



Die Cast Magnesium in Automotive Applications

Lynne Karabin and Warren Hunt, Jr.

Introduction

Automakers have studied the relationship between vehicle mass and fuel economy for decades. The majority of studies to date conclude that for every 10 percent reduction in vehicle weight there will be a corresponding six to eight percent decrease in fuel usage. One pound of magnesium typically replaces three pounds of ferrous metals and two pounds of aluminum, resulting in dramatic weight savings without compromising safety. The resultant fuel savings can lower the operating costs of the vehicle over its lifetime and reduce emissions.

The average 1,500 kg NA vehicle has ~ 120 kg each (8% by mass) of aluminum and plastic components, but it has only 5.2 kg of magnesium. At 1/4% of a vehicle's mass, that's not particularly noticeable. So why should anyone care about magnesium? The fundamental reason is its low density (2/3 of aluminum, 1/4 of steel) which gives it a remarkable ability to produce lightweight components. That is what has driven its ~ 20% annual growth over the past 10 years, from 1.2 kg/vehicle in 1992 to over 5 kg in 2004. Magnesium's use is growing faster than aluminum. There are approximately 62,000 metric tonnes (mT) of automotive magnesium castings in MY 2004 NA cars: General Motor Corporation is the largest at 30,000 mT, Ford Motor Company is in the middle at 22,000 MT, and DCX is the smallest at 10,000 mT.

While the average content is approximately 12 pounds per vehicle, some small, lower cost cars have only 1 pound (usually in the steering wheel armature); there are light trucks with over 35 pounds in the vehicle. An example is the Ford Explorer that has a magnesium instrument panel cross car beam, a magnesium transfer case, a magnesium lock housing and a steering wheel armature.

Almost 100% of automotive magnesium components are die cast; there are only a very limited automotive mechanically worked applications (extrusions, forgings, stamping) primarily because of cost. Magnesium's formability at room temperature is poor as a result of its hexagonal structure; however alloys can be rolled and formed when the temperature exceeds 225°C. While there has been little interest in producing sheet magnesium in the past, this seems to be changing as magnesium prices begin to decrease.

Aluminum sheet often is considered competitive with steel when the price of the aluminum blank is ~ \$2.20/kg. Magnesium sheet would then have to cost no more than 1.5 times, or \$3.30/kg. With current aluminum ingot-to-sheet conversion costs in the \$1.00 to \$1.25/kg, this can be achieved when the price of Mg reduces to the \$2.20/kg range. This hasn't happened yet in NA, but it has in the EU and it is there (and especially in Germany) where a considerable amount of stamping, forging and extrusion R&D is ongoing. As an example of the potential market for formed product, Thiessen Krupp is starting a \$10M forming laboratory in Germany, and will buy all of its own magnesium needs from a 50MT plant proposed by Samag (Pima)Australia

Benefits of Using Magnesium

Weight reduction can have significant advantages in addition to fuel saving, which is not a significant reason for materials' changes in NA vehicles. These include reduced Corporate Average Fuel Economy (CAFÉ); reduced emissions and a reduced dependency on foreign oil and foreign oil producers; increased carrying capacity and payload; more expensive (heavy) options possible without changing the vehicle's Inertial Weight Class (IWC); improved Noise, Vibration, Harshness (NVH); more fun to drive; improved safety via braking/acceleration; improved egress/ingress, as shown in more detail below.

- Corporate Average Fuel Economy (CAFÉ). This is a complicated issue since CAFÉ is a dynamometer-measured fuel consumption value calculated on the vehicle's IWC averaged over a whole fleet. It is based on government legislation and there can be penalties if the auto producer does not meet the regulations of 27.5 mpg(8.6L/100km) for automobiles and 20.7 mpg (11.5 L/100 km) for light trucks. Emissions are directly associated with fuel usage; reducing the amount of fuel consumed, reduces the emissions.

