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PREFACE

This is the 16th annual volume of papers from the Magnesium Technology symposium, which contains all aspects of magnesium technology, ranging from primary production to applications and recycling, as well as basic research to industrialization. Continuing with the longstanding tradition of presenting the most recent and highest quality work on magnesium, all presenters have submitted papers to this edited proceedings volume or other TMS-sponsored peer-reviewed journals. All papers in this compendium were thoroughly reviewed by experts, leading researchers, and industrialists in the field, and their contribution continues to be an important aspect to the success of this symposium. This proceedings volume is highly regarded as a centralized repository of magnesium research carried out globally and includes the finest and latest breaking articles in this area. Papers in this collection originated from 19 countries, highlighting the global competitiveness and interest in magnesium technology. This collection of papers represents the spectrum of research that will be presented during the 2015 Magnesium Technology Symposium at the 144th TMS Annual Meeting & Exhibition held in Orlando, Florida from March 15-19, 2015. This is one of the largest yearly gatherings of magnesium specialists in the world.

The symposium will start with a keynote session that consists of several distinguished invited speakers who were carefully selected as world-class experts who could provide their perspective on the future possibilities and opportunities on the topic of magnesium alloy research and development. The keynote speaker, Alan Taub, professor at the University of Michigan and the Chief Technical Officer of the American Lightweight Materials Manufacturing Innovation Institute (ALMMII), will provide us an overview of the activities of the institute, which constitutes one arm of the federal National Network for Manufacturing Innovation (NNMI) initiative, proposed by President Obama, and serves as a hub to accelerate the development and adoption of cutting-edge advanced lightweight materials and manufacturing technologies. His talk will be followed by a presentation by Bruce Davis from Magnesium Elektron, who will discuss the ongoing and recently standardized efforts by the Federal Aviation Authority to integrate magnesium alloys into structural applications in commercial aircraft. Tresa Pollock, professor at the University of California Santa Barbara, will summarize the outcomes of a recently held National Science Foundation–sponsored workshop to identify emerging and transformative research areas in metals and metallic nanostructures, where magnesium technology was highlighted as a topical area of interest. These broad-ranging, overview keynote session talks will be followed by a set of distinguished scientists, Jian-Feng Nie (Monash University), Matthew Barnett (Deakin University), and Sean Agnew (University of Virginia) who will discuss their latest technical research.

This year, integrated into the plenary are two new activities: (1) poster authors will be presenting elevator-pitch style presentations of their posters which will be later displayed during the poster session following the completion of the keynote session, and (2) the keynote speakers will participate in a panel for an interactive discussion with the audience on the future of magnesium research and applications. This discussion will be dictated, summarized, and then transcribed into a manuscript that will be subsequently released to the community.

Due to the large number of manuscripts submitted, each of the four days of the symposium are organized in parallel sessions of technical presentations, with two parallel sessions dedicated to the specialty symposium on Strip Casting of Light Metals organized by Kai Karhausen (Hydro Aluminium Rolled Products GmbH), Wim Sillekens (European Space Agency), Murat Dündar (Assan Aluminium), Jan Bohlén (Helmholtz-Zentrum Geesthacht), and Dietmar Letzig (Helmholtz-Zentrum Geesthacht). This
symposium is co-sponsored by the Aluminum and Magnesium Committees and is dedicated to continuous casting/rolling methods to directly transform aluminum or magnesium melts into (semi-finished) strip, thereby emphasizing scientific technological communalities in the processing of both light-metal classes. Implemented as twin-roll casting, the manufacturing of magnesium-alloy strip is currently one of the highlights in magnesium research and development with particular relevance to automotive applications.

We would like to gratefully acknowledge and thank all the authors for their contributions and, in addition, the reviewers, session chairs, and poster judges for their willingness to volunteer their time in order to ensure a successful, high quality symposium and proceedings volume.

