A Look at 2017 SAFETY COMPONENTS

and OPTIONS for Future Lightweighting

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Trade Study Results Highlight Opportunities to Innovate

Faced with pressing Corporate Average Fuel Economy (CAFE) 2025 targets, automobile manufacturers are using a number of methods to improve fuel economy. Engine downsizing, turbo systems, electrification, aerodynamics and lightweighting are among the most effective methods. In 2017, there was considerable focus on electrification—will it gain market acceptance, and if so, how will it affect material selection? Logically, range-limited vehicles will benefit most from lightweight materials. Yet because they are adding expensive batteries and related operating systems, costs must be carefully managed.

On the materials front, automotive magazines often include color-coded images representing different materials that make up the "multi-material vehicle." Quite frequently, this is a vehicle body structure, commonly referred to as the Body-in-White. Yet it often includes the closures—doors, hood and trunk. The body and closures cover a significant portion of the total weight of a light-duty vehicle, on the order of 30 percent.

But what about underneath the body, the safety critical components in the wheel-end and suspensions? What materials and processes are used there? Mayflower Consulting wanted to find out, so we crawled underneath almost 90 vehicles to see for ourselves and produced a trade study[1] about what we found.

Wheel-end and suspension components comprise roughly 20 percent of vehicle weight. Yet these components and systems get little attention in the automotive press and across consortiums promoting their respective materials and process innovations. Before embarking on this study, I had the impression that most suspension arms were solid—cast or forged, aluminum or iron. Boy, was I wrong. Keep reading, and you too will find out if your expectation is met or if the data tells a new story for you.

Our study examined 89 vehicles over 16 brands and is organized by market segments that include five performance cars, 24 cars, 38 crossovers/SUVs, 15 pickups, four minivans and three work vans. Let's take a deep dive into the car data from the vehicles that were found on dealership lots in the summer of 2017. In particular, safety-critical components in the wheel-end and suspension systems we looked at were wheels, brake discs, brake caliper, steering knuckle and suspension arms. (See Figure 1.)

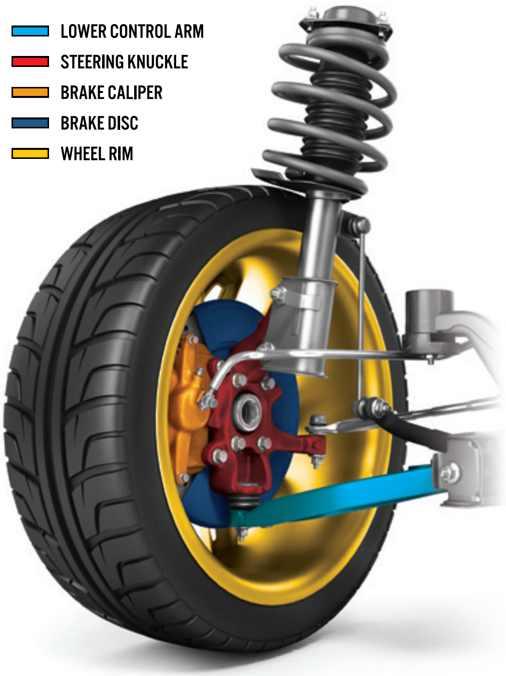


FIGURE [1] / Safety components of a wheel-end suspension system, including wheels, brake discs, brake caliper, steering knuckle and suspension arms.

WHEELS

The wheel, including the rubber tire, is the most important safety mechanism on a car. Once contact with the road surface is lost, the vehicle goes out of control. From a mass perspective, the wheel falls into the category of unsprung mass, meaning it is not supported by the suspension and includes the wheel-end components. Unsprung mass is more valuable than sprung mass, especially for finely tuned vehicles. The value varies by opinion and OEM calculations. Yet 1 kg of weight reduction in unsprung mass (i.e., a wheel) is approximately equivalent to 2 kg of sprung mass (i.e., the instrument panel). A performance car places more

Wheel-end and suspension components comprise roughly 20 percent of total vehicle weight, yet they get little attention in the automotive press and across the material consortiums promoting their respective materials and process innovations.

FIGURE [2] / Various cast aluminum wheel designs.

value on these components than a family sedan, and our data supports this claim.

"The lighter they [wheels] are, the better your car will ride," said the aptly named Jeff Karr, a *Motor Trend Magazine* writer, in a recent article. "The car will accelerate and stop better, too, if those big flywheels at all four corners have less rotational inertia." Automotive/transportation writer Gary Medley concurs. "The simplest way to reduce unsprung weight and increase performance is by installing lighter wheels,"[2] he says.

