials used in the Corvette changed in 1973 from conventional fiberglass to SMC,[9] which was composed of fiberglass, resin, and a catalyst formed under high heat and pressure. The use of SMC helped produce panels that were smoother right out of the mold, resulting in higher-quality paint finishes. Corvette's focus was never on the use of exclusive materials. It has always been about using the best materials to improve vehicle performance. The

[9]"Fiberglass to Carbon Fiber: Corvette's Lightweight Legacy." *Media.gm.com*. www.chevrolet.com., 16 Aug. 2012. Web.

materials for each specific component are chosen to offer the best part strength and surface quality while reducing weight for low-to mid-volume production.

Figure 12: Chevrolet Corvette
Source: GM 2015

The Corvette is made in Bowling Green, Kentucky, and GM produces nearly 40,000 Corvettes each year. The Bowling Green production plant produces 137-167[10] cars per day, or 17 cars per hour. From start to finish, the Corvette will take a seven-mile trip in the factory, taking nearly 36 hours for assembly. The modern Corvette Stingray continues to use lightweight materials throughout the vehicle. The Corvette has an aluminum space frame that is 100 pounds (45 kilograms) lighter than its previous steel design. It is made of segmented aluminum rails varying in thickness from 2 mm to 11 mm. This enables tailored gauge, shape, and strength properties with minimal weight to achieve a 57 percent stiffer frame compared to the previous steel design.[11] ZO6 models also have a carbon fiber hood and roof panel. Underbody panels are created with carbon-nano composite technology. The front fenders, doors, rear quarter panels, and the rear hatch panel are made from light-density SMC. Joining these mixed materials requires 39 spot-welds using a GM-patented process that uses a unique electrode designed specifically for aluminum, 188 flow drill-machined fasteners, 113 feet of structural adhesives, and 37 feet of laser welding.

Both inner and outer door panels are made from SMC. The door outer panel measures 1.2 mm (0.047 in) thick and the inner panel is 0.8 mm (0.031 in) thick. The cross intrusion beam is press hardened steel and the beltline reinforcement is also steel. The door's hinge and latch reinforcements are aluminum castings. Combined, the body materials, the design, and engineering of the parts saves approximately 37 lb. (17 kg) compared to the C6 body structure. Production of the C6 Corvette ran from 2005-2013.

[10] Lamarche, Jeff. "Corvette's New Plant Manager." www.superchevy.com, 16 Oct. 2014.
[11] Luft, Alex. "Deep Dive: The Light, Yet Stiff Frame Of The 2014 Chevy Corvette Stingray." *GM Authority*. 26 Jan. 2013. Web.