2015 Magnesium Technology Conference Organizers

Michele V. Manuel, Chair
Alok Singh, Vice Chair
Martyn Alderman, Past Chair
Neale R. Neelameggham, Advisor
ABOUT THE LEAD EDITOR

MICHELE V. MANUEL
MAGNESIUM TECHNOLOGY 2015 LEAD EDITOR

Michele Manuel is an associate professor in the Department of Materials Science and Engineering at the University of Florida. She received her Ph.D. in materials science and engineering at Northwestern University in 2007 and B.S. in materials science and engineering at the University of Florida. Prior to arriving at the University of Florida, she performed her post-doctoral work at the General Motors Technical Center in Warren, Michigan. She is the recipient of the NSF CAREER award, NASA Early Career Faculty award, ASM Bradley Stoughton Award for Young Teachers, AVS Recognition for Excellence in Leadership, TMS Early Career Faculty award, TMS Young Leaders Professional Development award, and TMS/JIM International Scholar award. Her research lies in the basic understanding of the relationship between processing, structure, properties, and performance. She uses a systems-based materials design approach that couples experimental research with theory and mechanistic modeling for the accelerated development of materials. Her current research is focused on the use of systems-level design methods to advance the development of new materials through microstructure optimization. In the TMS Magnesium Committee, she has previously served in the roles of Vice Chair, Secretary, and JOM Advisor, and she currently serves as Chair. Additionally, she serves as the Vice Chair of the Content Development and Dissemination Committee, as well as a member of the Education, Young Leaders, Integrated Computational Materials Engineering Committee (ICME), and the Women in Science Committees.

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Alok Singh
Alok Singh is a Chief Researcher in the Structural Materials Unit of National Institute for Materials Science in Tsukuba, Japan. He studied metallurgical engineering at undergraduate, masters and doctoral levels. His master’s thesis at Indian Institute of Technology at Kanpur, 1987, was on kinetics of phase transformation in steels. His Ph.D. work, at the Indian Institute of Science, was on the study of quasicrystalline and related intermetallic phases in aluminum alloys by transmission electron microscopy (TEM). He tackled the complex structures and reciprocal space of quasicrystals and its indexing problems. Subsequently, he worked several years studying advanced materials by TEM at the Indira Gandhi Center for Atomic Research, and visited National Research Institute for Metals in Japan. He studied the effect of interfaces on melting and solidification of embedded nanoparticles, and the structure of interfaces between simple crystals and quasicrystals. In 2002 he moved to his present working place and started work on magnesium alloys with special emphasis on Mg-Zn-RE alloys containing stable quasicrystal phase. His work has demonstrated very high strength with ductility in these alloys. He has employed TEM to study dislocations, grain boundaries and twins to understand deformation behavior of magnesium alloys. He has over 80 refereed publications, over 30 contributions to proceedings, and several patents on magnesium alloys. He is a regular attendee of TMS Annual Meetings & Exhibition and has been involved with the Magnesium Committee for many years. He received the TMS Magnesium Fundamental Research Award for year 2009 along with his coworkers.

Martyn Alderman
Martyn Alderman is Divisional Director of Technology for the Magnesium Elektron Group Worldwide. He obtained a master’s degree in material science from the University of Cambridge (United Kingdom) in 1979 and for the next 20 years he worked in aluminum rolling mills producing and developing Al-Cu-Zr, Al-Mn, Al Mg-Mn, Al-Zn-Mg, and Al-Li-Cu alloys for superplastic forming. He also has significant operational experience direct chill casting and in the extrusion of high strength aluminum alloys. In 2003 he joined Magnesium Elektron during the acquisition of their large Madison, Illinois rolling operation in the United States. For the next few years he was travelling between the United States and Europe encouraging the wider use of magnesium sheet in transport applications, in particular by use of superplastic forming, and later in managing the post-acquisition integration of the Revere North American Graphic Arts business. He chaired the 2010 International Magnesium Association Conference in Hong Kong, and in 2011-12 was involved in editing and producing a 270-page Handbook on Designing with Magnesium Alloys.
More recently he has been involved in a UK Technology Strategy Board Project aimed at the design of a magnesium intensive vehicle in conjunction with the Morgan Motor Company, and as an advisor to the International Magnesium Association Life Cycle Study on automotive and aerospace applications. As a member of TMS, SAE, and AMS, he is a regular attendee at worldwide magnesium conferences keeping abreast of global technology development with the aim of maintaining the Magnesium Elektron’s position as a world leader in magnesium alloys and their end use applications.

