Wrought Magnesium: A 21st Century Outlook

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Magnesium’s properties make it appealing for a wide variety of applications, and significant growth has occurred in the area of die-cast components. However, consumption of gravity-cast and wrought magnesium represents only 1% of total magnesium consumption. This article will outline some of the traditional applications of wrought magnesium and identify technical barriers for broader application, which are currently being addressed by researchers around the world.

INTRODUCTION

General interest in structural applications of magnesium alloys is growing. For automotive applications, this has been largely due to an appealing set of properties including low density, high specific strength, acceptable ductility, and most importantly, low-cost processing and assembly (via die-cast components of intricate shape.) Additionally, there has been interest from the electronics industry in cases for a variety of portable electronic devices because magnesium exhibits specific stiffness, heat conduction, and electro-magnetic interference (EMI) shielding typical of metals, not to mention a certain customer appeal which makes magnesium stand apart from the competing polymeric materials.

In fact, there has been double-digit growth in structural applications of magnesium throughout the past decade. However, essentially all of this growth has been largely due to an appealing set of properties including low density, high specific strength, acceptable ductility, and most importantly, low-cost processing and assembly (via die-cast components of intricate shape.) Additionally, there has been interest from the electronics industry in cases for a variety of portable electronic devices because magnesium exhibits specific stiffness, heat conduction, and electro-magnetic interference (EMI) shielding typical of metals, not to mention a certain customer appeal which makes magnesium stand apart from the competing polymeric materials.

TRADITIONAL APPLICATIONS

The number-one application of magnesium flat products (and wrought products in general) is photoengraving plate made of alloy AZ31. Magnesium’s reactivity makes it a superior choice for this application, which relies on acid etching of a patterned plate. The fact that magnesium sheet has never found a significant, stable structural application may help the reader to understand why, until very recently, there was essentially a single source of magnesium sheet world-wide, Spectrulite Consortium in Madison, Illinois—now operated by Magnesium Elektron Ltd.

The number-one application of extruded magnesium is sacrificial anodes used to protect steel heat exchangers, gas pipelines, ship hulls, etc. Thus, these extruded alloys (commercially pure magnesium, AZ31, AZ61, etc.) are highly prized for their ability to corrode. Unfortunately, the magnesium extrusion industry has never developed a mass market such as window and door frames, which has been the bread and butter of the aluminum extrusion industry. Additionally, some applications originally captured by magnesium, such as Maglite® hand trucks, are now made of aluminum.

Historically, there have been extensive applications of magnesium sheet, extrusion, and forgings (as well as castings) in the aerospace industry. Today, most all of these applications have been taken over by aluminum-alloy sheet and high-speed machined plate. Small pockets of magnesium application remain in the aerospace industry, such as sand cast (ZE41, EZ33, or WE43) or forged (AZ80 or ZK60) helicopter transmission housings. The opportunity for future aerospace applications of magnesium forgings appears limited. The potential for new sand-casting alloys of exceptional creep resistance looks more promising.

An area that remains a hot, yet heavily contested, market for magnesium is motorsports. An archetype for this discussion is the forged (typically, ZK60) “mag” wheel used in Formula One (F1) car and motorcycle racing. Wheels represent a significant portion of the unsprung weight and gyroscopic forces in a vehicle, thus they are an extremely weight-critical component. For example, a set of original-equipment manufacturer cast aluminum motorcycle racing wheels weighs 9–11 kg. Forged aluminum alloy wheels (7.5–8 kg) provide a weight savings in the range of 20%. Forged magnesium wheels (see Figure 1) may weigh as little as 6.25 kg, thus providing as much as a 50% weight savings over the conventional part. This advantage does come at a price: plan on spending approximately $2,500 for a set of forged “mag” wheels. Recent alloy development

Figure 1. A forged racing motorcycle wheel by Marchesini.
efforts of Magnesium Elektron have led to increased application of sand-cast and wrought magnesium (WE43 and WE54) within the powertrain sectors (gearboxes, pistons, etc.) of F1 racing cars. As mentioned previously, this high-performance market is extremely volatile, with new competition from polymer-matrix composites, titanium, and other new materials constantly changing the equation.