-Increased Carrying Capacity. Magnesium components are between 40 and 60% lighter than steel designs. For example a steel instrument panel weighs 8-12 kg while its steel counterpart weighs 28kg; a valve cover weighs 2 kg less in magnesium than aluminum, while it is 3 kg lighter than a plastic version. The load on the axles, determined by the vehicle's design is limited to an allowable Gross Vehicle Weight. If the GVW is in danger of being exceeded the OEM has to reduce weight somewhere; magnesium components provide a significant mass saving opportunity

-More Options. More expensive (heavier) options are possible without changing the vehicle's IWC. Vehicles are sold with a range of expensive options since more expensive items return more profit to the OEM. These include multiple CD players, leather/reclining seating and so forth. By adding a relatively low cost light weight magnesium component, the OEM can sell a heavier option that can return a higher profit.

-NVH. NVH is an important attribute influencing how a customer perceives his/her vehicle. Lighter weight magnesium elements allow the various components connected to the handling, body and suspension systems to be tuned to critical frequencies where NVH is reduced.

-Fun to Drive. Lighter weight vehicles are more fun to drive. Henry Ford said almost 100 years ago that fat men can't run as fast as thin men. Mass reduction makes the vehicle more nimble and more responsive, by moving the mass center of the vehicle (its center of gravity) rearward.

-Safety. Lighter weight vehicles can also be safer, since they are more maneuverable, accelerate faster and have shorter deceleration distances (with the same powertrain configuration). It is true that a larger, heavier vehicle will do more damage to a smaller/lighter vehicle. But lighter elements in the smaller vehicle can be more easily deflected away from the driver and passenger(s) to reduce overall human damage.

-Egress/Ingress. Seat structures that are removable and/or reconfigurable, allow improved passenger egress and ingress; for example, it is easier for customers to remove a 3rd-row seat that is 20 kg lighter than a heavier alternative, fabricated from steel elements.

Other Benefits

-Improved Craftsmanship. Craftsmanship describes the vehicle's fit and finish. In comparison to a typical steel instrument panel (IP) a one piece magnesium die casting improves craftsmanship by reducing the dimensional error associated with welding and joining all of the elements (typically >30 parts) that make up the full IP structure (steering column brackets, radio, air conditioning, glove box and so forth). In fact the experience has been that a one-piece die cast IP may be sufficiently accurate that it can be used as a gauge to define the frontal vehicle dimension.

-Reduced Squeaks & rattles. S/R are attributes that really bother customers. A single casting makes up the cross-beam in the IP structure, while many elements are assembled to make up a steel IP. The single magnesium casting allows less room for manufacturing error and misfit; there is thus a reduced susceptibility for rubbing and vibration between the elements and reduced squeaks and rattles.

-Design for crash. A one-piece magnesium die casting provides an enhanced ability to design for crash vs stamped and welded thin steel elements, by virtue of the ability to cast-in ribs and add surface that promote controlled deformation during a sudden deceleration. In addition, the casting can be designed to incorporate different section thicknesses that can locally change stiffness and rigidity where improved crash response is required.

-Reduced manufacturing cost. Magnesium castings have the potential to reduce manufacturing cost. Again, with reference to the IP, the steel version has 37 elements, whereas in magnesium there are only 6. This reduces the overall tool requirements and complexity, since a tool and gauge are required for each element in the steel IP fabrication. In addition, a rigid one-piece magnesium beam can eliminate the need for a separate cross-car beam to connect the "A" pillars. Also, lighter magnesium parts are easier to handle and manipulate during vehicle assembly. For low volume production (~

250,000 or less), tooling for die castings (~\$500,000) is much less than for steel fabrications, which can cost \$3-6 M

-Package improvements. Castings allow packaging improvements because of the design flexibility provided by HPDC. For example, compared to the stamped and welded architecture of a steel IP, the magnesium version allows air conditioning ducts, air bag housing, instrument clusters, etc. to be cast in place. As well, wiring harnesses can be configured to follow natural curvatures. This allows the designer freedom to incorporate new features, such as a laptop computer, tissue holder and so forth, in the space that can be made redundant.

Products

A variety of magnesium products are utilized in light vehicles, taking advantage of magnesium's lightweight and outstanding die casting characteristics. The variety and quantity of magnesium components used by global OEM's are listed below.

Chassis:

Brake/pedal brackets: ABS brake bracket/mounting bracket, passenger side air bag housing, brake bracket assembly, brake/clutch pedal bracket, clutch pedal assembly, clutch pedal bracket, brake pedal bracket, brake and accelerator pedal bracket.