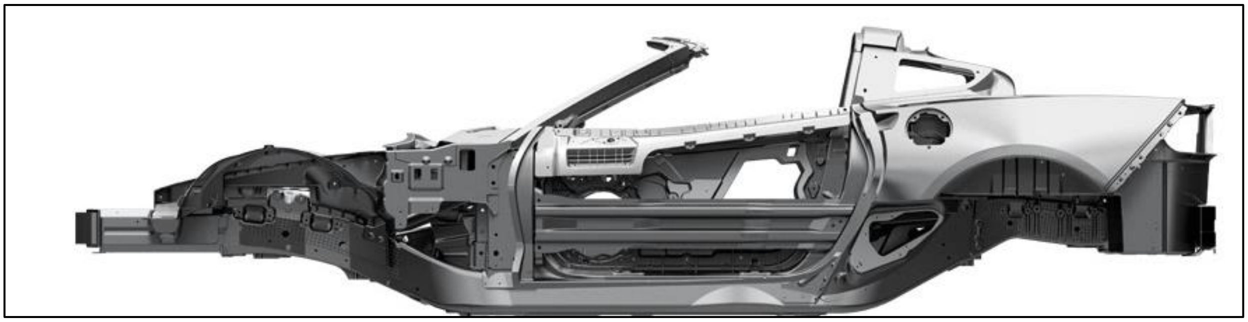

Figure 13: 2015 Corvette Body in White

Source: http://www.chevrolet.com/corvette-stingray

Figure 14: More in Detail Inner Panel of the Corvette 2015

Source: http://www.chevrolet.com/corvette-stingray

Silverado

The GM Silverado truck is a steel intensive truck. It has been a steel body pickup since Silverado's first generation in 1999. Prior to 1999, the Silverado had been a trim package. The Silverado is manufactured in three plants: Flint, Michigan, Fort, Wayne Indiana, and Silao, Guanajuato, Mexico. The plants have a combined capacity of 1,700 trucks a day. This vehicle has been the subject of several lightweight studies in recent years. The most recent study conducted by FEV demonstrated reduced weight by 1,162 lb using advanced high strength steels and other light lightweight materials including aluminum and plastics to reduce vehicle weight by 22 percent.[12]

The Silverado has a steel intensive body with a full frame conventional front door. The Silverado door used for the cost model is made out of mild steels, having an MS 270 MPa outer panel and an MS 140 MPa inner panel. The hinge reinforcement is MS 240 MPa and the crash beam is MS 200 MPa.

12 E.P.A., U.S. "Light Duty Truck Mass Reduction Study Results." EPA.GOV., 31 July 2014. Web.

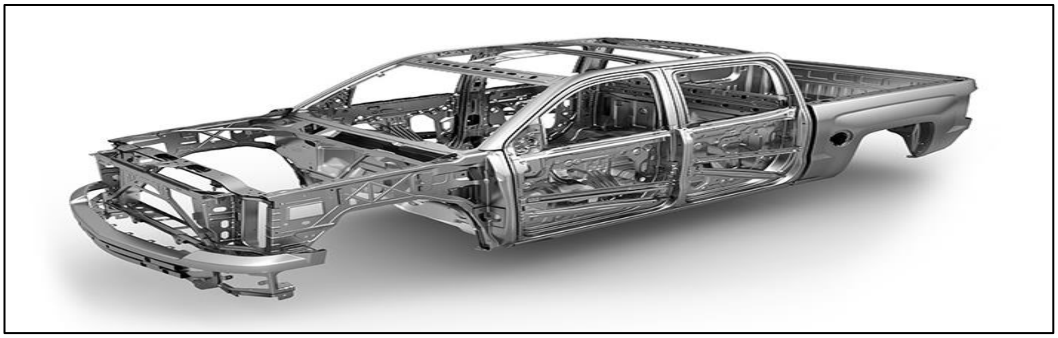

Figure 15: 2015 Silverado 1500 Track Body in White
Source: Silverado 2015

Western Star

Western Star is an American-made commercial truck. Western Star has earned a worldwide reputation for building trucks that do jobs no other trucks can tackle. Each truck is a premium highway and heavy hauling truck designed to each customer's specifications. Although this case may not be the best example of lightweighting it is the largest door architecture investigated in this report.

Figure 16: Western Star Commercial Truck
Source: Western Star 2015

The Western Star has a full frame door with a steel outer panel, as well as a steel inner door panel. All door hinge and latch reinforcements are made of steel. The door's cross beam is made of high strength steel. This vehicle is a low-volume production vehicle yielding 8,500 units per year. The steel panels are stamped and manually transferred. Due to the low volume, there are no robots in the production of the panels. These doors are manually spot-welded, mastic adhesive is manually applied, and the doors are hemmed. A single robot is used to automate the roller hemming in order to produce a quality assembly. The robot alternates between left- and right-handed doors.

OBSERVATIONS

Lightweighting is a key strategy for meeting targeted fuel consumption and emission reductions. Mass reduction is an enabling technology, because all efficient solutions benefit from moving less weight. As Newton demonstrated: Force = Mass * Acceleration. Powertrain efficiency improves when it can use a reduced force to accelerate a reduced mass.