**TECHNICAL ISSUES AND NEW OPPORTUNITIES**

A number of technical issues pose barriers to expanding the wrought-magnesium market. First and foremost are low production rates. A typical magnesium alloy must be extruded 5–10 times slower than a typical aluminum alloy. Recognizing this fact, researchers at Deakin University, Melbourne, Australia are investigating the causes and possible solutions. One of the fundamental issues is that the temperature window where the material is workable, yet does not suffer hot-shortness (incipient melting), is quite narrow for the conventional extrusion alloys (AZ31, AZ61, AZ80, and ZK60). There has been some recent research examining alloys of lower alloying content in order to substantially increase production rates while maintaining sufficient strength.

From a technological perspective, hydrostatic extrusion seems to offer a solution to the slow production rates of conventional direct and indirect extrusion processes. Additionally, researchers at the GKSS research center in Geestacht, Germany have determined that hydrostatic extrusion promotes a more uniform microstructure and improved mechanical properties.

Similar to the situation with extrusion, magnesium-sheet production has been plagued by the requirement to roll at elevated temperatures. While aluminum and steel may be finished cold, much of the reduction to final gages in magnesium must be performed at temperature. This distinction is likely the largest single factor responsible for the vast price difference between aluminum and magnesium sheets. Researchers at the Oak Ridge National Laboratory, Oak Ridge, Tennessee have been exploring radiant heating as a means of optimizing sheet metal production. Also promising is Australia’s Commonwealth Scientific and Industrial Research Organisation’s success with low-cost continuous strip casting of thin-sheet magnesium, which would reduce the number of rolling steps to an absolute minimum.

For many years it has been known that magnesium alloys exhibit superplasticity after careful processing and control of the deformation temperature and strain rate. More recently, researchers at General Motors demonstrated that everyday “off-the-shelf” magnesium alloy AZ31B sheet in the H24 temper exhibits superplasticity sufficient for consideration for autobody structures. Particularly if a sheet production technology can be developed to lower the cost of magnesium alloy sheet, the potential for future application via warm-forming operations appears great.

Hydroforming is another technology that has helped to enable metals of limited formability, such as high-strength steel and titanium, to break into the automotive market on a wider scale. Researchers at Ohio State University are working to develop an elevated-temperature tube hydroforming process for aluminum and magnesium alloys. As previously noted, another area of increased application of magnesium has been in the form of housings of portable electronic consumer goods, such as cell phones and laptop computers. In some cases, these have been produced by semisolid forming. However, some manufacturers are exploring warm stamping and press forming/forging of magnesium alloy sheet.

Finally, there has been a great deal of interest in developing a better understanding of the deformation of magnesium. Research groups in Germany, Japan, Korea, Australia, and the United States have all been investigating the crystallographic texture, anisotropy, and underlying deformation mechanisms of magnesium (with a focus on AZ31). It is recognized that the standard extrusion and rolling textures are connected with the strong tension/compression strength asymmetry and anisotropy that many magnesium alloys exhibit. Exploring new deformation-processing technologies, such as equal channel angular processing (capable of imparting a two- to three-fold increase in tensile ductility) provides insight for developing magnesium wrought products with extraordinary mechanical properties. Developing an understanding of the connection between alloying and the activity of deformation mechanisms is another important area of research.

**CONCLUSION**

Wrought magnesium has made significant contribution to niche applications within a wide range of industries. Difficulties (i.e., high cost) associated with primary deformation processing are perceived as the major factor inhibiting more widespread application. Focused R&D on a variety of promising avenues suggest that wrought magnesium may begin making a more significant impact in the very near future.

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**References**


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