



WHITE PAPER

FisherCast Global Corporation

Remarkable magnesium: the 21st century structural alloy for small components

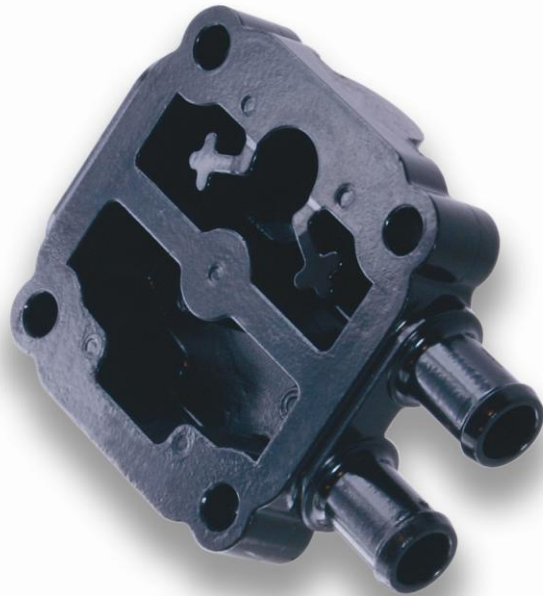
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Abstract

Magnesium alloy is increasingly being selected for automotive and non-automotive applications to replace aluminum, zinc and plastics as manufacturers strive to reduce component weight and production costs. High purity magnesium alloy AZ91D used in high pressure, hot chamber die casting machines is cast net shape, flash-free, eliminating the need for post-secondary machining. Magnesium is 33% lighter than aluminum and 73% the weight of zinc, yet it exhibits the highest strength-to-weight ratio of all structural metals. This paper reviews magnesium alloy's physical and mechanical properties, high castability and abundant supply. It also provides guidelines for designing magnesium die castings and corrects some misunderstandings about this alloy.

The introduction of magnesium alloy AZ91D for use in high pressure, hot chamber die casting has created opportunities for replacing aluminum, zinc and plastic components with magnesium. The automotive industry is using magnesium in steering column parts, shift actuators, valve covers and housings, brackets and intake manifold blades as it strives to reduce vehicle weight under the U.S. Government mandate of Corporate Average Fuel Economy Standards. In non-automotive applications, small magnesium die cast components are appearing in small engines, electronic devices, power tools and medical equipment, such as portable oxygen pumps.



While weight reduction in these applications is desirable, the net shape castability of magnesium in the hot chamber die casting process is often the impetus for replacement of aluminum as machining and waste material costs are eliminated. Magnesium's low creep and excellent thermal properties can withstand high temperature conditions where plastic would creep and deform.

Reluctance to use magnesium in small component castings is diminishing as design engineers recognize that

- its low weight per volume belies its strength
- it can be cast net shape, flash-free for reduced component cost
- it is highly abundant, with stable supply
- its, as cast, high thermal conductivity eliminates fire risk.

While daily prices for magnesium may vary, the long-term prospect is favorable. Magnesium is a highly abundant element, and numerous magnesium producers are providing a ready source of supply which should sustain long-term price stability.

Evaluating volume cost

Rather than evaluating the price per pound, consideration must be given to the total cost of a small die cast component when choosing a material. Magnesium is 33% lighter than aluminum and 73% the weight of zinc, yet it exhibits the highest strength-to-weight ratio of all structural metals, with the exclusion of titanium. So in effect, magnesium is the lower cost metal per volume, with a component of equal geometry using about two-thirds the amount of aluminum.

Additional magnesium economics

Other factors make magnesium die cast components even more economical. Magnesium has a low volumetric specific heat, (1.03 J/g-K) for efficient heat dissipation, which enhances its castability in hot chamber die casting and reduces production costs. Less heat per volume reduces the time for solidification, and quicker cooling permits faster cycle times, which can be up to 50% faster than a comparable aluminum component. This also contributes to longer die life, as does iron's low solubility in liquid magnesium alloy. Die life is typically two to three times longer than for an aluminum die casting tool.

