Magnesium Technology 2002, Part II: Wrought Products, Alloy Processing, R&D Strategies, Corrosion, Welding

D.L. Albright, F. Bergeron, R. Neelameggham, A. Luo, H. Kaplan, and M.O. Pekguleryuz

Editor's Note: Full proceedings, Howard Kaplan, Ed., *Magnesium Technology 2002,* (Warrendale, PA: TMS, 2002) are published in book and CD-ROM versions. Purchase information is available at *doc.tms.org/*

INTRODUCTION

Particularly interesting among the topics covered at the annual TMS Magnesium Symposium are sessions devoted to new materials and processes. While high-temperature alloy development (reviewed in Part I) has been a major emphasis in recent magnesium symposia, the surprise development during the 2002 TMS Annual Meeting in February was a new interest in magnesium wrought products. This Part II conference review article describes key conference papers on magnesium wrought products and processes as well as other processes (e.g., semi-solid processing, welding), and themes reviewed will be corrosion, always of interest to magnesium applications, and general R&D strategies.

MAGNESIUM WROUGHT PRODUCTS

The majority of magnesium structural use today is in die-cast applications. Due to the hexagonal-close-packed structure of magnesium, and, hence, the challenges in forming operations, wrought products have been for many decades limited to a few applications (aerospace, anodes, sporting goods). A surprise development at this year's TMS Magnesium Symposium was an interest shown by automotive end users in magnesium sheet and extruded shapes. As usual, a conference session was devoted to wrought products, but an informal discussion was also held at the end of the session to get the input of the industry and the R&D community on how magnesium wrought applications can be developed.

The program on wrought products began with a tribute by session chairman D.L. Albright to the lifelong contributions of William A. Barnes, a pioneer and entrepreneur of magnesium wrought products. A review of the wrought magnesium industry, as well as projections for the future, was given by R. Brown in his topic "Magnesium Wrought and Fabricated Products—Yesterday, Today and Tomorrow". This presentation highlighted global advances that marked the industry's development over the last 70 years and indicated blueprints for success.

The papers that followed focused on the crystallographic, metallographic, and processing characteristics of alloy AZ31 (a wrought alloy based on Mg-Al-Zn system) in both extruded and sheet forms. A presentation from J. Bohlen entitled "Relationship between Microstructure and Mechanical Properties of Magnesium Wrought Alloy AZ31" combined texture determinations with microstructural and property data to interpret deformation mechanisms in extruded bars and rolled sheets of AZ31. S. Agnew, a professor at the University of Virginia, continued on this theme with "Plastic Anisotropy in Magnesium Alloy AZ31B Sheet," where simulations using the viscoplastic self-consistent model were used to link crystallite level plastic anisotropy with macroscopic properties. This information helps explain the challenging forming behavior and provides insight for improved approaches to forming. "Elevated Temperature Behavior of Sheet Magnesium Alloys" was presented by P. Krajewski. This paper demonstrated the critical role of temperature and strain rate in arriving at total elongation exceeding 400%. A correlation between microscopic failure mode and total elongation was also established.

K. Mueller (Technische Universität Berlin), in the paper "Direct and Indirect Extrusion of AZ31", summarized horizontal trials of both methods at different temperatures and extrusion speeds and compared the benefits of direct versus indirect extrusion of AZ31 utilizing a computer-controlled press. It was shown that indirect extrusion would result in more uniform extrusion at lower extrusion pressures. A computer-aided measuring system helps to insure a largely homogeneous flow of the material and, thus, an important decrease in the total extrusion force required.

In the session's final paper, "The Hot Working Flow Stress and Microstructural Evolution of Wrought Magnesium Alloy AZ31" by A.G. Beer and M.R. Barnett, Deakin University, Australia, Beer presented the results of elevated temperature hot-torsion and compression of AZ31. Torsion and compression testing at various temperatures and strain rates led to the development of constitutive equations that described peak and steady-state flow stresses. Insight was also provided as to the role of the deformation-accommodating processes of prismatic slip, twinning, and dynamic recrystallization. Subsequent microstructural analysis described the effects of these variables on the deformation processes and on the degree of dynamic re-crystallization.

