Leading LIGHT

DEMAND-LED INNOVATION SHAPES LIGHTWEIGHT METAL TECHNOLOGY

BY DANIEL ALLEN

Porsche will take its first step into the electric vehicle market in 2019 with the release of its highly-anticipated Taycan, based on the carmaker's Mission E concept.

Market forces

Today an ever growing range of industries are looking for higher performance materials that can minimise their costs, energy consumption and overall environmental footprint. As a result, lightweight metals, such as aluminium, magnesium and titanium, are increasingly being considered as alternatives to steel. Thanks to new research into alloys and surface technologies, engineers and designers can now use these metals in ways that would previously have been impossible.

The metal castings market is projected to be worth nearly USD 40 billion by 2025. The recent trend of vehicle lightweighting and the rise of the electromobility sector means the focus of this market will shift increasingly toward lightweight castings.

"The lightweight metals market includes ferrous and non-ferrous materials and is continuing to increase in tonnage per year driven primarily by the automotive industry," says Gregory Peterson, Principal Materials Engineer at the Michigan Manufacturing Technology Center (MMTC). "Advanced high strength steels, aluminium and magnesium are replacing traditional lower strength steels, while non-automotive industries, including sustainable energy, agriculture and military, are also considering lighter weight materials."

Charging ahead

The electric vehicle (EV) market is currently booming. According to the recently released Global Electric Vehicle Market Outlook 2018 report from US-based business consulting firm Frost & Sullivan, global sales are poised to surge from 1.2 million in 2017 to 1.6 million in 2018, and further upward to an estimated 2 million in 2019. Business intelligence company CRU Group expects EVs to account for around 30% of the global vehicle fleet by 2030.

The burgeoning electromobility market will lead to a considerable increase in the use of light metal castings. The integration of lightweight components into automotive design can mean both longer ranges and more reasonably priced EV batteries.

The lightweighting trend associated with electromobility means lightweight cast components made from non-ferrous metal – aluminium and, to a lesser extent, magnesium – are becoming increasingly important as rivals to steel and aluminium sheet. Components for chassis and body parts, such as struts and longitudinal bars, are increasingly being made from diecast aluminium too.

With the automotive market moving toward more complex components with increased functionality, lower weight and lower cost, the lightweighting trend presents both a challenge and an opportunity for foundries across the globe. The growing demand for efficiency and sustainability means die casters are encountering new challenges, not least of which is to master the die casting process and ensure cast components meet the required level of quality. ►

FEATURE

StrikoWestofen's "BigStruc" melting furnace can handle everything from complete stacks of pig iron through to small, thin-walled return material.

Structural shift

In EVs the addition of fuel cells and additional drive elements such as electric motors can increase vehicle weight significantly. While this can be partially offset through the use of lighter construction materials for vehicle bodies, structural components made of die cast aluminum can also provide additional weight gains. Such components are now playing an ever-increasing key role in the electromobility sector.

The demands placed on lightweight structural components are high. They have to withstand highly dynamic stresses and meet the strict requirements of vehicle manufacturers in terms of crash safety and joining technology. They must be easy to weld, clinch and bond. And despite these requirements, production must also be cost efficient.

The summation of these demands means the entire die casting process chain must be carried out and monitored within narrow boundaries – from the selection and handling of the melt, through die design and casting technology, to the clear labelling of each individual casting. And this means new solutions are required across all phases of the part lifecycle, from component development right through to production.

Through thick and thin

Structural components unify the function of numerous metal component parts, thereby reducing the overall complexity of vehicle bodies. Conversely, as more and more components are integrated, single castings become larger and more complicated. In order to keep weight down, wall thicknesses have been reduced from the 2.5-3mm range to less than 2mm, and are only reinforced according to local requirements. In order to ensure the reliable production of such high specification components, the employment of dedicated machines and processes is critical.