Doors are made from different materials using different architectures, yet different manufacturers still use common design elements with each having inner and outer panels, hinge reinforcement, and an intrusion beam that accounts for 80 percent of weight.

Mass reduction affects fuel economy and emissions; a 10 percent weight reduction can improve fuel economy by 5-7 percent. Reducing 100 kg of vehicle weight can reduce 9.0 g of CO_2 emissions or 0.2 L fuel consumption per 100 km[13].

Closures offer more potential weight savings than other areas of the vehicle: "Reducing 20 kg reduction in closure mass leads to another (nearly) 20 kg reduction in the vehicle mass which help[s] improve [the] fuel economy benefit of lightweighting."[14] (This does not work in a reverse compounding effect). Removing weight from the frame or other areas does not allow for mass decompounding of closures, due to stiffness, safety, and other engineering requirements specific to closures.

Lightweighting reduces battery cost for electrified vehicles. Batteries are one of the biggest costs of electric vehicles. Reduction of mass in electrified vehicles enables the use of a smaller battery by reducing the energy consumption required to propel the vehicle (the less a vehicle weighs the less energy it takes to move it).

The adoption of lightweight materials in automobiles is growing but is limited by several factors: cost, material properties, availability, joining technique, corrosion protection, manufacturing processes, cycle times, and resistance to change. Use of conventional methods and materials will result in lower manufacturing costs, but may not be effective in meeting fuel economy targets.

Production volumes affect direct manufacturing cost (e.g., material, overhead rate plus labor) because volume determines the equipment needed to produce at any given rate of production. The change in equipment and automation affects the overhead rate cost charged for manufacturing processes. Increasing the volume will increase the tooling cost, as the quality or grade of tool steel is upgraded to sustain higher production rate without excessive maintenance. Increased volumes also increase the total labor cost required to meet increased production rates (though per unit costs may go down).

---

[13] Mock, Peter. "Reducing CO2 and Fuel Consumption from New Cars: Assessing the Near-term Technology Potential in the EU." (n.d.): n. pag. www.theicct.org. The International Council on Clean Transportation | ICCT, Jan. 2013.

[14] Verbrugge, Mark. "On the Costs and Benefits of Materials Choices for Automotive Applications." *General Motors Research & Development, Warren, USA* 2013.

One of the greatest attractions for lightweighting of automobiles is the mass decompounding effects or secondary weight savings. This effect compounds opportunities for mass reduction, where mass reduction in one area leads to further weight reduction possibilities in other areas.

This research investigates the differences in manufacturing between steel and aluminum closures. Different joining methods are required: spot welded steel joints are commonly be replaced by clinching, rivets, adhesives, screws, laser welding, and spot welding for aluminum. Other changes in automation are needed (e.g., use of suction cups in lieu of magnets to transfer aluminum). Both steel and aluminum use roll hemming or press hemming in the marriage of the inner and outer panels.

Aluminum is more resistant to corrosion. It is a more chemically reactive metal than iron. While malleability is very important for manufacturing, aluminum's greatest attribute is that it is corrosion resistant without further treatment. This is primarily because aluminum spontaneously forms a thin but effective oxide layer that prevents further oxidation.

Too often the costs associated with mass reduction are oversimplified. A detailed assessment of lightweighting solutions must compare direct manufacturing costs and mass changes for the total system, not just the components replaced by lower density materials. Lightweight engineered solutions require a systems approach in place of a simple material substitution approach before accurate cost estimates of mass reduction can be made. Cost neutral solutions are attempted on a component basis, but often are not achieved. Under these circumstances, a system wide approach toward mass decompounding may be appropriate.

One area of growth in lightweight solutions is the use of integrated parts, where a number of components are combined into one part. Integrated parts help to reduce weight and assembly cost by combining functionality and structural requirements to reduce the number of components that are produced. This method can often reduce cost and mass simultaneously.