Informal Discussion Session on Wrought Magnesium

The objectives of the informal discussion session chaired by F. Bergeron (IC2 Technologies) were to identify potential applications of wrought alloys inside and outside the automotive industry and to find ways of initiating collaborative R&D in this field. Automotive companies expressed interest in using wrought magnesium in certain applications for weight reduction, including air bag covers, new transmission housing, instrument panel structures that combine castings and extrusions, structural components for the chassis, inner doors and lift-gates similar to those developed by the aluminum industry, and bumpers.

Magnesium producers also expressed interest in opportunities for wrought magnesium. D.L. Albright (Hydro Magnesium) mentioned that many technical issues need to be addressed in the development of wrought alloys. The magnesium microstructure is more difficult to form than aluminum, and hot forming has to be used instead of cold forming. Also, there is a limited number of magnesium alloys compared to the numerous aluminum alloy extrusion series (3000, 4000, 5000, 6000, etc.) already on the market. Albright believes that one of the best avenues for the development of magnesium wrought alloys is to prepare a project that could be presented to the U.S. Automotive Materials Partnership/U.S. Council for Automotive Research (USCAR).

M.O. Pekguleryuz (Noranda) stressed the importance of an industrywide development program on wrought alloys, which would be pre-competitive in nature and could benefit the industry as a whole. This could address many facets of the technology, such as the development of alloys, processes, equipment, and applications. The participants agreed that it is important to look at different and new ways of developing new technologies and to gradually eliminate the technical challenges of producing wrought components through extrusion, stamping, and forging.

MAGNESIUM ALLOY PROCESSING AND R&D STRATEGIES

Magnesium Alloy Processing

Semi-solid processing is a novel processing method commonly used with magnesium. The various semi-solid processes—thixomolding, thixocasting, and rheocasting—are being developed and used for magnesium applications, especially in telecommunication and computer housings. In the session on Alloy Processing chaired by R. Neelameggham, the first paper presented by B.L. Tiwari was a useful discussion on the "Evaluation of a New Concept for Semi-Solid Magnesium Billet Forming" (B.L. Tiwari and R.K. Mishra) using the alloy system ZC63 (Mg-Zn-Cu alloy system), which is being considered for automotive applications. He noted that the presence of 16% liquid phase (by volume) presented opportunities for metal forming at low pressures and temperatures along with flexibility in heat treatment without oxidation problems. This is an application of semi-solid metal forming using a billet in a semi-solid state.

"Tensile Coherency in Semi-Solid AZ91 Alloy" (J.F. Grandfield, J.A. Taylor, and C.J. Davidson) was presented by J.F. Grandfield, Cooperative Research Center for Cast Metals Manufacturing (CAST), Australia. The study investigated the tensile strength of AZ91D in semi-solid state since hot tearing during casting is related to tensile loads arising in the semi-solid regions during solidification. This was a very interesting study that explored and analyzed the fundamentals of tensile property relations and the strengthening mechanisms at various solid fractions in the semi-solid temperature regimes. It was found that in high-fraction solids, the tensile strength of the mushy (semi-solid) AZ91 is related to the strength of the interlocked network of solid grains. On the other hand, the tensile strength of semi-solid AZ91 in low-fraction solids is related to the surface tension of the liquid film between the grains. In the case of equiaxed AZ91, the transition from one regime to the other is at 85% solid-fraction. This consideration needs to be incorporated into hot-tearing studies of magnesium and other metals in the future.

R. Beals of Daimler-Chrysler summarized the advances in "Thixomolding Magnesium Alloys AZ91D and AM60B" with measurements of physical properties at high- and low-percent solid temperature regimes of molding. This database is planned to be utilized to design parts with desirable physical properties by applying the rule of mixtures. In the future, the authors plan to investigate the properties of new alloys in the thixomolded state.