More often, it is the ability of AZ91D to be cast net shape, flash free using hot chamber die casting technology that influences the decision to switch from aluminum. This eliminates the high cost of machining the aluminum casting to tolerance. The opportunities for part consolidation and for casting thinner wall sections are also part of the evaluation. Some plastics are competitive in price per volume and are slightly lighter than magnesium, but in certain applications where strength, stiffness, heat dissipation, dampening, EMI shielding or recyclability are prerequisites, the physical and mechanical properties of magnesium outperform.

The Magnesium Advantage

- **Reduced costs**
 - no post-processing
 - long-term price stability
 - faster machining
 - longer die life.
- **Reduced weight**
 - 33% lighter than aluminum
 - 73% lighter than steel and zinc.
- **Better performance**
 - highest strength-to-weight of structural metals
 - excellent and repeatable dimensional stability
 - low creep characteristics
 - inherent EMI shielding
 - high thermal properties
 - excellent noise and vibration dampening.



Magnesium myths and legends

At a recent Magnesium Automotive Seminar in Germany, a survey was conducted with buyers which asked the reasons keeping them from selecting or obtaining quotes for parts in magnesium. Below are the typical buyer concerns about using magnesium for structural components.

- **Fire risk using magnesium – catches fire immediately.**

Many engineers have never forgotten the high school science teacher who ignited a magnesium strip in class. Dramatic ... but not a true life representation. Magnesium alloys must be heated to near their melting point (850°F) before ignition can occur, although thin edges and fine particles are more easily ignited. It is very difficult to attain such temperatures because the thermal conductivity of magnesium allows rapid dissipation of heat. There are flammability issues with handling and casting the powdered magnesium alloy, but these are the concerns of the die casting supplier, not the end user of the die cast component. Once cast, the component is usually the last thing to ignite in a fire. Tests have shown that even in a car fire, the vehicle is consumed before magnesium parts will burn.

- **Magnesium is an exotic material.**

As magnesium is the lightest of all structural metals, it forms the basis for commercial alloys that are successfully used in a wide variety of applications. It is also a plentiful element, comprising 2.7% of the earth's crust. Although magnesium doesn't occur in nature in metallic form, magnesium compounds occur worldwide, and commercial amounts of magnesium ores are found in most countries.

- **Quality of Magnesium parts are only around 50%.**

This statement may be true if purchasing magnesium castings offshore, but if any North American die caster ran at this reject rate, they wouldn't be in business very long. FisherCast Global's state-of-the-art hot chamber, high pressure magnesium die casting machines, along with its highly skilled personnel, provide the same high quality castings that is expected from the company's net shape, flash-free precision zinc alloy castings.

- **Buyers are worried about the price fluctuation of magnesium.**

Magnesium is not a traded commodity like zinc and other metals. This unique situation, plus the abundant supply of magnesium, ensures the price remains relatively stable.

- **Buyers are worried about the lack of magnesium supply.**

The world's most common ores are carbonate, dolomite and magnesite. Double chloride carnillite forms salt deposits in natural brines, such as in the Great Salt Lake in Utah, the current source of high quality magnesium for FisherCast Global. The major source of magnesium is ocean water, constituting 0.13%. The world's oceans provide a virtually inexhaustible supply of the metal.

Abundant magnesium

Magnesium is one of the world's most abundant elements, comprising approximately 2.7% of the earth's surface composition. In its natural state, magnesium is dissolved in salt water and brines rich in magnesium chloride, and in magnesium bearing minerals such as dolomite, brucite, magnesite and serpentine from which it is extracted by electrolysis or thermal reduction. While too soft for structural applications in its original state, magnesium's high strength properties are achieved with the addition of metals, primarily aluminum and zinc.