During 2015 he will again be chairing the International Magnesium Conference in Vancouver, and participating in the organization of the 10th International Conference on Magnesium Alloys and their Applications on Jeju Island in South Korea.

Neale R. Neelameggham

Neale R. Neelameggham is ‘The Guru’ at IND LLC, involved in technology marketing and international consulting in the field of light metals and associated chemicals (boron, magnesium, titanium, lithium and alkali metals), rare earth elements, and battery and energy technologies, etc. He was recently a visiting expert at Beihang University of Aeronautics and Astronautics, Beijing, China. He has over 38 years of expertise in magnesium production and was involved in process development of its startup company NL Magnesium through to the present US Magnesium LLC, UT from where he retired in 2011. He is developing thiometallurgical processes – a new concept of using sulfur as the reductant and or fuel. He has published a heat transfer model for global anthropogenic warming based on thermal emissions independent of energy conversion source.

Dr. Neelameggham holds 16 patents and patent applications, and has published several technical papers. He has served in the Magnesium Committee of the TMS Light Metals Division (LMD) since its inception in 2000, chaired it in 2005, and in 2007 he was made a permanent co-organizer for the Magnesium Technology Symposium. He has been a member of the Reactive Metals Committee, Recycling Committee, and Titanium Committee, and a Programming Committee Representative of LMD.

In 2008, Dr. Neelameggham was the inaugural chair of the Energy Committee, a joint committee between the TMS Light Metals and Extraction and Processing Divisions, and has been a co-editor of the Energy Technology symposium through the present. He received the LMD Distinguished Service Award in 2010. Neale is the Chairman of Hydrometallurgy and Electrometallurgy Committee of the Extraction and Processing Division for the 2013-2015 term, during which time he organized the Rare Metal Technology 2014 and 2015 symposia. He is the co-editor of the Essential Readings in Magnesium Technology compendium of TMS papers published in 2014. He is a co-editor of the 2015 symposium on Drying, Roasting and Calcining.
MAGNESIUM TECHNOLOGY 2015
Session Chairs

Keynote Session
Michele V. Manuel,
University of Florida
Alok Singh,
National Institute for Materials Science (NIMS)

Elevated Temperature and Creep
Amit Pandey,
LG Fuel Cell Systems
Karl Kainer,
Helmholtz-Zentrum Geesthacht

Primary, Sustainability, Recycling, and Processing
Neale R. Neelameggham,
IND LLC
James Saal,
QuestTek Innovations, LLC

Deformation I
Bilal Mansoor,
Texas A&M University at Qatar
Haitham El Kadiri,
Mississippi State University

Deformation II
Suveen Mathaudhu,
University of California, Riverside
Kiran Solanki,
Arizona State University

Wrought
Bin Li,
University of Nevada, Reno
Eric Nyberg,
Pacific Northwest National Laboratory

Forming and Alloy Design
James Saal,
QuestTek Innovations, LLC
Mesut Varlioglu,
John Deere Moline Technology Innovation Center

Corrosion, Coatings, Fatigue, and Fracture
Brian Jordon,
University of Alabama
Syamala Pulugurtha,
Medtronic

Casting and Metal Matrix Composites
Lei Zhang,
University of Alaska, Fairbanks
Wim Sillekens,
European Space Agency

Biomedical Applications
Raymond Decker,
Nanomag
Norbert Hort,
Helmholtz-Zentrum Geesthacht

Functional and Emerging Alloys
Vineet Joshi,
Pacific Northwest National Laboratory

STRIP CASTING OF LIGHT METALS
Session Chairs

Modeling and Properties
Dietmar Letzig,
Helmholtz-Zentrum Geesthacht
Murat Dündar,
Assan Aluminium

Process Technology
Kai F. Karhausen,
Hydro Aluminium Rolled Products
Jan Bohlen,
Helmholtz-Zentrum Geesthacht
The completion of this volume would not have been possible without the volunteer assistance of these individuals from 19 different countries. Their commitment to the advancement of magnesium research and scientific knowledge is to be commended. They are listed here in alphabetical order by their last names:

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REDUCING WEIGHT FOR TRANSPORTATION APPLICATIONS: TECHNOLOGY CHALLENGES AND OPPORTUNITIES

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Keywords: lightweight materials, manufacturing processes, systems engineering principles