The remelting of structural components also poses a challenge, with furnaces increasingly being required to handle a heterogeneous mix of large, flat cast parts and smaller, thin-walled material. This has led to the development of new, complicated furnace solutions which often push up investment costs. In addition to the use of natural gas, these often involve consumption of considerable amounts of electricity, such as for the electromagnetic agitation of holding baths and to operate the hot gas fans designed to melt the material inside them.

German company StrikoWestofen (part of the Norican Group), which develops and manufactures plants for the non-ferrous light metal foundry, has simplified the remelting process by developing several products designed specifically for the casting of structural parts. One of these is the so-called StrikoMelter "BigStruc", a melting furnace that can handle everything from complete stacks of pig iron right through to small, thin-walled return material.

Even if the return material to be remelted is very demanding, BigStruc guarantees minimum metal loss and relatively low energy consumption levels. After loading, the shaft of the furnace is closed with a cover called a "hot gas baffle". This keeps the heat in the shaft, preventing energy from escaping and keeping the melting process efficient, even when there is a high volume of void space.

While still at the foot of the shaft, cast parts are preheated without direct exposure to the flames and rapidly melted. The hot metal then flows directly from the melting bridge into a holding bath, where it is heated to the desired temperature. BigStruc's continuous melting process avoids temperature fluctuations in the holding bath and means liquid metal is available at all times.

"The special feature of BigStruc is its high energy efficiency, even at a low bulk density in the shaft," says StrikoWestofen engineer and product developer Rudolf Hillen. "In comparison to normal StrikoMelter systems, BigStruc can handle returns with a size of up to 2.5 square metres."

Best frame forward

In the automotive industry advanced high strength steels, aluminium and magnesium are now replacing traditional lower strength steels in vehicle structures such as the body, chassis, suspension and closures. Since 2009 the percentage of aluminium as a component of vehicle weight has surged by 17% to around 170 kilogrammes a vehicle, or nearly 10% of the total. Non-automotive industries, including sustainable energy, agriculture and military, are also considering lighter weight materials.

"The primary market driver here is efficiency," says the MMTC's Peterson. "This means improved fuel economy and lower emissions for automobiles and trucks, and improved payload capability and lower fuel costs for military vehicles."

Last year the MMTC and a range of other partners unveiled a lightweight, multi-material frame engineered to replace traditional steel frames for custom aftermarket vehicles such as replica cars, as well as low volume hybrid/electric vehicles, military trucks and potentially light duty pick-up trucks. ▶

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The new frame, which uses aluminium extrusions, aluminium and magnesium castings and ultra high-strength steel (UHSS) front and rear cradles, was engineered by an experienced automotive team using state-of-the-art automotive design tools. Compared to the baseline steel frame, it is 33% lighter, 4.5 times stiffer in bending, has a relatively soft crash pulse, and is cost competitive with custom aftermarket steel frames.

The frame development team used ablation casting (a variation of sand casting that uses a soluble binder) to derive properties similar to forged metal.

"The frame uses magnesium castings for high performance sports cars and aluminum for military truck applications," explains the MMTC's Peterson. "The castings are used as KPC (key process control) datums and eliminate the need for fixtures by using integrated reference points to set the wheelbase and overall length of the frame."

Move to magnesium

The search for strong, lightweight metals has seen intensified interest in magnesium and innovative magnesium alloys. Magnesium, designed and optimised in the correct manner, will provide enhanced strength, stiffness and stability and deliver a higher specific yield strength and specific modulus than nearly all other structural metals.

At 1.8g/cm³ magnesium is the lightest of all structural materials, the eighth most abundant element on Earth, and 100% recyclable. It can provide:

- The best strength-to-weight ratio of any commonly used structural metal
- Excellent dimensional stability as well as high impact and dent resistance
- Exceptional dampening capacity and low inertia making it ideally suited for parts that undergo frequent and sudden changes in motion direction
- The newer high purity alloys can deliver better corrosion resistance than carbon, steel and some aluminium alloys

Greater use of die cast magnesium parts is now playing a key role in realising fuel savings that were unheard of just a decade ago. While magnesium is expensive compared to aluminium and steel, it can have a "compounding" effect when it comes to vehicle lightweighting. A lighter tailgate, for example, can result in smaller brackets or even a smaller motor to open the door.