T.K. Nandy, in "Blended Magnesium Alloys Produced by the Thixomolding Process" (T.K. Nandy, J.W. Jones, T.M. Pollock, D.M. Walukas, and R.F. Decker), discussed the feasibility of making alloys with specific mechanical properties by blending alloys AZ91D and AM60 at different proportions. This approach is feasible in the thixomolding process. The microstructures of samples processed at low-to-medium solid fraction were investigated and compared with unblended thixomolded specimens. This study showed that the rule of mixtures was observed in the physical properties seen, as was mentioned in the previous paper. E. Cerri, Lecce University, Italy, discussed variations in the aging kinetics between a die-cast and a thixo-cast magnesium alloy, which are related to the heat-treating effects during solidification and thereafter. A thorough microstructural investigation of the various phases in the thixo-structure was performed in the study.

One of the thought-provoking papers presented in this session was "Rapidly Solidified Powder Metallurgy $Mg_{97}Zn_1Y_2$ (subscripts in atomic percent) Alloys with Tensile Yield Strength of 610 MPa and Elongation of 5%" by Y. Kawamura and A. Inoue. The measured tensile yield strength is about four times that of conventional AZ91 thixocast alloy. It has been known that yttrium enhances the creep resistance of magnesium alloys as seen with WE series alloys used in aircraft parts. Rapid solidification of the present alloy results in twice the strength of conventional WE54 alloys. Besides the property improvement from yttrium stabilization, it is possible that fine grain development associated with rapid solidification itself will improve properties of other, less expensive alloys.

R&D Strategies

Because magnesium is a small industry, materials research is limited. Therefore, strategies are needed to leverage funds, form consortia, or develop industry–government synergies in major materials development activities. Good examples of such research synergies are USCAR and the European Council for Automotive R&D. Another successful example of magnesium R&D is CAST. G. Dunlop of CAST gave an extensive overview the organization's various research efforts, including casting and physical metallurgical studies on magnesium alloys. These encompass the cover gas alternatives to SF6 using Freon-134, solidification studies in horizontal casting of AZ91, twin-roll casting studies, flow-modeling software for die-casting mold development, mechanical property studies, aging kinetics, and development of a high-temperature magnesium gravity casting alloy.

P. Bakke gave Hydro Magnesium's views related to research on magnesium die-casting alloy design described in the paper by K. Pettersen, P. Bakke, and D. Albright. The authors noted that using Mg-Al-Mn alloys as the basis, the added element must cause formation of a strengthening phase that is thermodynamically stable and which facilitates a stabilized matrix structure in order to give high-temperature strength properties. Castability is another criterion that must be fulfilled.

In the final paper of the session, "Research Strategy for AM60 Magnesium Steering Wheel" (co-authored by S.K. Kim, H-J. Yoo, and Y-J. Kim of Hyundai Motors), S.K. Kim, Sungkyunkwan University, gave an overview of a systematic engineering optimization study done for Hyundai Motors, which involved selecting high-pressure die-cast AM60 for the steering wheel. It was refreshing to learn about some of the computer-aided engineering techniques used by automotive designers, such as noise vibration harshness reduction, crash-worthiness in simple and inclined compressive modes, as well as flow modeling for improved castability.

CORROSION & WELDING

Magnesium parts need to be joined to other metallic components in automotive and other applications, which can be a challenge when galvanic corrosion is an issue. Corrosion science has in the past solved general corrosion problems for magnesium with the development of high-purity alloys. The R&D focus has now shifted to galvanic corrosion protection as well as appropriate joining techniques.

Six papers were presented in the Corrosion session chaired by A. Luo and H. Kaplan. The first paper, "Emerging Trends in Corrosion of Magnesium Die-Casting" by J.I. Skar and D.L. Albright, provided a good summary of existing and newly developed methods for corrosion protection and finishing of die-cast magnesium automotive components. "Corrosion and Wear Resistance of Electroless Nickel on Magnesium Alloys" by G.E. Shahin discussed the pretreatment of magnesium alloys in addition to electroless nickel plating. The corrosion and wear resistance of magnesium alloys with various electroless nickel coatings were evaluated.