Today’s land, sea and air transportation industries – as a business necessity – are focused on technology solutions that will make vehicles more sustainable in terms of energy, the environment, safety and affordability. Reducing vehicle weight is a key enabler for meeting these challenges as well as increasing payload and improving performance. The potential weight reductions from substituting lightweight metals (advanced high-strength steels, aluminum, magnesium and titanium alloys) are well established. For magnesium castings, weight savings of 60% have been reported [1]. The value of weight reduction depends on the transportation sector and ranges from about $5/kg saved for automobiles to over $500/kg saved for aircraft [2]. The challenge is to optimize the material properties and develop robust, high volume, manufacturing technologies and the associated supply chain to fabricate components and subsystems at the appropriate cost for each application.

The American Lightweight Materials Manufacturing Innovation Institute (ALMMII) was established as a public-private partnership to accelerate the adoption of these materials. ALMMII is one of four new institutes that are part of the growing National Network of Manufacturing Institutes and serves as the nation’s essential bridge between basic research and final product commercialization for lightweight metals [3].

The institute will take advantage of opportunities to drive synergies across the various industries serving both commercial and defense transportation needs. Advanced manufacturing processes will be developed through projects executed by our industry partners in collaboration with an extensive network of universities and the national and federal laboratories. Commercialization of the resulting technologies is enabled by the early integration of the capabilities of the full production supply chain from material producers and metal formers to OEM’s.

Improved manufacturing processes for magnesium in both cast and wrought forms are required to expand the alloy utilization. Our industry and government partners have identified a number of focus areas including higher integrity and larger thin-walled castings, overcasting of magnesium on aluminum and steel substrates, and joining of mixed-material components with particular emphasis on mitigation of galvanic corrosion.

The projects will employ systems engineering principles as shown in Figure 1. The industry members will select the particular alloy and an associated component and platform. In developing the new manufacturing process, the project team will employ ICME enabled models that can support both the design and certification/validation phases of the work.

![Figure 1: Each ALMMII project will utilize systems engineering principles to deliver innovative manufacturing processes integrated with product design modeling](image)

References
THE APPLICATION OF MAGNESIUM ALLOYS IN AIRCRAFT INTERIORS – CHANGING THE RULES

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Extended Abstract

The commercial aircraft market is forecast to steadily grow over the next two decades. Part of this growth is driven by the desire of airlines to replace older models in their fleet with newer, more fuel efficient designs, to realize lower operating costs and to address the rising cost of aviation fuel. As such the aircraft OEMs are beginning to set more and more demanding mass targets on their new platforms.

The cabin interior, including furnishings and operational items, account for 19% of the overall aircraft weight. This establishes it as a significant area for weight savings. Modern magnesium alloys can offer up to 30% mass reduction when directly replacing aluminum components, which makes them very attractive to designers and engineers. However, until recently, there have been restrictions on the use of magnesium in aircraft interiors that have been enforced through the SAE and the FAA.

The FAA has been working for the last seven years to assess the safety issues associated with the introduction of magnesium into the cabin interior. This work began with simplistic flammability testing of a wide range of alloys that identified different ignition behaviors of magnesium alloy types. This lead the FAA to undertake full scale fuselage staged burn tests of seat structures. The typical structural seat components are shown in Figure 1. The seats tested in the full-scale fuselage assessment contained five key parts fabricated from magnesium: spreader bars, seat leg assembly, cross tubes, baggage bars and the seat back frame.

The testing arrangement is shown in Figure 2, which indicates the monitoring systems that were in place. The test assessed standard seat ignition properties compared to two magnesium containing seats containing either AZ31B alloy or Elektron®43.

The results of this testing showed that the presence of magnesium did not compromise passenger safety. The FAA has now issued guidelines on a laboratory scale flammability test. The test setup is shown in Figure 3. Magnesium alloys that meet the criteria of this test will be considered allowable for use in aircraft seat applications. The test method is available in the FAA’s Aircraft Materials Fire Test Handbook Chapter 25 Oil Burner Flammability Test for Magnesium Alloy Seat Structure.