Photo: Meridian Lightweight Technologies

Magnesium cross car beams manufactured in Meridian Lightweight Technologies' China facility.

Remove enough weight from a vehicle and the entire engine can be downsized.

Magnesium is already widely used in alloys that decrease the weight of parts used in vehicles, airplanes, power generation equipment, industrial processes and buildings. The ease with which it can be moulded, with areas of varying thickness on the same part, increases the opportunity to cut waste and allows designers to do more shaping.

"Magnesium is incredibly useful because you can use it in a wide range of automotive parts and components to reduce weight, without compromising safety and performance," says Professor Stephen Brown, a UK-based engineering manager for Meridian Lightweight Technologies, one the world's leading supplier of innovative lightweight cast metal solutions for the transportation industry.

Antipodean advances

In Australia, Canberra-based CSIRO (the Commonwealth Scientific and Industrial Research Organisation) and the Brisbane-based CAST CRC (Cooperative Research Centre) have invested in the development of various light metal materials and processes over the last 25 years. These technologies are available for deployment, either directly from CSIRO, or from the private companies who possess the rights to the technologies.

Such technologies include a low-cost, creep-resistant magnesium alloy for higher temperature applications (suitable for the precision sand casting of powertrain components), a high-efficiency grain refiner for magnesium alloys (AMCAST), and the T-Mag process, a solution for lightweight, high-integrity heat treatable magnesium alloy castings. The latter technology has been commercialised through the formation of a spin-out company, in partnership with several investors from the Australian casting industry.

While magnesium is the lightest engineering metal, and casting is the lowest cost route to near net shape parts, standard permanent mould casting processes for magnesium alloys are difficult to carry out reliably and cost effectively. When molten, magnesium reacts on exposure and its quality can be impaired as a result.

By facilitating melting and casting operations in a single compact unit, the T-Mag process is an efficient and cost-effective way of making clean, low-oxide magnesium ▶


Photo: Meridian Lightweight Technologies

Die cast magnesium automotive front end structures such as these help manufacturers reduce vehicle weight.

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CSIRO's Voxeljet 3D sand printer offers the flexibility required to develop high value castings using additive manufacturing techniques that build complex structures, layer by layer.

A mould produced with the Voxeljet VX1000 for an engine block casting to repair a 1914 Delage car.

castings. The unit holds a furnace with an enclosed retort of molten magnesium alloy under a covered gas atmosphere, connected to a die via a steel transfer pipe.

With the machine resting in the horizontal position, the molten magnesium alloy in the transfer tube lies just below the die. When casting, the machine rotates about a horizontal axis at a controlled speed, allowing molten magnesium to fill the die from the bottom. Bottom filling ensures a smoother flow of material into the die and greater casting integrity than high-pressure methods.

At the programmed angle of rotation, the machine comes to rest with the head of molten magnesium above the casting. When solidification has progressed from the extremities of the casting to just beyond the gate, the machine rotates back to horizontal, causing the molten magnesium in the transfer tube to drop away from the small solidifying sprue. The machine rests in this position allowing the casting to develop sufficient rigidity to be ejected.

Global research

Across the Pacific from CSIRO, research work being carried out at the Detroit-based LIFT (Lightweight Innovations for Tomorrow) research institute is also bearing fruit.

"Today we are seeing increased use of both aluminium and magnesium castings," says the institute's chief technology officer Alan Taub. "LIFT has recently completed projects demonstrating the ability to cut casting weight by reducing wall thickness, while still producing the required microstructure and mechanical properties."

A key aspect of LIFT's technology development is the parallel execution of both modeling and experimental work. The institute's new ICME (Integrated Computational Materials Engineering) tools allow it to model processes and predict resulting microstructures to guide experimental work.

