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Issues Affecting the Acceptance of Magnesium

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The false perception that magnesium components will burn has limited the acceptance of magnesium in the marketplace. This issue as one of many associated with the general lack of consumer knowledge on what magnesium is and what it can do as a material of construction; few automotive engineers know how to design with this relatively new material. The reader should be aware that it was only in 2000 that The Metallurgical Society (TMS) of the American Institute of Mining and Metallurgical Engineers (AIME) reclassified magnesium from its Reactive Metals Division to be in the same Light Metals Division as aluminum.

Ten infrastructural issues that influence magnesium's penetration into the automotive industry are discussed below:

1) The magnesium die casting supply base is generally small, and poorly capitalized.

The die casting supply base, except for one noteworthy exception (Meridian Products Limited in Canada) provides only limited technical support for CAE, component design and vehicle applications.

Because of limited financial and human resources die casters do not perform significant R&D. The result is that the magnesium die casting suppliers have had only marginal success in continuously improving and optimizing the die casting process. There are few industry procedures and standards on how to optimize casting/component quality and casting design/shape to promote lightest weight, highest value, lowest cost components.

2) The Supply of Western-High Technology Magnesium is Insecure

The aggressive 400,000 tonne supply of low cost Chinese magnesium, has depressed world prices, it is not clear whether the current Western suppliers will be able to survive. In 1999, Dow Chemical closed its magnesium plant in Freeport TX. In 2001, Pechiney (France), Northwest Alloys (NA), and Norsk Hydro's Porsgrun (Norway) plant closed; Magcorp was in Chapter 11 reorganization and has emerged (as the only US producer) a new company, U.S. Magnesium. Western supply currently comes from Hydro Magnesium's Becancourt (Canada) plant, 2 plants in the Ukraine, and Israel's Dead Sea Magnesium plant

Western producers produce high quality magnesium. Unfortunately most Chinese magnesium is produced by a large number of small (<10,000 MT) suppliers whose processes and quality are not well controlled, and can vary from supplier to supplier.

If Western producers disappear, the flow of technology that they provide to the supply base and to the OEM's will be compromised

3) Magnesium Corrodes

Yes. But the environmental corrosion of modern alloys is less than that of aluminum A380 and non-stainless steels.

Galvanic/bi-metallic corrosion is the real culprit and while there are solutions, they are not friendly. Certainly there are acceptable assembly procedures to ensure that fastening - magnesium cases to magnesium covers, magnesium components to aluminum and plastics, and magnesium to steel components - will not cause durability problems. But, because each application is different, each new situation requires additional design time, manufacturing effort, and inevitably cost. This increases the apparent risk of converting aluminum, plastic or steel parts to magnesium. Fortunately, there are companies (such as Henkel Industries), which are now taking a full service supplier approach to solving surface protection and bi-metallic corrosion issues, with various coatings, and fastening modalities.

4) Magnesium's Mechanical Properties are Poorly Understood.

There is a large literature on the physical, chemical (corrosion) and mechanical properties of magnesium test bars; unfortunately, test bar castings do not represent actual magnesium castings. Real castings have different gate, runner systems and filling hydrodynamics, and varying section sizes and solidification characteristics compared to the simple shapes of test bars. As well, large commercial machines operate at different die casting machine parameters compared to the small 50-200 MT castings units that produce test bars.. Unfortunately, test bar information has not been statistically correlated to component production data such as machine operations, component design, tooling design and thermal/mechanical events throughout the tool. While test bar databases are widely available, component mechanical property databases suitable for FEA are only available within certain technically astute companies. Fortunately, there is a new USCAR project to develop an FEA-reliable casting database.

Automotive engineers require detailed FEA models on how each component will function, in each different vehicle when exposed to fatigue, corrosion, impact and crash. Without a realistic database of properties, magnesium designs will be sub-optimal and components will be over-designed. They will consequently be too heavy and therefore too costly to be considered as replacement for materials currently used.

Analytical models of the casting process are not yet mature. FEA filling models do not uniquely describe how to modify gate designs and filling profiles (shot speed & pressure) to predict and control porosity throughout all cross-sections in all locations. Foundrymen do not have friendly solutions to improving casting quality. While they do use some modeling, the better foundries use their considerable collective practical experience to gradually remove function-impairing defects from critical locations.

Alloys:

The older family of die cast AZ91D alloys can generally be used from ambient temperature to 125 °C in cases and covers where ductility (~3%) is not important.

The newer grades of AM50 and AM60 alloys have test bar ductility in the +15% range, and can be used in structural applications. Unfortunately this ductility is not achieved throughout all sections of large castings as a result of uncontrolled non-metallic inclusions and solidification porosity defects in the casting. This has caused consternation among designers who need an assured component ductility in critically loaded sections for their FEA vehicle models to work correctly.

Newer class of magnesium alloys containing Sr, Si, Rare Earth, and Ca alloy additions have been developed that improve strength and creep properties at temperatures well above ambient; i.e. near engine compartment operating conditions of between 150 and 175°C. These alloys are beginning to be exploited for component use in transmission cases, oil pans, engine blocks and other under-hood applications.

5) Magnesium is Not Easily Worked

6) Magnesium is Not Easily Joined

There is no problem in joining magnesium. In fact since there is not the tenacious surface oxide, magnesium can be joined more easily by all methods used to join aluminum, viz., mechanical fastening, thermal techniques (welding/brazing/laser/e-beam), and thermo-mechanical joining (such as friction/stir welding). Processing takes a little more care (to ensure no burning, but the resultant joint can be as good as the original structure. Since high pressure die castings are prone to porosity, any joining process that melts a porous section of what is considered a good die casting, can have poor weld quality because of gases released. Laser and e-beam usually produce better thermal welds since the heat-affected-zone is very small and the amount of liberated gas is minimal. Chemical bonding is a little more difficult with magnesium: adhesives can release acids on curing which can attack and damage the magnesium surface, and any moisture can promote corrosion. Both of these events can reduce bond strength. However, with appropriate surface priming, and the correct adhesive, chemical bonding may be the preferred method in the future of joining magnesium to magnesium, magnesium to aluminum and magnesium to ferrous parts.