Road wheels

Interior:

Seating: captain chair seat base, bench seat riser, console bracket, front and rear seat frames, Instrument Panel: Instrument Panel (IP) cross car beam, IP reinforcement/console support bracket/brace/support beam/support bracket assembly, ABS housing passenger side,

Steering: steering wheel armature, steering column bracket, steering column hub/jacket assembly, lower bearing housing, shell housing fixed and tilted, upper mounting bracket, lock housing, actuator housing, retainer and lower bearing retainer,

Misc: door inner, small motors for glass window drivers

Body exterior:

Front engine support assembly (FESA)/grill opening reinforcement...“ Challenged to reduce weight in the all new 2004 Ford F150, Ford turned to die cast magnesium and discovered improved performance at less cost-and a new direction in body-on-frame manufacturing. With die casting, unlike sheet metal, material can be deposited in different thickness based on where the higher stress areas are located. This helped reduce

weight and cost, tune performance and eliminate vibrations. What once was 30 individual pieces was now incorporated into a single casting—significantly smaller than the assembled individual parts, resulting in much better packaging. While there were concerns about durability and crash performance, the end result was that the magnesium support more than stood up to Ford’s Tough Truck image, doubling the life of the carry-over steel radiator support in durability testing. The magnesium FESA for Ford’s F-150 truck passed extensive testing & met all vehicle requirements. The design passed CAE, 4-poster testing, APG full durability tests, corrosion and front-end crash. The front-end mass was reduced by 9.3 kg. The FESA achieved a competitive business case, increased build quality and enhanced overall performance”. Corrosion was a major concern. The casting and brackets were designed to eliminate debris & water that might have collected at magnesium-steel contact locations. The casting was coated with Alodine 5200 to promote paint adhesion and corrosion resistance, with additional corrosion resistance provided by a powdercoat. To eliminate galvanic corrosion, aluminum spacers were assembled between the steel brackets and the casting, with >5 mm overlap, and nylon bushings were used around the frame-mount steel bolt, to isolate the bolt from the casting. Coatings on J-clips passed corrosion performance. Frame mount fasteners passed 165 NM (92 Nm torque loads required).

Headlight retainer..... “To meet Saab's demanding requirements, the reflector surfaces are uniquely made from Mg, instead of the commonly used steel, which allows more complex shaping for even better lighting”.

Sunroof cover/cap assembly, outside mirror armature.

Convertible structure.... “The all new Saab 9-3 Convertible brings a stylish, open-top dimension. To save weight, the soft-top's frame, the swiveling braces and the large padded front rail which connects to the windscreen header are all made from Mg”.

Electrical:

Amplifier housing

Powertrain:

Brackets/supports: Alternator/A-C bracket, alternator/idler/FEAD bracket, miscellaneous engine brackets.

Sealers: valve cover, cam cover, oil pan, engine front cover

Air system: EGR valve plate, intake manifold

Transmission: transfer case, transmission case ...”compared to aluminum, a 25% lighter magnesium die-casting gear case with small extra costs, With respect to the high torque (700 Nm), and thermal stresses up to 150 oC, new magnesium-process engineering concepts had to be developed by DaimlerChrysler”, engine block.... “with its Audi Magnesium-Hybrid engine block, Audi demonstrates how it can employ new alloys with

high hot strength and use the lightweight material magnesium even in highly loaded engines. In comparison to a conventional aluminum cylinder block approximately 8.7 kg can be saved. Using this same technology for a turbo-charged motor, it is possible to save over 20 kg.”

Crashworthiness

There were concerns about the durability and crash performance of Ford’s F-150 new Front End Support Assembly. The magnesium support more than stood up to Ford’s Tough Truck image and passed extensive testing meeting all vehicle requirements. The design passed CAE, 4-poster testing, test track - full durability tests and front-end crash requirements. Tests performed on vehicles containing magnesium instrument panel cross-car beams have shown no problems as long as the die castings are sufficiently high quality. Die castings of magnesium alloy AM50, (the common alloy for components that can be involved in a crash) have nominal elongation of 8-10%. Depending on the die design and the die caster’s processing (tool temperature, pressure distributions), the ductility can be reduced to less than 4%. This can alter the deformation mode from ductile to brittle. But proper design interaction between the vehicle engineer and the caster can ensure sufficient properties in the critical sections that have to resist the crash.