Trends in Lightweighting With Metal Castings

Opportunities for lightweighting with metal castings abound through material choice and smart designs.

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Note: This article is based on a presentation the author was scheduled to make at the 2020 Metalcasting Congress in April, which was unfortunately cancelled due to the coronavirus.

Metal castings are found in almost all industrial markets, and certainly in the transportation business. Castings can be produced in many materials and processes, each offering its uniqueness in properties, in tolerances and in the ability to seek efficiencies. Efficiency becomes the ability to design and produce to an optimized shape, minimizing material and post-processing. New tools and new foundry techniques, combined with the long-honed skills of the metalcaster, are a winning combination for the future.

Lightweighting is a term that encompasses the task of reducing material to achieve weight reduction. There are motivations to cut weight, just as there is resistance to cut weight. Improving performance and assembly ergonomics, reducing part count, and reducing material costs are some of the motivations. Yet considering these factors, it does take considerable effort to reduce component weight.

Cost Is King

Low cost usually wins. In ground vehicle transportation, lightweighting activity is constant, yet it is usually delivered as cost neutral. If there is an appetite to cut weight, we often ask, "How much per pound will you pay?" which sounds like a straightforward question, yet it is often difficult to

4 KEY WAYS

LIGHTWEIGHTING WITH METAL CASTING IS MET WITH RESISTANCE

Cost is king.

System over component.

Changing the supply chain.

Other material innovations.

answer. The product developer may value weight on the wheel more than weight on the cab. I contend that if the target value is $1-2/lb., then the lightweight solution remains within the incumbent supply chain; iron to ductile iron or austempered ductile iron (ADI); or aluminum to stronger aluminum. Target values exceeding $3/lb. may allow iron to aluminum conversions. Seldom do I hear of a ground vehicle willing to pay more than $5/lb. for weight savings, though in specialized commercial trucking—those carrying cryogenic fluids—I was told they would pay $12/lb. for weight savings.

Recognize that the cost increase includes the cost at the foundry; at the machine shop if different than the incumbent, at the producer, at the assembler, and at the OEM to the customer. That does not leave much margin for the foundry to innovate, which is one reason why despite the wide range of high performance alloys, the transportation business often selects the vanilla-grade alloys.

System Over Component

In the electric vehicle (EV) market, for example, the new powertrain costs are immense, which doesn't leave much cash to buy lightweight materials. Even internal combustion engine vehicles are adding new levels of autonomy and data sharing, all adding to vehicle cost. Mayflower Consulting is studying suspension components now, and we will soon see what materials are selected for a few EVs, and dozens of SUVs and pickups.

Changing the Supply Chain

Imagine as a buyer, you have been working with a gray iron foundry for years, and now the engineers designed the next component iteration in ADI or aluminum. This forces you to seek out new suppliers, to learn their business, the differentiators between good and bad casting, and the robustness of the processes. Change is difficult for everyone, so

Fig. 1. The steering knuckle conversion from an aluminum forging to a ductile iron casting achieved a 40% cost savings and 30% reduction in weight, while improving strength and stiffness by 20% and 25%. (Photo courtesy of Waupaca Foundry)

the more change that is required, the more resistance to make the change, regardless of the upside efficiencies.

Other Material Innovations

As we look at the entire vehicle through the lens of the chief engineer, there are many lightweighting options. Should we optimize the steering knuckle, or should we address the windows? Converting the rear window from tempered glass to polycarbonate offers a 40% reduction in weight. This may be a much easier conversion than reengineering a safety critical component that offers similar weight reduction.

Success Stories

Despite the resistance, metalcasters are a hardy crowd and still find successes in lightweighting. Communicating success is much easier to me in pictures than words, as was intended at the Metalcasting Congress 2020. In preparation for the presentation, I reached out to my global network and received success stories from the U.S., Bulgaria, Sweden, France, and Canada. Metalcasting lightweighting examples were categorized as material conversions, sheet metal-to-castings, multi-metal, generative design, powertrain influence, and process optimization. Last, we found two new alloy developments that will enable lightweight castings.

The best applications in lightweighting cut costs while improving performance. Waupaca Foundry (Waupaca, Wisconsin) achieved success on an automotive steering knuckle, converting an aluminum forging to an optimized ductile iron design that is 20% stronger, 25% stiffer and 40% lower cost, while narrowing the weight delta to an acceptable 1.32-kg increase over the forging.

Again, cost is king in most applications, and this example shows that delivering a lower weight than the incumbent is not mandatory to win the sale.

