White Paper

New Combustion-Free Methods for Magnesium Die-Casting

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Magnesium has a strength-to-weight ratio equal to steel, is lighter than aluminum, and can be extracted from seawater in virtually unlimited quantities. It is rugged, fatigue-resistant, and easier to machine than all other structural metals.

But until recently, its high cost, together with its alleged flammabil1ty and susceptibility to corrosion, limited the use of magnesium as an engineering material. Today, however, the changing economics and availability of raw materials, coupled with new extraction processes, are closing the gap in cost between magnesium and its major competitor; aluminum.

In fact, magnesium actually costs less than aluminum on a cents per cubic inch basis. And new developments in hot-chamber diecasting, die-temperature control, aluminum diecasting alloys, and protective coatings and finishes have made magnesium an attractive alternative to aluminum, zinc, and plastic in numerous applications.

Thin strips of magnesium can be purchased at any chemical supply house. Hold one of these strips in the name of a match and it will quickly burst into white flame.

Pure magnesium--or, to be more, precise, the layer of magnesium oxide that forms on pure magnesium--is a highly flammable metal. But its die-casting alloys are not; most magnesium alloys must be heated to 990°F before they will burn. And thicker castings are even harder to ignite because of the alloys' high thermal conductivity.

Any heat source hot enough to ignite a magnesium casting in an automobile would have already done so much damage that the burned magnesium component would be insignificant. Although ignition of molten magnesium has been a problem in the past, the problem has been remedied by a new technique called *fluxless melting.*

Fluxless Melting

The traditional solution to preventing molten magnesium from catching on fire has been to put a layer of salt flux on the melt; the flux forms a non-reactive barrier which isolates the metal from the air, preventing combustion. But the salt flux creates problems like fumes, corrosive agents, and metal loss in the melting pot.

A new approach, fluxless melting, prevents combustion as effectively as salt flux -- but without the undesirable side effects. In fluxless melting, inhibitors in the air prevent oxidation.

Researchers at the University of Michigan have found that small amounts of sulfur hexafluoride (0.1 to 1 percent) form an atmosphere over the melt that keeps it from burning. The Magnesium

Research Center reports that adding carbon dioxide to the sulfur hexafluoride produces a significant improvement in protection for the melt. (Sulfur dioxide has been used in diecasting but this gas is both foul-smelling and noxious.)

Hot-Chamber Diecasting

Because magnesium's high casting temperature (1,185°F) once made hot-chamber injection systems impractical, magnesium parts were cold-chamber diecast; the molten metal was ladled by hand or machine into the shot cylinder. This allowed cooling of the hot charge prior to injection, which had an adverse effect on product quality: quick cooling of the metal, for example, meant incomplete filling of the cavity.

Advances in the design and development of high-temperature steel have now made hot-chamber magnesium-diecasting a reality, resulting in a 30 percent increase in the rate at which parts are produced. Since there is no cooling of the hot charges prior to injection -- the cylinder and injection piston are submerged in a crucible of molten magnesium --, the finished product is sounder, walls are thinner, and surface finishes are smoother.

In addition, hot-chamber diecasting machines cycle at high rates. Coupled with magnesium's characteristic rapid solidification, this means that for smaller parts, the speed at which they are cast is a function of the maximum machine cycling rate -- and not the thermal characteristics of the die. This allows parts to be cast up to 50 percent faster in magnesium than in aluminum.

Die Temperature Control

Unlike the cold-chamber process, hot-chamber diecasting is easily automated. And in hot-chamber diecasting, injection of the molten magnesium directly from the reservoir to the die makes closer control of the die temperature during casting possible.

Die temperature heating/cooling units maintain the casting die at the proper temperature (within $\pm$5°F) throughout the entire production run. Consistent die temperatures result in greater part-to-part tolerance control, Bounder castings, increased production efficiency, and a reduction in the shock of thermal tooling (this shock reduction lengthens the life of the die)

Diecasting Alloys

By adding various amount of aluminum, rare earths, thorium, zirconium, sliver, zinc, copper, manganese, and other elements to magnesium, a wide variety of magnesium cast and wrought alloys have been made for different applications. The most often-used of these, along with some of their properties and characteristics, are listed in Table I.

The diecasting standard is alloy AZ91B. It has high strength, good corrosion resistance, is creep resistant to 250°F, and exhibits excellent dimensional stability. This highly-desirable combination of physical, mechanical, and chemical properties allows AZ91B to meet a wide range of performance requirements.

AZ91A is similar to AZ91B, but its lower copper content makes it better able to resist saline atmospheres. The addition of six percent manganese gives AM60 a ductility of eight percent as cast; AM60 was developed for high-pressure diecasting of mag wheels for automobiles.

AS41A, developed for use in Volkswagen crankcases, is ideal for high-temperature and high-stress applications because of its outstanding creep resistance, good elongation properties, high yield, and tensile strengths. Unfortunately, AS41A cannot be hot-chamber diecast, so it can't be cast into parts with thin walls.

Table I. Major Magnesium Diecasting Alloys

Alloy	**Tensile strength (MPa) 1000 psi**	**Tensile yield strength (MPa) 1000 psi**	**Elongation in 2 in. (%)**	**% creep, 100 hr. at 5000 psi at 350°F**	**Electrical conductivity 10^4 Mhos/cm^3**	**Comments**
AZ91B	34	23	3	3	6.8	Best known arid most widely used Mg alloy
AZ91A	34	23	3	3	6.8	More resistant to saline environments than AZ91B
AM60A	32	19	8	1.5	7.9	Good impact resistance
AS41A	31	20	6	0.35	9.0	Used in high-temper ature and high-stress applications; out-standing creep resistance

Of the newer magnesium diecasting alloys, ZA124 is as tough as AS41A but can be cast into thinner wall sections. AZ61 and AZ88 both exhibit a high degree of palatability, while AM60A's superior impact resistance make it the perfect alloy for diecasting of automobile wheels.