High purity AZ91D magnesium alloy used in hot chamber, high pressure die casting has excellent fluidity which allows casting of close tolerance net shapes. The A and Z denotes aluminum and zinc with the numerals indicating the nominal percentage by weight of nine and one per cent respectively. The D stands for the fourth composition of the alloy registered (ASTM). As the principle alloying element, aluminum adds strength and corrosion properties, while zinc imparts a minor increase. Other elements in magnesium include tin (Sn max. of 0.02), copper (Cu max. 0.300), nickel (Ni max. 0.002), iron (Fe max. 0.005), cadmium (Cd max. 0.02) and lead (Pb max. 0.02). AZ91D is called a high purity alloy because of the low content of iron, nickel and copper. The addition of silicon or rare earth elements (AS and AE series alloys) produces a magnesium alloy with improved creep characteristics at elevated temperatures to 350°F. The AM series of alloys (AM50 and AM60) have a lower aluminum content which enhances fracture toughness. A large portion of magnesium (about 45%) is used in the production of aluminum alloys to improve strength and corrosion resistance, with about 35% used in casting.

Magnesium's die casting properties

The high fluidity of AZ91D magnesium alloy and its dimensional stability and consistent, predictable shrinkage rates enable the casting of small components with intricate, complex geometry and very thin wall sections to net shape using today's high pressure, hot chamber die casting technology. Walls can be as thin as .040 in. and to as little as .020 in. for short distances while still maintaining a component's integrity. This net shape ability, which is a combination of the alloy's properties, tooling techniques and high pressure casting technology, often outweighs magnesium's low density as the criteria for selection. The elimination of secondary machining, required for aluminum components, significantly reduces production cost in processing time and waste material.

With high strength and thermal properties that withstand operating conditions up to 250°F, die cast magnesium blades provide a low-cost, high performance solution for the air intake manifold in the World Engine.



The tolerance of the die cast tool plays a significant role in production of as-cast close tolerances. Flashing at the tool faces defeats hot chamber die casting's economics when deburring or secondary finishing is required. In conventional die casting tools, molten alloy is forced into the cavity until it flashes out between adjoining surfaces. In FisherCast's small component hot chamber die casting process, tools are assembled to tolerances of $\pm .0001$ in., closing to form a very tight seal around the cavity that eliminates this flashing action. Linear tolerances are typically $\pm [.0008 \text{ in.} + (.001 \times \text{dimension})]$ with $C_{pk} = 1.33$. Straightness is $.001$ in./in., flatness is $.0015$ in., perpendicularity is $.001$ in./in. and concentricity is within $.002$ in. TIR. Wall thickness can be as thin as $.020$ in. Surface finish is typically 16-64 micro inches. Certain bores can be cast to a dimensional tolerance of $\pm .0005$ in.

Enhancing properties by design

FisherCast's Application Engineers can improve component properties through inclusion of design elements. As well as reducing wall thickness, weight can be removed from the component with the incorporation of cross sections and recesses. Strength can be enhanced through design with the addition of ribs and other features.

Alloy properties

Magnesium's low density, which significantly reduces weight by volume as compared to aluminum and zinc, belies its strength. While 33% lighter than aluminum and 73% lighter than zinc, magnesium has the highest strength-to-weight ratio of structural metals. With a density only slightly higher than many plastics, and physical and mechanical properties that challenge most metals, magnesium is an option for many applications where weight reduction is at a premium. The alloy's heat dissipation characteristics make it a suitable replacement for plastic in elevated temperature applications such as small motors where creep can be a concern.

For specifics on selected physical and mechanical properties of magnesium in comparison to aluminum and zinc, refer to Figure 1.

Magnesium, as most metals, is inherently conductive and provides EMI shielding capability, but its fluidity provides a bonus to other alloy choices. Magnesium and aluminum housings of equal weight provide similar shielding effectiveness, but as frequency increases, wall thickness required for the needed level of shielding effectiveness decreases. In the 1 MHz frequency spectrum into which most commercial applications fall, the high fluidity of AZ91D magnesium alloy allows casting of very thin walls while maintaining structural integrity.