Sheet Metal Conversions

You may hear this phrase in the automotive market, "If they can stamp it, they will." Metal stampings are popular in vehicle construction, yet the innovative foundries and engineers are finding ways to convert to castings. Here are four examples:

1. Meridian Lightweight Technologies (Strathroy, Ontario, Canada) converted an eight-piece steel stamped and welded assembly to a one-piece magnesium casting

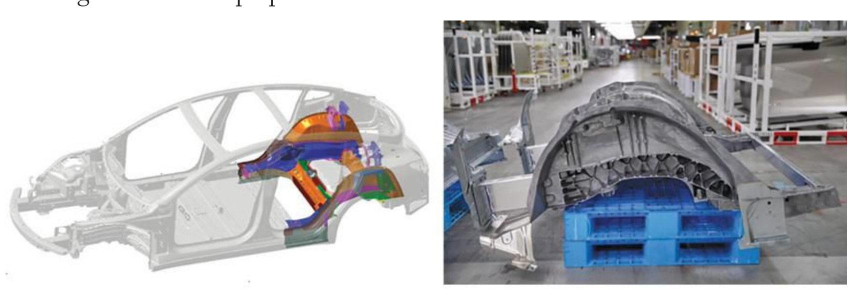

Fig. 2. Tesla is replacing 70-piece steel weldment in its Model 3 (left) with two large castings in the Model Y (right).

to cut the weight of the inner panel on the Jeep Wrangler rear swing gate by 6.7 kg.

2. Automotive shock towers are transitioning from steel stampings to high pressure die cast (HPDC) aluminum with a weight savings on the vehicle as high as 24 kg. This is not a new story, yet this application is evolving into non-heat treated aluminum alloys to avoid distortion in heat treat. I project shock towers will eventually be produced in aluminum via rheocasting, and further converted to a new alloy, magnesium via high pressure diecasting.
3. The Tesla Model Y has two extremely large castings in the rear compartment, replacing 70 steel stampings and made with an AlSiMg alloy in HPDC. For a view of this casting, refer to the "mega casting" in this benchmarking video by Munro & Associates, www.youtube.com/watch?v=KVGvwLnNyF0.
4. Skuld LLC (Tipp City, Ohio) shared a success story in an industrial plant where a 50-kg hot-rolled steel fabricated ramp was redesigned in 80-55-06 ductile iron, cast in lost foam with just 3.2mm walls, and reduced to 15.8 kg. The big winner was the shop floor personnel, as the lightweight ramp could be moved by just one person.

> **ter·mi·nol·o·gy**
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> **Rheocasting**
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> *Metalcasting process where liquid metal is agitated during initial stages of solidification to produce a semisolid structure that remains highly fluid after 60% solidification.*

Multi-Material Integration

"Put the best material in the best location," is the thought behind multi-material integration. Two interesting examples include the following.

Steel and aluminum automotive subframes, uniquely joined by friction stir welding, achieved 25% weight savings and are 25% more rigid in its third generation on the 2018 Honda Accord.

A bi-metal brake disc with a unique method of joining is 25% lighter than the baseline 350-mm outer-diameter, one-piece gray iron disc. The aluminum flows around the iron peg, joining the two pieces. Called COBADISK, the center of the brake disc is low-weight aluminum while the wear ring is gray iron.

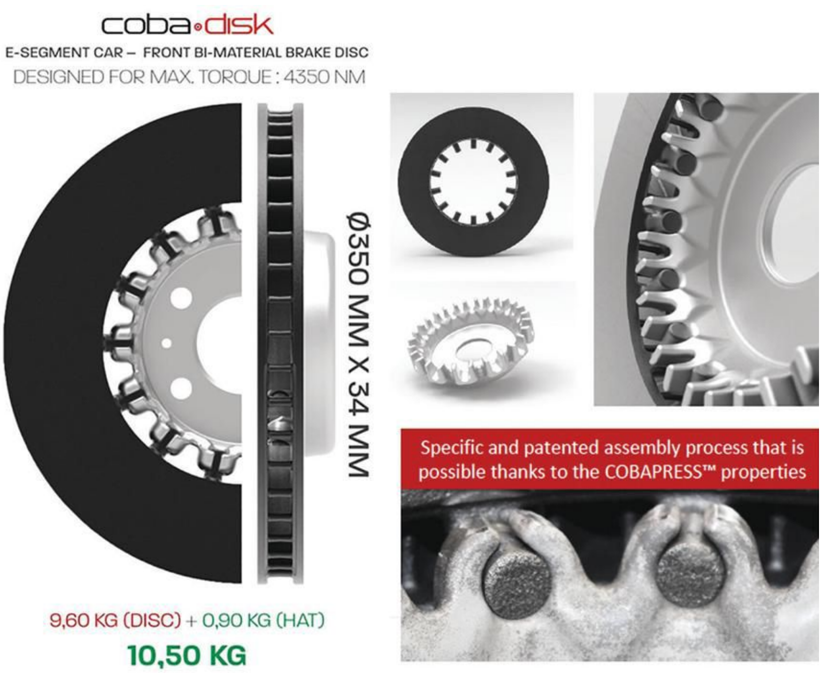

Fig. 3. This bi-metal brake disk is 25% lighter than the baseline iron disc. (Photo courtesy of Saint Jean Industries.)