Decades ago, the wheel market was dominated by steel—a formed and welded construction. Then came aluminum, primarily cast aluminum. When first introduced, cast aluminum was a "weight-add," meaning that it was heavier than the incumbent steel. As time went on, wall thickness was reduced and cast aluminum designs dropped in weight. Equally or more important, cast aluminum enables attractive designs, making them popular in OEM design studios. (Figure 2 shows five different aluminum wheel designs found on 2017 cars.)

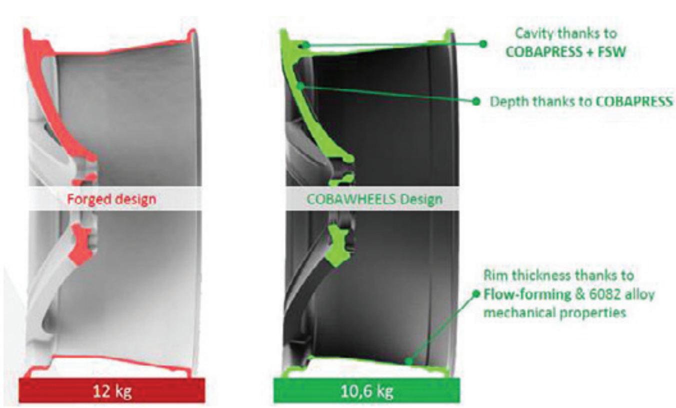
In all vehicles across all segments, the study shows that nine of 10 wheels are aluminum. Industry insiders say that the overall aluminum wheel content is around 75 percent, because most spare tires are steel. That is until OEMs replace the spare tire and lift jack with a can of "fix-a-flat," saving about 30 pounds and reducing vehicle cost.

The automotive-wheel business is hypercompetitive, with most wheels produced in aluminum on highly automated, low-pressure, permanent mold-casting equipment in low-cost labor countries like Mexico and China.

What, then, are the lightweight wheel options? In consideration of an aluminum wheel, the density of all aluminums is essentially the same. That means the opportunity to reduce weight comes with an increase in strength that corresponds to reducing wall thickness. The standard cast aluminum automotive wheel is produced of A356-T6 in a low-pressure permanent mold process. The yield strength is on the order of 35 ksi (240 Mpa), and elongation varies by location. Here are three options currently available to produce lower-weight aluminum wheels.

1. **COBAWHEEL™ from Saint Jean Industries.**[3] This is a unique design that integrates an aluminum casting and a rolled sheet of aluminum that is joined by friction stir welding. Saint Jean Industries claims a weight reduction of 3.5 kg (7.7 pounds) from a cast aluminum 19-inch design and in the graphic (See Figure 3), a 1.4-kg (3.1-pounds) reduction in a 9.5-by-20-inch size from an aluminum forging. The COBAWHEEL™ technology is real and in production on the new Dodge Charger.

FIGURE [3] / Forged aluminum compared to the COBAWHEEL™ design.



2. **Forged 6061-T6.** Yield strength of 276 MPa with 12-percent elongation enables thinner walls and high toughness everywhere in the geometry and designs that reduce weight by 10 to 15 percent, up to as much as 35 percent, according to COR Wheels.[4] This is common on medium and heavy trucks, yet not so much on light-duty vehicles.
3. **High-strength cast aluminum alloy.** Stronger alloys are in development. Yet as elements are added to improve strength and toughness, castability may be reduced. This makes it more of a challenge to produce a lightweight wheel with thinner walls and spokes. In addition, wheels play a significant role in the appearance of the vehicle. This, too, presents a challenge when selecting strengthening elements in the casting alloy and how the material is able to maintain a high-quality appearance without pitting or discoloration.

What about materials other than aluminum? Magnesium is the lightest metal, on the order of 75 percent lower density than steel and 33 percent lower density than aluminum. Forged magnesium wheels are available in high-performance markets such as motorcycle and automotive racing, in the automotive aftermarket and on limited production vehicles. SMW[5] lists the weight of cast versus forged, in both aluminum and magnesium.

	Magnesium	Aluminum
Forged Wheels	7.3 kg	11 kg
Cast Wheels	10 kg	15 kg

A forged magnesium wheel is 2.2 times lighter than the typical cast aluminum wheel on the market today. This begs the question, are there production cars using forged magnesium wheels?