Lightweight material applications are growing. Previously, lightweight materials were only used in high-end vehicle programs, but now these materials are being implemented in mass-produced, mainstream vehicles. High-end vehicle programs often have the profit margins necessary to afford exotic lightweight materials along with their material-specific manufacturing process. Increasing requirements for cleaner, more efficient vehicle fleet averages has opened the door to solutions once considered too risky to attempt on smaller-margin, mainstream production vehicles. Higher volumes can help offset higher tooling and equipment investment required for new materials and manufacturing methods.

Most doors, regardless of the material composition, still utilize steel intrusion beams to enhance occupant safety and meet engineering requirements. Steel intrusion beams do not typically reduce mass but offer the strength necessary for a cost neutral solution.

Often lightweighting considerations for thinner gauges or less dense panels can require more noise vibration harshness (NVH) measures due to amplifications of vibrations. This can have a negative effect on mass and affect the cost by adding measures to reduce NVH. Lightweighting strategies can lead to

NVH issues that are potentially difficult to eliminate because they arise from interactions of complex systems.

There is a lower cost of investment for carbon fiber compared to aluminum or steel sheet manufacturing as it pertains to forming the parts. This is because steel and aluminum sheets require multiple die sets and blanking equipment (e.g., a draw die, trim die, pierce die, flange die, and a restrike die). Carbon fiber forming requires fewer tools, with a material cutting station, a preform die, a resin transfer molding die, and a trim operation typically using water jet or laser cutting. The reduction in required equipment, especially in required die sets, can significantly reduce upfront investment costs.

Manufacturing Issues

New materials create new manufacturing issues. Many of these issues are discussed below in detail.

Material availability may be a concern when an exotic or newer material is specified. The existing supply chains are built around standard materials, and changing higher volume vehicles to new materials can strain the supply chain. Even common materials, such as aluminum, can have supply chain issues when specified for the first time on high volume vehicles, such as the Ford F-150 pick-up.

New materials drive the requirement for new part design modeling. Every OEM designs cars and trucks using internal design standards and best practices. Changing to new materials redefines these standards for modeling designs standards for new models.

New tooling is often required when deploying new materials into a plant. It is typical for a new vehicle to require a standard set of new tooling, but new material can increase this significantly. For example, any shape change requires new end-of-arm tooling for robotic handling, but changing from steel to aluminum not only brings a new shape, but also new mechanical properties. Automakers typically use magnetic properties to assist in handling steel panels, while changing to aluminum eliminates that opportunity and requires additional new tooling (e.g., vacuum cups for handling).

New equipment is often driven by the introduction of new materials. As described in the above handling example, press lines typically are set up to destack steel blanks loaded on pallets. When a company switches to aluminum, those destackers have to be replaced by systems using air knives to separate and load individual blanks. Significant rework to the front of the press line along with new equipment is required to make such a transition.

Forming technologies are different for almost every new material used in the automotive industry. Finite element analysis (FEA) is used to help detect differences and to accommodate the variety of materials any single press system might encounter. Aluminum and steel typically require different lubrication for the material. Boron steel forming requires the application of heat with dedicated ovens and cooling systems built into forming tools. Magnesium requires special handling and care to avoid chipping, along with the special care taken to avoid sanding and grinding which produce potentially flammable dust.

Transfer equipment is different both in the press room, as mentioned, as well as in the body shop. SMC outer panels are soft, so they require extra support while handling, along with special racks for going into the paint shop.

Joining methods are different for every material. An existing body shop is typically established to handle mild steel assemblies. Moving to advanced high strength steel requires a change in resistance, requiring altered controllers on the equipment. Mixed material vehicles can require mechanical fasteners, adhesives and welding, all in the same assembly. Mixing materials also requires isolation of the various materials to avoid creating an anode condition which could result in corrosion.

The orientation of the assemblies throughout the process might have to be altered to accommodate new materials, due to the need to add rivets or adhesives in place of or in addition to, the resistance spot welding typically seen in body shop applications. Although this may seem like a small problem, it becomes significant when the body shop is assigned multiple vehicles, and the mix of materials is different among the vehicles. Requiring different orientations may drive additional tooling and ergonomic challenges.