The high purity AZ91D used in hot chamber, high pressure die casting has good corrosion resistance similar to mild steel. Cast magnesium components can be used in many applications without the use of a protective coating, but galvanic corrosion can be an issue when in direct contact with a dissimilar metal in an environment with an

electrical contact and an electrolyte or continuous conducting liquid path. It is possible to neutralize galvanic corrosion by design by eliminating one of these catalysts.

**Figure 1
Magnesium, Zinc and Aluminum Alloys Properties**

Physical Properties	AZ-91D	Zamak 3	ACuZinc 5	AL380
Thermal conductivity, BTU/ft-hr-°F	41.8	65.3	66.3	55.6
Electrical conductivity, %IACS	12.2	27	27.7	27
Tensile strength, kpsi	43	41	54.2	47
Yield strength (0.2% offset), kpsi	23	32	42	24
Shear Strength, kpsi	20	31	40	27
Hardness, BHN (Brinell)	up to 63	up to 82	up to 103	up to 80

Zinc is compatible with magnesium, as are some of the aluminum alloys with restricted copper content. Accumulation of the electrolyte can be eliminated by joining with tapped blind holes with threaded studs, instead of nuts and bolts. The component can be designed so that moisture will drain away or positioned where moisture won't accumulate. The two materials can be insulated against electrical contact in the presence of electrolytes by coating the components, using non-absorbent tapes or fabricated insulators. Washers, spacers and bushings between the surfaces break the galvanic circle. Operating temperature and load may be a determining factor in the method used.

Magnesium's high thermal conductivity (72 W/m-K) makes it suitable in elevated temperature environments. Magnesium head and valve plates in a small compressor dissipate heat through the housing and themselves. Plastic would insulate the cylinder allowing a temperature rise which would reduce piston seal life.

In addition, to these characteristics, magnesium also has good vibration and noise dampening abilities, high impact strength and dent resistance, and is fully recyclable.

Design for magnesium die casting

To gain maximum benefit from magnesium alloy and the hot chamber die casting process, the die casting supplier must be included in the initial project planning team.

This will ensure that the design incorporates necessary die casting requirements and specifications. Value engineering can translate into major cost savings in both design and production. Critical characteristics need to be discussed, and a dimensional and datum scheme established. FEA analysis, mold flow and thermal analysis will verify the results.