As a matter of fact, yes. BBS began in Germany in 1970 and supplies forged magnesium wheels for the Porsche 918 and GT3/RS/911R, available as dealer/package options. Their North American entity, BBS of America,[6] put the retail cost on a set of wheels for a Porsche GT3 at $17,000. These are almost nine pounds lighter per wheel than forged aluminum.

Forged aluminum wheels cost less, retailing for $9,000. BBS does produce low-pressure cast aluminum wheels that are then flow formed, and a set of those for a car retails at $3,230. The path to mainstream automotive for forged magnesium wheels does not look viable, however, partially due to lack of demand. According to BBS of America, most luxury and sports cars still sit on cast aluminum wheels, even opting away from lighter forged aluminum wheels because the price is too high.

FIGURE [4] / Carbon Fiber Composite Wheel from Carbon Revolution.[7]

Other hurdles for magnesium wheels include corrosion resistance and developing mechanical properties to withstand curb strikes across hot and cold temperatures.

Another high-performance wheel option is made of carbon fiber composite. The weight is close to forged magnesium, and it has not been used for as many years. One manufacturer, Carbon Revolution, produces such wheels in Australia, and they are available for premium road cars like the Z06 Corvette and the McLaren 650S. (See Figure 4.)

Carbon Revolution carbon fiber wheels are in production for the new Ford GT. They are also on the Ford Mustang GT350R, although they are painted black, so it is not obvious that they are carbon fiber composite. The typical weight savings of carbon fiber composite from cast aluminum is on the order of 40 percent. The retail cost for a set of rims is about $12,000.[8]

Lightweight wheels improve vehicle dynamics and handling, and steering and braking. For electric cars, the reduced weight wheel translates to reduced battery consumption and increased range.

BRAKE DISCS

Nearly all brake discs on mainstream cars and trucks are made of cast iron. The automotive market has introduced new technologies in recent years—carbon disc, two-piece discs, coated discs, to name a few. None were used on the study cars we examined. All 24 had iron discs (aka rotors) in the front axle where 60 to 70 percent of the brake energy is applied.

FIGURE [5] / Light-duty automotive brake disc options.

Figure 5 shows the four primary brake disc options, all of which are or have been used on American streets.

Not all vehicles have disc brakes, yet in our study on cars and performance cars, in 29 vehicles, 55 of 58 axles had disc brakes front and rear. Three low-cost cars had drums on the rear. It takes considerable engineering to produce high-quality brakes that will perform well on the street and provide customers with a long-lasting, quiet, and reliable brake system. Here is a summary of the four brake-disc options in the graphic above.

1. **Gray cast iron.** The standard brake is low cost and heavy, yet it works pretty well. There are ample friction material choices, and it has trillions of miles of proof that it works for a wide range of vehicles.
2. **Two-piece or bi-metal.** The disc shown is from an Audi R8, and it incorporates the cast-iron wear surface with a center region, called the hat, made from aluminum. The weight savings is on the order of 20 percent from the baseline gray iron disc. The price is higher because it incorporates additional processing of the aluminum section, as well as the joint between the aluminum and iron. On performance cars, the aluminum hat is attached to the iron ring via bolts or a continuous spring. The ability to use standard friction materials is a significant advantage in this lightweighting brake product. A variation of this two-piece is a stainless-steel hat with an iron disc, yet with a weight reduction of just 10 to 15 percent from a one-piece iron casting.
3. **Aluminum metal matrix composite (MMC).** MMC is a composite, and in the case of the brake disc shown, the matrix is an aluminum casting alloy and the reinforcement a silicon carbide particle. The silicon carbide provides the necessary wear resistance, along with stiffness and temperature stability. The majority of the total material is aluminum, which is low density, and it conducts heat away efficiently. The disc shown is a homogeneous mixture of Al-SiC and is a one-piece casting produced in a semi-permanent mold process. Al-MMC discs are also made by squeeze casting with a ceramic sponge called a preform, and there are pros and cons to the preform method. The weight savings of AL MMC is on the order of 40 to 50 percent for a comparable performance disc. The challenge to commercialize an AL-MMC brake disc is threefold: cost, temperature and friction.