Production rates are paramount in importance to an efficient assembly or fabrication operation. Introducing new materials can disrupt standard production rates while the plant operations are adjusted. These disruptions can drive overtime costs, or even increase incidents of rework, either of which would result in falling production rates.

Large production volumes can also cause issues for any material, especially if unexpected. Every issue raised by a new material introduction is compounded by high volume requirements, further straining the learning curve.

Mitigating Additional Costs

Including new materials can challenge manufacturers in a multitude of ways. Care must be taken to address these early in the planning stage in order to have a solid plan in place to mitigate the issues. There are a variety of ways to mitigate the additional cost impact of lightweight closures. A few examples of these methods are described below.

Product engineers may attempt to consolidate parts as much as possible when switching to polymer and plastic panels. These materials bring opportunities for consolidations that are not attainable with metallic parts due to limitation in metal forming.

Manufacturing engineers implement new manufacturing processes to reduce cycle times to help mitigate the expense of new materials. These processes can include new handling techniques, new paint shop facilities, or new body shop equipment. New welding controls allowing variation in the weld cycles can help shorten the time required for assembling components from aluminum or higher strength steels.

Mass decompounding is a popular method to offset additional costs brought on by implementing newer, lightweight materials. For example, if the body of a vehicle is lightened significantly with lighter material, the vehicle does not require the same size of engine to perform at the same level. Reducing the size of the engine also brings weight reduction. This may allow the vehicle to use smaller brakes to attain the same level of performance. All this is considered to be decompounding, as lower weight enables another area to reduce weight further.

Learning curves exist in any new manufacturing process. Over time plant operations adapt to using new material and new techniques for processing and handling of these materials. This enables the operation to increase process speed, resulting in lower overall cost.

High volume production can bring the opportunity for faster amortization of new equipment, reducing the cost of production processing while enabling the change to new, lower weight materials. Higher volume demands drive more rigorous processing, which can create additional opportunities to improve overall process times.

Better tooling is one way for a plant to enable the transition to new materials. Although overkill is possible in planning new tooling, leading to waste of investment, there are times when additional investment in tooling enables the plant to overcome challenges more quickly. As a plant accelerates to full volume, any opportunity to shorten the time to attain full production rate has to be analyzed. New or upgraded tooling may be the enabler to quickly ramp up to full volume.

Just as there are premium grades of material available in steel, similar advantages are available for lightweight materials. It may be an advantage for a stamping plant to start with a premium grade of aluminum, for example, during the transition from steel to aluminum. As the process develops standard grades can be introduced on a gradual basis, easing change-over issues.

Another option for remediating the cost impact of lightweight closures is to apply appropriate joining technologies. If an OEM is moving from a long history of mild steel production to a lightweight aluminum structure, it might first use a process where mechanical fasteners are used in concert with adhesives or new welding techniques. While this may seem excessive, it allows the plant to quickly transition to the new materials and processes while absorbing a lower level of risk. These often redundant methods can be pared back on subsequent launches as the entire organization becomes more capable with the new materials and processes.

Steel

Steel industry and component suppliers are investing heavily in innovation. The results of the investment are numerous examples of successful, cost-effective use of steels, new formulations of high-strength steels, advanced high strength steels, and an associated variety of new design, fabrication, and assembly techniques. Applications include vehicle bodies, chassis, closures, and many other parts.

Steel is the base material used in the automotive industry and has maintained its popularity since the start of mass production by Henry Ford. Steel leverages an existing automotive manufacturing infrastructure which has produced quality parts at scale for more than 100 years.

It is possible to reduce vehicle weight with steel, by substituting a higher strength material grade while reducing the gauge thickness.