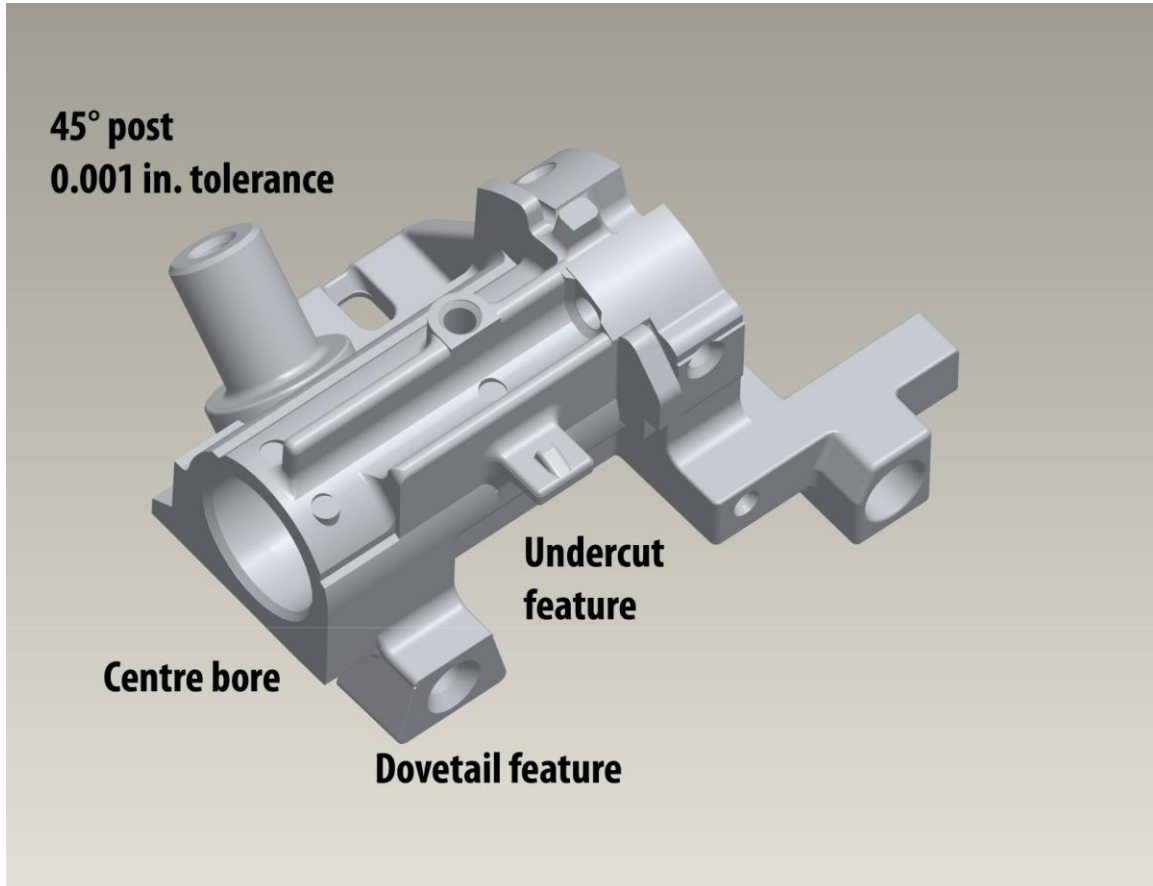


Figure 2 *The conversion of this gear shift bracket from die cast aluminum to net shape, die cast magnesium significantly reduced manufacturing cost, by eliminating the extensive machining required for the complex geometry and tight tolerances. The center bores and the 45 ° post are cast-to-size to fit with bushings. The outside tolerance on the post diameter is .001 in. An additional benefit is component weight reduction.*

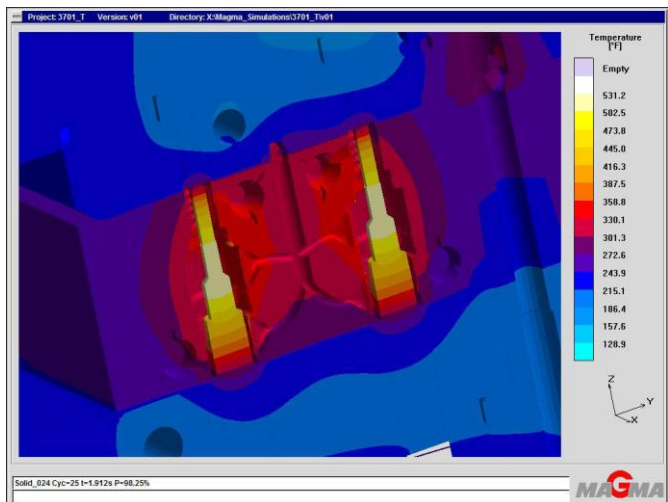
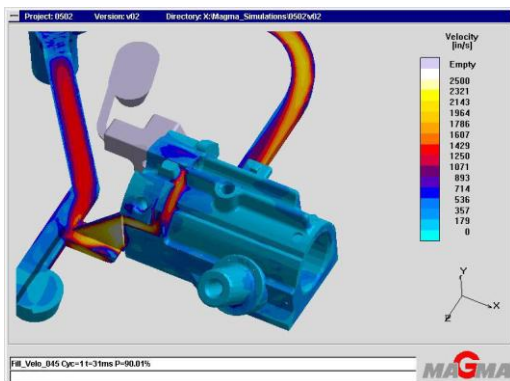
Before the design can be finalized, the die casting supplier will calculate process factors such as flow vectors, gate and runner design, fillets, radii, draft, metal velocity and fill time. Even minor changes can improve performance and reduce costs. Elements, such as ribs, may increase the component's strength, stability and density, while at the same time reduce wall thickness and material usage. A cross-section can be reduced and/or recesses designed into the component to remove additional material. An inside corner designed with a fillet will enhance creep resistance, while extra threads in a bolt connection will reduce creep and ensure the load is retained over a longer period of time.