   Brakes work as a friction couple between the pad and disc. A drawback to AL MMC is that it requires a unique friction material, which costs more because of a different makeup and a limited supply chain. And as important, it is imperative that customers select the MMC-grade brake pad and not one that was developed for gray iron brakes. The disc shown was in production on the rear axle of the Plymouth Prowler and produced by Eck Industries Inc.
4. **Carbon ceramic.** Carbon ceramic brakes likely began on airplanes and then were carried over to the automobile racetrack. These brake discs contain no metal. Instead they are made with carbon fiber reinforced with silicon carbide and silicon. This material composition is very stable at high temperatures, which correlates to strength, stiffness and wear resistance at temperatures where metal-based brakes cannot perform at a comparable weight. The weight savings is on the order of 40 to 50 percent from gray iron. However, because the cost is very high (MSRP replacement on a C7 Corvette is $2,990 per disc), carbon brake discs are limited to high-performance cars.

FIGURE [6] / Examples of front and rear LCA's

Ford Fiesta, Stamped Steel, Front | Chevy Impala, Welded Steel, Front | Ford Focus, Forged Aluminum, Front

Chevy Impala, Extruded Aluminum, Rear | Dodge Dart, Cast Aluminum, Front | Ford Taurus, Forged Steel, Front

Like AL MMC, carbon ceramic brake discs require a specific friction material.

This list is not all-inclusive. Indeed, another technology in between the low- and high-cost options are coated brakes. Here, a substrate material has a coating applied that enhances the substrate, enables higher performance and reduces weight.

Mainstream vehicles today use primarily gray iron brake discs, with a few cars having the two-piece disc and only premium cars using carbon ceramic. Three scenarios that could motivate OEMs to introduce reduced-weight brake discs such as the three options above are:

- More stringent CAFE fuel economy targets
- Growth in electric cars
- Growth in autonomy—sensors predict events, leading to a reduced need for panic stops and otherwise aggressive braking

Many who drive electric vehicles (EVs) speak to their style of "one-foot driving," meaning that they do not use the brake pedal. When the driver lets up on the accelerator, the regenerative brake system, essentially an electric motor running in reverse, provides braking energy. This braking energy is captured and used to replenish the battery. As this "regen" braking system becomes proven and reliable, will OEM brake engineers reduce requirements on the wheel-end brake system? Can the thick, vented gray iron disc be replaced by a thin, solid-steel disc or aluminum composite at about half the weight?

SUSPENSIONS

Look no further than the suspension, specifically lower control arms (LCA) on cars, for another multi-material story. Did you know that there are six different ways to produce a lower control arm on a small sedan? We found seven different ways to produce rear upper control arms.

Looking at a subset of six cars with curb weights ranging from 2,246 pounds to 3,969 pounds (1,018 to 1,800 kg), our study found forged steel, welded steel, stamped steel, forged aluminum, cast aluminum and a unique product on a rear LCA—extruded aluminum with a cover. One of the six cars is a plug-in hybrid electric vehicle (PHEV). It has steel suspension arms, a mix of aluminum and iron on the brake calipers and steering knuckles, and it has a cast aluminum subframe. (See Figure 6.)

Most of these cars fall beneath a gross vehicle weight of 4,700 pounds (2,132 kg), which is about the maximum weight for a front suspension using MacPherson strut (no upper control arm). Heavier vehicles with independent suspension use a double wishbone (upper and lower control arms).

FIGURE [7] / Suspension Material & Process Selection

	FRONT		REAR	
MATERIAL, PROCESS	LCA	UCA	LCA	UCA
Forged Aluminum	9	1	0	3
Cast Aluminum	2		7	2
Extruded Aluminum	0		2	2
Forged Steel	2		0	1
Stamped Steel	3	1	1	2
Welded Steel	8	2	13	6
Ductile Iron			0	3
N/A		20	1	5

On the upper control arms, we found seven different material and process combinations with the addition of ductile iron, which was not found on the lower control arms. Across 24 car models in the study, the upper and lower suspension data is as shown in Figure 7.

The unique extruded aluminum lower control arm on the rear of the Chevy Impala and Buick Regal is a product called ExtruForm from Raufoss Neumann, shown in Figure 8. This technology has been on the market for nearly 15 years, and according to Raufoss Neuman, it often delivers as much as 50-percent weight reduction at nearly the same cost of a "clamshell" welded steel arm. Despite the claim of significant weight reduction at nearly the same cost, why did the welded steel clamshell LCAs outnumber extruded aluminum 13 to two? There are multiple potential reasons.

- **Geometry—**the extruded design is limited in allowable geometry to a fairly linear profile
- **Spring support—**both extruded aluminum and clamshell steel rear LCAs need to support the spring, yet it is a little easier to package the steel arm
- **Carry-over parts—**OEMs often want to use components from prior models rather than invest in new tooling
- **Supply chain—**there is always resistance to introducing a new supplier and a new material for common components

WHAT DOES THE FUTURE HOLD?