Shared Manufacturing Processes

Aluminum and steel have similar part manufacturing processes. Blanking, stamping, assembly, and hemming are used on panels of both materials. There is no physical process change required for blanking or stamping steel or aluminum panels, they can use same equipment. There may be a different press program which slightly affects cycle time. There were two noticeable process differences in using aluminum instead of steel panels: different transferring methods (aluminum requires suction cups instead of magnets) and alternative joining techniques (aluminum uses clinches in place of spot welds).

Aluminum

At the outset of our research we found several companies implementing aluminum components to replace what would have been manufactured from steel. Our research validates increasing use of aluminum is a logical next step in the progression from mild steel to future materials. In many cases automotive closures can be changed to aluminum from steel with the least disruptions to existing facilities and equipment.

Carbon Composites

The research validates composites and carbon fiber as the overall lowest weight material, but it remains very costly compared to steel. The cost for the basic material is coming down, but it is still several times the cost of a similar aluminum part and is even more compared to steel. As the need for weight reduction increases, many manufacturers are exploring carbon composites as a future solution to meet CAFE requirements. This potential future demand requires more study and testing to reduce cycle times and decrease the production cost of carbon fiber.

Recycling

Aluminum is initially more difficult and expensive to make, but is readily recycled by melting and re-use if the scrap is separated when collected. This reduces the need to smelt original aluminum from ore, where the higher material cost originates.

Scrap steel is far less valuable, worth approximately 10 percent of separated aluminum. Ford is using an aluminum recycling system installed as part of a $359 million overhaul of the Dearborn factory, allowing the company to recover up to 30 percent of the material as offal, which in turn offsets about 20 percent of its higher production costs.

CHALLENGES

The research and site visits used to validate the cost model challenged many existing theories and perceptions. This section discusses those items that were challenged by the research findings. These (few) cases refute a stated hypothesis, or add clarification, for the following reasons.

Mass Reduction Costs

Mass reduction is not free in most cases. Investigations show that there is incremental cost with nearly every pound saved. It may be easier to reduce the first few pounds of weight from a vehicle, but as weight reduction efforts increase, the cost to manufacture the lighter weight solutions increases. This is due to changes in DMC or material, forming, assembling and labor cost increases; as well as new investment that must be made to be able to manufacture lightweight components out of new materials.

Cost Neutral Aluminum

It is commonly stated a block of aluminum weighs one third as much as a block of steel the same size. If aluminum costs three times as much as steel the $/lb cost of mass reduction would be neutral. However, this research shows that changing to aluminum increases the purchase price or cost. For every application studied, the thickness of the aluminum sheet increased over the original steel thickness to be able to achieve the same rigidity and strength. This analysis demonstrates that switching to aluminum comes with a cost penalty and is not cost neutral.

3rd Generation Steels

Generation 3 steel (Gen3) is being developed with advanced high strength, which will allow further reduction in gauge thickness and mass. It is not currently in production vehicles.

Spot Weld Aluminum

Many case studies do not discuss resistance spot welded aluminum. GM is using this technology to eliminate the use of rivets, which can help to reduce the weight in doors, hoods, and tailgates. Using this new type of spot welding allows GM to lightly modify existing production lines with the same robots and welding guns used for steel. However, resistance spot welded aluminum requires higher thermal and electrical conductivity compared to joining steel. This means up to three times higher welding currents are needed because the oxide on the surface of the aluminum makes it difficult to create a strong, durable weld. This requires larger, more powerful, and more expensive welding transformers and works only with thinner sheets of aluminum.

There is a chance to modify existing welding equipment in body shops to handle aluminum in place of steel when powerful transformers are already present. In cases where they are not in use for steel applications, the changeover is costly.

Aluminum Forming

Initial research led us to investigate the stamping of aluminum in place of steel. According to literature, it is more expensive to stamp panels from aluminum, and the press line would run slower. However, tier 1 suppliers are producing major aluminum components using the same capital equipment (presses) running at the same production rates of approximately 18 strokes per minute, whether the panels are aluminum or steel. Maintenance, or cleaning of the dies, is required more often with aluminum, but the production rates attained were just as fast.