As die casting provides the unique opportunity for part consolidation, the design engineer should review with the die caster any application that consists of several parts. Applications requiring assembly of two or more parts can often be die cast in one operation. Manufacturing costs are cut by eliminating separate components, the joining operation and inventory.

Design guidelines

Here are some basic guidelines in designing for magnesium die casting. Wall thickness should be as uniform as possible to avoid local hot spots during solidification which could cause formation of porosity or voids. Transitions from one section thickness to another should be gradual to avoid stress concentrations. Edges and corners should be rounded to allow smooth filling of the die with the molten magnesium. Draft angles of 2 to 5 degrees are recommended, although 1 to 3 degrees and zero draft can be used in certain applications. Lettering should be raised rather than sunken into the component's surface.

A thermal simulation of the die casting tool shows how heat dissipates through the tool allowing the tool designer to identify potential hot spots as the molten alloy flows into the cavity and ensure the balance of the tool's heating and cooling system. Maintaining uniform cavity temperatures are critical to casting net shape, close tolerance magnesium components.



Flow and thermal simulation shows the speed of the molten magnesium alloy entering and flowing through the die cavity. This allows positioning of the risers or overflows to eliminate the formation of trapped air pockets which could create porosity in the casting.

Case studies

Eliminating expensive machining

When a gear shift bracket was being redesigned, the OEM, who traditionally had the component cast in aluminum, evaluated reducing manufacturing costs. Eliminating the extensive machining required for the complex geometry and tight tolerances was a prime consideration. Net shape die cast magnesium provided the opportunity with significant cost savings, plus the additional benefit of reducing component weight. The center bores and the 45 ° post are cast-to-size to fit with bushings. The outside tolerance on the post diameter is .001 in. Process improvements were incorporated into the design such as the undercut feature on the small rectangular post (see figure 2) to hold a plastic assembly in place. The dovetail feature was added to hold the bracket to its mating component to aid in the assembly process.

Reducing weight, enhancing performance

With high strength and thermal properties that withstand operating conditions up to 250°F, die cast magnesium blades provide a low-cost, high performance solution for the air intake manifold in the World Engine. FisherCast's flash-free die cast magnesium components outperform aluminum and plastic. There is no aluminum post-processing costs and 33% less weight. Magnesium's low creep and excellent thermal properties won't deform under the high temperature loads.

Withstanding high temperature loads

Every bit of weight reduction counts in portable medical devices, but performance requirements are high. Magnesium's high thermal properties made it the material of choice for head and valve plates in an oxygen concentrator pump over aluminum and plastic. FisherCast's flash free die cast magnesium components need no post-processing for close tolerances and surface finish. Light-weight magnesium holds its own in high temperature conditions where plastic can creep.

Thin walls enhance shielding

When thin walls are critical to functionality, FisherCast's hot chamber magnesium die casting process can cast wall thickness to as little as .020 in. for short distances. The net shape die cast components are ready-to-use, with no extra handling or post-processing costs. Magnesium and FisherCast's die casting expertise combine low cost, high performance with light-weight, EMI shielding and close tolerances for electronic components.