Powertrain Effect on Metal Castings: Internal Combustion Engines

It was enlightening to learn a compact graphite iron (CGI) engine block could enable a lower weight engine than one using an aluminum block. Compare the stats and images in Figure 4. Both are 3.0 L engines, yet because CGI has a higher modulus of elasticity (stiffness) than aluminum, it enables a smaller engine block for the same output. Even though the CGI block is heavier than the aluminum block, the reduced size requires smaller components to produce the complete engine, thus the total package is both smaller and lighter. Engine compartments are always space limited, and most IC engine vehicles are overweight in the front. It sounds like a great application for CGI.

Powertrain: Electrification

In battery electric vehicles, there is considerable conversation and development activity in battery box housings and structures. Most of the battery boxes are made with aluminum sheet and extrusions.

It is interesting to see the growth in the "skateboard" chassis, such as the one in Figure 7 from Rivian (Plymouth, Michigan).

The skateboard chassis offers significant versatility in building vehicles; over the top of the chassis, one can build an SUV, a pickup, or a delivery truck. Rivian has taken considerable investment from Ford Motor Company and Amazon, and they received an order from Amazon to provide 100,000 delivery vans.

Cast steering knuckles may be used on Rivian's pickup and SUV, and on the Amazon van, and on the next vehicle that integrates the skateboard.

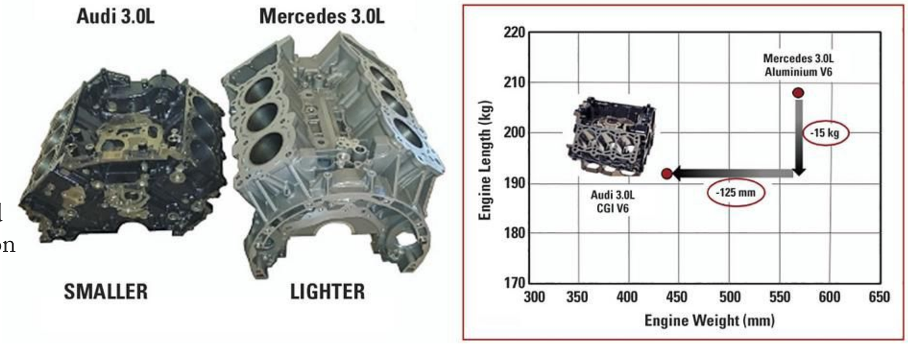

Fig. 4. An engine block cast in compacted graphite iron is heavier, but smaller than an aluminum block, and the surrounding components are both smaller and lighter. (Image couresty SinterCast.)

Fig. 5. The skateboard chassis for EVs can be used for various vehicles. (Image courtesy Rivian.)

Process Optimization Enables Lightweighting

Process optimization sometimes takes months or years. In the case of rheocasting, also known as semi-solid molding (SSM), CompTech spent ten years to optimize the process and the equipment. Now, the outlook is promising in the delivery of both thin-walled castings like heat sinks as thin as 0.4mm that are pressure-tight and weldable, and thick castings with up to 88-mm walls.

The structural HPDC applications on vehicles, such as those alluded to earlier on the Corvette, use a vacuum to ensure low porosity, high elongation, and high fatigue properties. I have recently learned that the use of vacuum is in development on counter pressure casting machines that use sand cores. The sand core gases escape through vents prior to aluminum fill. Early properties shared by Gordon Peters of Counter Pressure Casting (Lake Forest, California) (320 Mpa UTS, 240 MPa YS, 14% elongation) ought to enable lightweighting in steering knuckles and control arms, including hollow components.

Fig. 6. The casting method called rheocasting can produce thick and thin sections to aid with lightweighting.(Photo courtesy CompTech AB.)

New Alloys Enable Lightweight Castings

Many lightweighting materials target a higher density material and go to show how they enable weight reduction. In that light, magnesium manufacturers are targeting aluminum using AM60 for toughness and energy absorption and AZ91 for structures. Allite Inc. (Dayton, Ohio) is developing a diecast alloy designated as WE54, a rare earth HPDC alloy. With advertised properties of 298 Mpa UTS, 213 Mpa YS and 20% elongation, it would deliver lightweighting over the typical magnesium alloys and compete with aluminum HPDC. Of course, a full assessment requires evaluation of castability, availability of material to multiple foundries, tool life, material cost, and recyclability in the foundry.

In engines and turbos, a material innovation by Eck Industries Inc. (Manitowoc, Wisconsin) and the Critical Materials Institute (Ames, Iowa) is one that delivers superior mechanical properties at very high temperatures, on order of 315C (599F). The base is aluminum, and like the alloy system mentioned earlier, it also uses a rare earth element, in this case, cerium (Ce). The Al10Mg8Ce alloy is 86% stronger than 2618-T61 forged aluminum at 315C, and it maintains 75 Gpa modulus at 300C. With attractive tensile and fatigue data at high temperatures, engineers can design thinner walls with confidence, and this enables reduced weight components.

Innovation is ever-present in the metalcasting market as evidenced by optimization in ductile iron, aluminum and magnesium products, and processing technologies. Combining these advancements with generative design tools will further optimize cast products to reduce weight and cost. **CS**