Aluminum Supplier Availability

A long lead-time is required before aluminum capacity will be able to meet the growing demand in the automotive industry; up to three years may be necessary to add the capacity needed for another high volume application, such as the Ford F-150. Nonetheless, aluminum companies are making expensive bets on this future—building plants and reconfiguring factories—to meet anticipated demand. So far, these investments are paying off because the F-150 selling as fast as it can be built. Nonetheless, the long lead-time for transition is a real issue, one that requires long range planning for the automotive companies.

RECOMMENDATIONS

Lightweight Closures

Lightweight closures are an important area of opportunity for incremental lightweighting. The unique opportunity in closures for mass reduction is that baseline closures can be redesigned to be lightweight, and integrated into existing assembly lines. This is less disruptive to overall manufacturing operations and does not require a complete revamping of the plant. It is easier to reduce mass from closures than to redesign an entire vehicle. Making a change to a closure has less impact on the load path, stiffness, or other structural measures for an auto body. Closures have unique engineering requirements for strength, safety, and crash impact.

Cycle Time Reduction

One of the inhibiting factors of using composites is that their cycle time is greater than that of sheet metals. Each material has unique properties that affect cycle times. Composites often have increased cycle time due to the time required to cure the material or resins until they have solidified. The increased time to form the parts causes the cost per part based on overhead rate to increase. Because of the longer cycle times, total production line volume capability may be limited when using composites. As a result, cycle time is often a key factor limiting composite to low volume production. We recommend that additional research be conducted to improve cycle times for composites so that production volume capability can be increased. This could be done by means of prepreg (material pre impregnated with a resin), fast cure adhesives, improved die heating, or other technologies in development.

Part Integration

Closures are complex assemblies made from multiple components. Part integration creates an opportunity to integrate multiple components, reducing the number of manufacturing operations, such as stamping and assembly stations. Fewer operations may allow manufacturers to use fewer stations, less transfer equipment, and fewer tooling dies. Part integration is part of a method to reduce investment cost to offset increased material cost.

Advanced Tooling

Advanced tooling operations can reduce die count because of multi-process dies. Computer aided engineering can help develop more effective tooling with fewer operations. Advanced tooling could combine multiple processes in one stroke, such as combining trim and pierce functions. Combining processes in die operations can lower investment costs, by reducing die count, and overhead cost for press lines.

Mixed Materials

Weight reduction has become a key issue in the automotive industry in recent years, this trend will continue as manufacturers look to justify every gram of weight in their vehicles to increase efficiency and reduce CO_2 emissions. There is need for more mixed material solutions, as each material has its own unique properties. This enables optimization of performance (e.g., weight and strength), compared to any single material. This optimization requires manufacturers to support the cost-effective and efficient use for lightweight materials in automotive applications.

Glass Weight Reduction

Automotive manufacturers are looking for every possible way to construct lighter vehicles with higher fuel efficiency. Reducing the weight of glass could help reduce the vehicle's weight and lower its center of mass helping improve fuel economy by a few percent. The exact improvement in fuel economy would depend on reducing the glazed area of the body, reducing the thickness of the glass, or finding a suitable lighter substitute.

CONCLUSION

This research investigated vehicle doors utilizing conventional and lightweight materials. This research uncovered many opportunities to reduce vehicle weight, and confirmed the mixed material vehicle is the most likely solution for the future.

Different aspects of manufacturing lightweight doors have been investigated: material cost, manufacturing processes, overhead rates, labor cost, production volume, and investment cost, to determine the working relationships between these variables to create a recipe for cost effective mass reduction. A cost model was designed to determine changes in the direct manufacturing cost of automotive closures. DMC calculations include cost of labor, material and overhead rates for manufacturing. Investment costs are often amortized over the life of production and recovered through piece pricing, so are not included in modeling DMC.