7) Magnesium Burns

Yes it does, when finely divided (as in chips), and especially in the presence of moisture, since magnesium can oxidize H_2O to O_2 and H_2. But so do gasoline, wood, plastics, and grain flour in silos. In fact, magnesium is safer than these materials since a localized fire on one part of a component will be quenched by thermal conduction into a neighboring cold region. As well, while magnesium burns at a high heat, the amount of energy liberated per unit volume is about ½ compared to plastics or gasoline. There has been a considerable amount of investigation by firefighters around the world to understand how to deal with magnesium fires in foundries, in assembly plants and on highways. In an April 2002 study sponsored by the International Magnesium Association, German firefighters concluded that they had no problems dealing with vehicle containing magnesium components. Another study was completed in 2000 under the auspices of USCAR and the NA insurance industry, at Underwriter Laboratories near Chicago. It was concluded that if a fire occurred in magnesium components shipped and stored in plastic dunnage, no additional changes to existing factory sprinkler systems were required to prevent the fire from spreading and/or damaging the building.

During machining operations there are special work standards to ensure that no sparks are generated, and that the cutting tool does not heat the work piece above its ignition temperature (~ in the 400° C range). A major concern is to maintain the workplace clean. If there is a fire, water (as mist or spray) can be reduced by the molten magnesium, and in the presence of the liberated hydrogen, the fire can expand dramatically. Flooding the fire with water works, since it cools the region around the burn and the fire quenches out.

8) Limited Casting Processing Other Than High Pressure Die Casting

There is limited automotive engineering/process data on the properties and applications of non-HPDC, high production volume casting in sand and metal molds. These processes include, semi-solid (except for Thixomolding where there is a large body of information), gravity casting, low pressure casting, squeeze casting, foam casting, V-Process, vacuum processing, bonded and green sand molding. These process are used to produce structural-grade aluminum castings, but their use in magnesium casting production has been subordinated by high pressure die casting (which is the process of choice for 95% of all magnesium castings). Now that magnesium is approaching aluminum in price per unit volume, it is expected that there will be increased investigation of the quality and productivity advantages that these alternate casting processes could offer. In addition to new processes, new low cost alloys are now being developed that respond to slow solidification rates and T5/T6 heat treatment to produce high strength, ductile components.

9) Magnesium Components are not Prototyped using Make-Like-Production Processing

Production magnesium components are produced in a HPDC machine and freeze at high solidification rates in a turbulent metal flow environment. Most magnesium components are prototyped with gravity casting processes, using sand or plaster molds, and using alloys that differ from those used in die castings. This procedure does an admirable job for reproducing production components' static mechanical properties. However, there are metallurgical differences between HPDC and sand castings that affect mechanical properties (fatigue, ductility, crash behavior) and corrosion behavior. When the prototyping process is analogous to production operations (e.g. welding, bonding mechanical fastening), the prototype's properties will be more-or-less similar to what is observed during production. Thus, with steel, there is little concern that a prototype will not have the same properties as the final production-approved process. But if the prototyping process uses different materials and different physics, there are serious concerns that the testing protocol is flawed:

..the prototype may survive but the production version might not, and not for the same reason in the same location(s) that the prototype failed,

.. if the prototype fails, perhaps the production version could survive.

10) Competition with Other Materials is Fierce

A major problem with magnesium is that there are not enough magnesium zealots in the Tier 1 supply base. When the auto industry needs to cut costs, magnesium-based components are the first to go.

Steel is a more "friendly" material. It is the lowest cost automotive material and there are many experienced fabricators with industrial experience. Fabrications can produced in 1-2 weeks and design changes can be made rapidly using make-like-production processing. The steel industry is very aggressive at heading off the competition by developing lighter weight, higher strength steels.

The aluminum industry (at ~20 Mt annually, vs Mg at 1/2 Mt) produces almost 50 x the amount of ingot as the magnesium industry. Aluminum casting applications have grown aggressively over the past 20 years. Components have migrated from purely housings (e.g. transmission cases and intake manifolds) to more aggressive high temperature applications in engine blocks and heads, to cast structural uses as knuckles and control arms; some sheet usage is beginning in hoods, deck lids and space frames. According to the Aluminum Association, automobiles have 121 kg, while trucks have 127 kg of aluminum parts.

The plastics industry is 10 times larger than the aluminum industry at 180 M t. Polymers have a large following and there are thousands of formulations for different automotive applications. Over 125 kg of polymer and polymer composite parts are used on the average vehicle.

These industries are not static and respond quickly to customer needs:

Plastics eventually will solve recycling problems. Low cost (<$1.50/kg) graphite fibers will be developed so that low cost, high strength, high stiffness composites will be produced that could be stronger, stiffer and cost-competitive with magnesium.

Steel costs keep being reduced. Higher strength, thinner (and therefore lighter), more formable and more weldable sheet stampings will be produced.

Ductile aluminum die castings are being developed and will begin to compete with magnesium for structural application; however they are 20% more expensive than current permanent mold/sand casting alloys. Chemical bonding will be used in place of welding to join high strength extrusions into low cost space frame structures.

Composite aluminum, steel and plastic fabrications will be developed to optimize both material properties and manufacturing, thereby providing low cost and enhanced properties.