Mainstream vehicles appear committed for now to cast aluminum wheels. Yet the introduction of the friction stir welded wheel is a sign of an open mind to new technology within the aluminum construction paradigm. The suspension arms represent a myriad materials and technologies spanning cost versus weight trade-offs. The referenced trade study also included brake calipers, which OEMs predominantly selected, cast iron over the lower weight aluminum. From a risk and complexity standpoint, it would be expected that OEMs would apply lightweighting in the calipers and other wheel-end components before brake discs. The steering knuckles were mixed between cast aluminum and cast ductile iron, with the benefit of aluminum offering 30-

FIGURE [8] /
Chevy Impala rear lower control arm from Raufoss Neuman.[9]

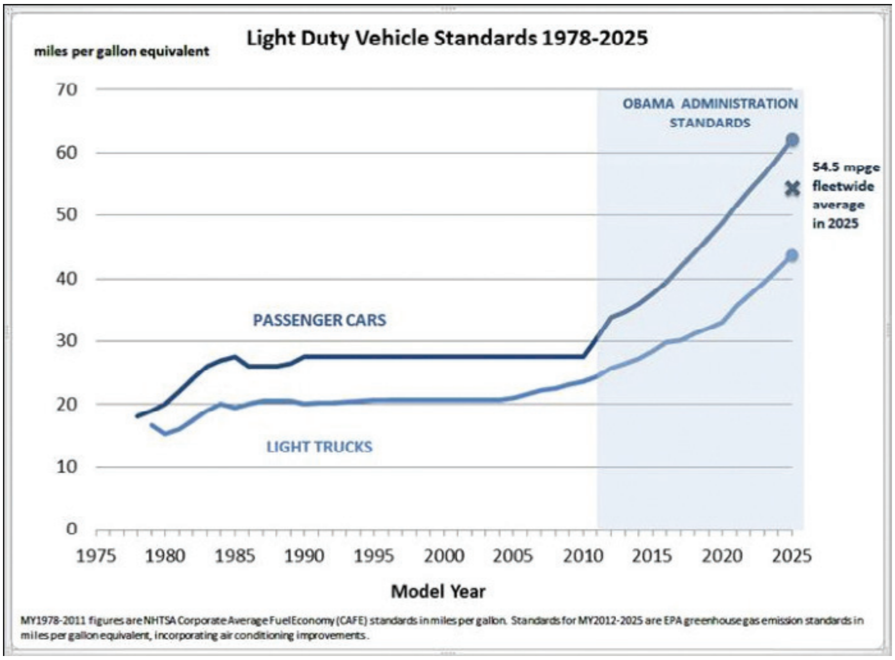


FIGURE [9] / Corporate Average Fuel Economy (CAFE) Targets[10]

Data shows that there is ample opportunity for lightweighting merely by selecting the reduced-weight alternative.

to 50-percent weight reduction for applications where it meets performance and crash-testing requirements.

It is now 2018, and the aggressive CAFE targets are on an upward climb to 2025 as shown in Figure 9. The unique extruded aluminum lower control arm on the rear of the Chevy Impala and Buick Regal is a product called Extru-Form from Raufoss Neumann, shown in Figure 8.

Approaching these stringent CAFE targets, what role will lightweighting play? There is considerable focus on body materials, yet these suspension, braking, and wheel-ends make up about 20 percent of a vehicle's weight and are commanding attention, as well. Especially the components that are multiples—four wheels per vehicle, four brake calipers and four brake discs. Pay attention to these components to maximize the impact, and reduce tooling and testing.

What is the material and process direction for each component? An analysis of the data in our trade study shows that there is ample opportunity for lightweighting merely by selecting the reduced weight alternative—no invention is required. The automotive aftermarket has the luxury of a customer base willing to pay higher premiums. Will the magnesium and carbon fiber wheel developers be able to reduce costs and earn a foothold in higher volume OEM markets? LW

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Andrew Halonen is President of Mayflower Consulting, LLC, a lightweighting consultancy that provides strategic marketing, market research and business development for high-tech clients in automotive, defense and commercial trucking. Mr. Halonen works with castings, composites, additive manufacturing and new material development programs. Mayflower Consulting LLC produced a self-funded trade study on the materials and design of suspension and wheel-end components on 89 vehicles spanning six market segments. More information is available at http://lightweighting.co/market-research.