Case studies were conducted to validate the cost model; each case encompassed a different use of materials, processes, and manufacturing volumes. This broad mix of variables input into the cost model helped to create a better understanding of the relationships between materials and manufacturing processes to find ways to reduce the cost of lightweighting automobiles. Material substitution is one way for manufacturers to reduce weight. However, new lightweight material typically has a cost premium increase from the conventional material. Combining parts through integrations reduces the number of components. Combined manufacturing processes could lead to a reduced number of stations, reduced transfer equipment and a reduced number of required tooling dies. These were some of the most effective methods to offset increased material cost. Their use could lead to a reduction in both DMC and investment cost.

Closures have common design elements even when manufactured from different materials. Doors have four main components that comprise the majority of the weight: an inner panel, outer panel, hinge & latch reinforcement and crash beam/beltline reinforcement.

When compared to sheet metals, composite materials often require less equipment and tooling dies to form the parts. Composites can also require less equipment and processing stations to assemble the parts. This reduction of required equipment means that there can be a reduced investment cost, and because of these changes to equipment, the overhead rates affecting DMC may also change. Composite materials can offer a more economical method for a manufacturing solution toward lightweighting, until cycle times for the comparative operations are considered. Composite manufacturing forming cycle times take longer and are usually more than one minute per cycle, compared to sheet metals which can be formed at nearly 16 parts per minute. This increase in time also increases the overhead rate cost per unit produced and also limits the total production capability. This may be why mass reduction utilizing composites in vehicle doors such as the BMW i3 and Chevrolet Corvette work well, because they are limited to low volume production. Applications that require high volume production typically utilize the stamping processes for sheet metal materials due to the ability to produce nearly 16 times faster.

REFERENCES

1. Steel purchase pricing derived from www.metalprices.com & AK STEEL price book. 2015.
2. Aluminum 6000 series pricing derived from London metals exchange & Alibaba. 2015.
3. Steel scrap prices obtained from www.metalprices.com September 30, 2015. Web
4. Aluminum scrap pricing: http://www.metalprices.com/metal/aluminum/aluminum-alloy-6061-scrap. September 30, 2015. Web
5. Turkus, Brandon. "2015 Ford F-150 Shaves 700 Pounds, Adds 2.7-liter EcoBoost [w/video]." Autoblog. 13 Jan. 2014. Web.
6. Williams, Mark. "Ford on Track to Sell 700,000 F-150s - PickupTrucks.com News." Ford on Track to Sell 700,000 F-150s - PickupTrucks.com News. www.pickuptrucks.com, 25 Feb. 2015. Web.
7. Blanco, Sebastian. "BMW I3, I8 Sales Strong Enough to Reach Almost 17,800 in 2014." Autoblog. 16 Jan. 2015. Web.
8. Sloan, Jeff. "BMW Leipzig: The Epicenter of I3 Production : CompositesWorld." BMW Leipzig: The Epicenter of I3 Production : CompositesWorld. 31 May 2014. Web.
9. "Fiberglass to Carbon Fiber: Corvette's Lightweight Legacy." Media.gm.com. www.chevrolet.com., 16 Aug. 2012. Web.
10. Lamarche, Jeff. "Corvette's New Plant Manager." http://www.superchevy.com, 16 Oct. 2014.
11. Luft, Alex. "Deep Dive: The Light, Yet Stiff Frame Of The 2014 Chevy Corvette Stingray." GM Authority. 26 Jan. 2013. Web.
12. E.P.A., U.S. "Light Duty Truck Mass Reduction Study Results." EPA.GOV., 31 July 2014. Web.
13. Mock, Peter. "Reducing CO2 and Fuel Consumption from New Cars: Assessing the Near-term Technology Potential in the EU." www.theicct.org. The International Council on Clean Transportation | ICCT, Jan. 2013.
14. Verbrugge, Mark. "On the Costs and Benefits of Materials Choices for Automotive Applications." General Motors Research & Development, Warren, USA 2013.