B.L. Tiwari and J.J. Bommarito presented "A Novel Technique to Evaluate the Corrosion Behavior of Magnesium Alloys." As a magnesium alloy sample dissolves in 5% NaCl solution, the dissolution rate is determined by measuring the amount of HCl added to the NaCl solution to control the pH between 5 and 7. The corrosion rate is then determined from the slope of the curve where the dissolution rate reaches a steady state. In "Aqueous Corrosion Properties of Mg-4Ni-Xl Alloys in Acid-Chloride Solution" by Y-S. Choi, J-G. Kim, S.K. Kim, and Y-J. Kim, micro-galvanic corrosion in various Mg-Ni-Al-based compositions was investigated. Increasing the aluminum content decreased the corrosion rate, and this was related to the amount of grain boundary α-Mg/Mg_2Ni phase. The fourth corrosion paper of the session (by S. Shrestha, A. Sturgeon, P. Shashkov, and A. Shatrov) described the corrosion behaviors of a die-cast magnesium alloy AZ91D coated with the Keronite process, an electrolytic coating process. The study demonstrated the improved corrosion resistance of Keronite-coated AZ91D and its potential use in severely corrosive environments. Corrosion studies continued with the paper "Sealing Methods for Enhanced Corrosion Protection of Anodized Magnesium Alloy WE43A-T6" by R. Rateick, S-J. Xia, and V. Birss. The effect of sealing compounds on the corrosion resistance of high-voltage anodized coatings was reviewed and potentially beneficial coatings were identified.

"Joining of Light Hybrid Constructions Made of Magnesium and Aluminum Alloys" by A. Ben-Artzy, A. Munitz, G. Kohn, B. Bronfin, and A. Shtechman studied the weldability of Al 6063 to cast magnesium alloys AM50 and AZ31 using gas tungsten-arc and electron-beam welding. Preliminary results indicate problems with low tensile strength and ductility in the welds, with future work suggested to evaluate alternate filler materials and low-fusion bonding techniques as a means to obtain better bonding of these materials. The paper entitled "Resistance Spot Welding of Mg-AM50 and Mg-AZ91 Alloys" by A. Munitz, G. Kohn, and C. Cotler discussed the microstructures of resistance spot welds and identified some of the welding parameters necessary to make acceptable welds.

A most interesting paper was the "Microstructure and Mechanical Properties of Friction Stir Welded AZ31 Mg Alloy" by W-B. Lee, Y-M. Yeon, S.K. Kim, Y-J. Kim, and S-B. Jung. A study of welding parameters that led to successful friction stir welding of magnesium was described. Weld microstructures were presented along with weld properties and fracture analysis.

The final paper of the conference (by D. Wang, R.A. Overfelt, Y. Fasoyinu, and M. Sahoo) was on the challenging process of measuring the thermophysical properties of magnesium. Presented by D. Wang of Auburn University, the paper discussed some of the methods used to measure latent heat, liquidus, solidus, solid fraction, and specific heat with differential scanning calorimetry; thermal expansion and density with dilatometer and laser distance detection; and viscosity with oscillating cup viscometer.

D.L. Albright is a vice president with Hydro Magnesium. F. Bergeron is president of IC2 Technologies. R. Neelameggham is the technical development scientist at and H. Kaplan is senior vice president of Magnesium Corporation of America. A. Luo is a staff research engineer in the Materials & Processes laboratory at General Motors Research & Development Center. M.O. Pekguleryuz is principal scientist and group leader of Materials Engineering/Light Metals at Noranda Technology.

For more information, contact M.O. Pekguleryuz, Noranda Technology Centre, 240 Hymus Blvd., Pointe-Claire, Montreal, Quebec, Canada H9R 4R8; fax, (514) 630-9379; e-mail pekguler@ntc.noranda.com.