"Some of the benefits we are seeing include thin-wall ferrous castings which were developed using modeling and based on a new ADI (austempered ductile iron) alloy," says Taub. "We have also developed thin-wall aluminium castings using ultra high-vacuum die casting, and are exploring the use of 3D printed moulds and cores for castings."

Another LIFT project now underway is exploring the scaling up of a casting process involving sub-micron reinforcing particles, including aluminium nitride (AlN) and titanium carbide (TiC), to improve the high-temperature capabilities of aluminium castings.

Superalloy development

So-called "superalloys" are a group of nickel, iron–nickel and cobalt alloys that have been developed to withstand high temperatures without deforming or corroding. Many of these have been developed for use in applications such as gas turbine and jet engines, more specifically in areas where extreme heat is encountered (approximately 75% of superalloys are used in aerospace applications).

Reducing the density of superalloys is critically important for the aerospace and marine industries in order to improve fuel efficiency. The search for lightweight superalloys has so far been restricted by the existing physical metallurgy strategies based on one or two principal elements. The latest generation of superalloys incorporates expensive alloying metals to improve strength, so lowering material costs is another critical challenge.

Researchers at the Gothenburg-based Chalmers University of Technology are currently working on the development of high-entropy alloys (HEAs). Loosely defined as solid solution alloys containing more than five principal elements in equal or near equal atomic percent, HEAs potentially boast unique properties which cannot be achieved through the conventional micro-alloying approach based on only one dominant element.

"We are targeting the development of novel materials with comparable high-temperature performance as nickel-base superalloys but with lower density, which can certainly benefit aerospace industries," says Sheng Guo, an associate professor at Chalmers who is co-leading the research.

Printing progress

The field of powder metallurgy for 3D printing applications is currently in a growth phase, with an increasing demand for high grade metal powders of various types. In the light metals space this means in alloys such as Titanium 6%-aluminium 4%-vanadium (Ti-6Al-4V).

Titanium alloys offer high tensile strength, light weight and extreme corrosion and temperature tolerance, making them valuable materials in the construction of planes, ships, spacecraft and armour plating. The rise of additive manufacturing, or 3D printing, is increasing the use of this versatile metal. While 3D printing with metal was once prohibitively expensive, technological development means it is now more efficient than some traditional manufacturing methods and can produce a comparable or even higher quality end product.

Additive manufacturing is advancing because the materials used in the process are also evolving. Tailored to specific 3D printing technologies, metal powders such as Ti-6Al-4V are now emerging rapidly to meet a diverse range of applications. Additively manufactured Ti-6Al-4V is popular in the aerospace and biomedical industries where speed of manufacture and unique designs are critical.

The road ahead

Those involved in the lightweight metal casting space will appreciate the ever increasing nature of production economy, quality and customisation demands. This, together with a rapidly evolving automotive market and the ongoing implementation of smart manufacturing, is leading to a multitude of development directions. The challenge for casters is how to balance the development roadmap with minor short-term and major long-term improvements to products and processes.

Professor Stephen Brown believes more investment needs to be made in actually understanding new lightweight materials.

"OEMs are increasingly believing that they 'understand' the material they are developing," says the Meridian Lightweight Technologies engineering manager. "As a result they are not exploiting the material and are developing substandard parts using persons trained in other materials.

"At present, due to the urgency of lightening fuel-burning propulsion, there is an increasing tendency to almost copy a part made from another material and expect it to work," he continues. "This is dangerous for both the future perception of the new material, and the application for which it is being developed."

Despite the challenges involved, both for researchers and light metal casters, the future looks bright for lightweight metal manufacturing. With seemingly no end to the new technological advances and uses for ferrous and non-ferrous lightweight metals, leading foundries are driving and implementing innovation on a growing scale. In this way they will continue to play a critical role in the provision of lighter, greener and more capable castings. ■