Typical wrought alloys include AZ31B, used in sheet and plate applications, and AZ80A for forgings and extrusions.

Magnesium and magnesium alloys are less susceptible to corrosion from alkalines than aluminum and its alloys. Aluminum is better able to resist acids than magnesium. But for most applications, magnesium alloys in the as-cast state resist corrosion as well as mild steel.

Corrosion resistance of magnesium alloys can be enhanced by simple chemical treatments, protective finishes, or coatings. Electrostatically-applied powder coatings and vinyls are two recent innovations in coatings for finished parts made from magnesium alloys.

New Production Techniques Make Magnesium Cheaper

The cost of magnesium has risen only four percent a year for the last two years, while aluminum has gone up 18 percent a year during that time. This has made magnesium more cost-competitive with aluminum.

A decade or so ago, the cost ratio of magnesium to aluminum in cents per pound was 2.0; today it is less than 1.7. And since magnesium's density is two-thirds that of aluminum and one-fourth that of zinc, it is actually less expensive than both those metals on a cents per cubic inches basis.

Part of the reason that magnesium is becoming cheaper to buy is that it has become cheaper to make. The Dow Chemical Company, a major supplier of magnesium, has developed new energy-saving production techniques that cut the cost of producing magnesium nearly in half.

The company’s new extraction method and new electrolytic-cell process allow Dow to extract magnesium from either salt water or brine using 70,000 to 80,000 Btu's per pound of material instead of the current 140,000 Btu’s – cutting energy costs almost in half.

By way of comparison, conventional aluminum plants consume 120,000 Btu's or each pound of aluminum produced. Also keeping the price of magnesium down is a 40 percent increase in production Dow's conventional magnesium plants over the last five years.

The United States is self-sufficient in supply and production of magnesium, but depends on Jamaican and South America bauxite for its aluminum and on petroleum for much of its plastic. Robert Hansen, an operations manager for Dow’s Corporate Production Department, predicts that the world magnesium production capacity will be 360,000 metric tons in 5 years, up from a projected 256,000 metric tons this year.

But a competitive price and an ample supply aren’t the only things that make magnesium a viable engineering material. Its greatest virtue is its low density: Because magnesium has the highest strength-to-weight ratio of any commonly available structural metal, it is a better choice than sine or aluminum for automotive diecastings, where light weight results in fuel savings.

Volkswagen uses magnesium in its engine blocks, and some Fords have magnesium steering column lock housings, mirror sail trim housings, and EGR valve plates. Ford has also approved more than 20 other magnesium parts for production, including luggage rack supports, headlamp ornaments, outside mirrors, and wiper-washer switch housings.

In addition to its light weight and great strength, magnesium has outstanding dimensional stability and creep resistance. So some of its alloys--AS41A, for example--are particularly well-suited for applications where the components are exposed to constant stress and extremes of temperature, as they are in the Volkswagen engine.

Magnesium alloys are also able to absorb energy elastically: their exceptional damping capacities allow them to withstand the constant shock, vibration, and noise of machine construction and material handling equipment as well as motor housings.

Take magnesium alloy AZ91B: it can dissipate 0.72 percent of the total vibration energy per cycle at a stress of 1000 psi and 4.0 percent of the energy at 5,000 psi. Another magnesium alloy, K1 A, has demonstrated a damping capacity superior to that of cast iron (the "classical" damping metal).

Of all the structural metals available to the designer, none can be machined more efficiently, economically, and with greater ease than magnesium. It machines 45 percent faster than aluminum with 56 percent less power required--and that helps keep production costs down.

Some other advantages of magnesium include:

• *Lower draft and taper requirements*. Draft and clearance angles on magnesium dies can be up to 25 percent less than required for the same part when cast in aluminum. This reduces the weight of the finished part and saves material in production.

• *Thinner walls.* Maximum mechanical performance in magnesium diecasting can be obtained when the wall thickness is in the range of 0.078 to 0.150 inches.

• *Consistent and predictable shrinkage rates in all planes*, which mean that parts can be cast to very close tolerances.

• *Low reactivity with iron*, allowing magnesium to be processed in unlined steel containers.

• *High stiffness-to-weight ratios* for improved ruggedness and durability.

• *Superior fatigue resistance*, which increases part life.

• *High impact and dent resistanc*e. Magnesium's high strength and energy-absorbing characteristics make it the ideal material of construction for baseball bats, catcher's masks, and other pieces of equipment subject to shock loading or other severe impacts.

• *Low inertia properties.* The light weight and structural strength of magnesium alloys make them the logical choice for die cast parts and products that undergo frequent and sudden high-speed changes in direction of motion, such as fan blades, computer tape reels, and vacuum cleaner impellers. The greatly reduced starting inertia of moving parts made from magnesium in a substantial savings in energy consumption and operating costs.

Our magnesium future

The Dow Chemical Company estimates that magnesium consumption will grow at a 7.4 percent annual rate. Magnesium parts will be diecast in greater numbers for power tools, tanks, cameras, cars, lawn mowers, motors, household and business machines, aircraft, satellites, and sports equipment.

If Ford’s acceptance of magnesium production parts spreads to other major automobile manufacturers, U. S. car makers could consume 60 percent of the world's total magnesium output in the next few years, according to a recent article in Automotive Industries.

Magnesium may not be the answer to every design problem. But in many applications--especially those requiring lighter parts for energy savings--magnesium offers significant advantages over aluminum, plastic, zinc, and other design materials favored by engineers in recent years. Whether or not magnesium will continue to gain even wider acceptance among design engineers and equipment manufactures remains to be seen.

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