The work by the FAA has culminated with a lifting of the ban of magnesium’s application in aircraft seat applications. The FAA will now accept application for special conditions that will allow magnesium containing aircraft seat certification in commercial transport aircraft. Future work by the FAA will investigate methods of compliance (MOC) to allow magnesium in other aircraft interior applications, thereby extending the weight saving potential and benefit of today’s advanced magnesium alloys.

Furthermore, the SAE standard AS8049 Rev B, which defines the engineering requirements of a commercial aircraft seat, restricts the use of magnesium in paragraph 3.3.3. AS8049 is currently undergoing its scheduled five year review. Revision C is scheduled to be issued in 2015 and paragraph 3.3.3 has been altered to allow the use of magnesium. The document now states that magnesium alloys maybe used in aircraft seats so long as the conform to the requirements set out in the Aircraft Materials Fire Test Handbook.

The application of the next generation magnesium alloys in aircraft interiors is now positioned to grow.
EMERGING SCIENCE AND RESEARCH OPPORTUNITIES FOR METALS AND METALLIC NANOSTRUCTURES: A REPORT ON THE NSF MMN WORKSHOP

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Extended Abstract

In the next decade, fundamental research in metals and metallic nanostructures (MMN) has the potential to continue to transform science into innovative materials, devices, and systems. This talk summarizes the findings of a workshop to identify emerging and potentially transformative research areas in MMN. The metals and metallic nanostructures (MMNs) workshop aimed to identify significant research trends, scientific fundamentals, and recent breakthroughs that can enable new or enhanced MMN performance, either alone or in a more complex materials system, for a wide range of applications. Additionally, the role that MMN research can play in high-priority research and development (R&D) areas such as the U.S. Materials Genome Initiative, the National Nanotechnology Initiative, the Advanced Manufacturing Initiative, and other similar initiatives that exist internationally was assessed. The workshop also addressed critical issues related to materials research instrumentation and the cyberinfrastructure for materials science research and education, as well as science, technology, engineering, and mathematics (STEM) workforce development, with emphasis on the United States but with an appreciation that similar challenges and opportunities for the materials community exist internationally.

The societal and economic impacts of MMN research will continue to be significant. Metals and metallic nanostructures underlie systems and technologies critical to solving national and global grand challenges. Innovations in metals, metal alloys, and metallic nanostructures are needed to advance systems for:

- energy generation, harvesting and storage – thermoellectrics, batteries, fuel cells, advanced turbines, magnetic induction, motors, hydrogen production and storage, nuclear reactor materials, separation membranes
- propulsion and transportation – high strength, high performance lightweight structures, materials designed for improved creep, impact, fatigue or corrosion resistance, high temperature metals, alloys and coatings for extreme environments, non-destructive evaluation
- electronics, telecommunication, and information technology – electronic packaging, process modeling, device nanostructures to overcome the end to Moore’s law, thin film and nanostructured electrical interconnects, magnetic devices and motors, and sensors
- sustainability – nanostructured metals for catalytic converters, polymer catalysis, hydrogen and ammonia production, low pollution smelting and refining processes
- health care – imaging systems, integrated in-vivo sensors, electronics, and communication systems for health monitoring and drug delivery, prosthetics and implant materials and systems, cancer treatment technologies
- manufacturing – additive and nano-manufacturing technologies, non-equilibrium processing approaches, recycling and reuse, rapid deployment of alternatives to “critical” materials.

A central theme of the Workshop was the view that research in metals and metallic nanostructures has provided and will continue to provide benefit to the nation through the coupling of experiment, theory, and simulation to link atomistic, nanoscale, microscale, and mesoscale phenomena across time scales for an ever widening range of applications. Within this overarching theme, the workshop participants identified emerging research opportunities that are categorized in terms of:

- 3-D and 4-D Materials Science
- Structure Evolution and the Challenge of Heterogeneous and Multicomponent Systems
- The Science Base for Property Prediction Across the Lengthscales
- Nanoscale Phenomena at Surfaces – Experiment, Theory, Simulation
- Prediction and Control of the Morphology, Microstructure, and Properties of “Bulk” Nanostructured Metals
- Functionality and Control of Materials Far from Equilibrium
- Hybrid and Multifunctional Materials Assemblies
- Materials Discovery and Design: Enhancing the Theory – Simulation - Experiment Loop

This talk will summarize the findings of the workshop and will provide a brief overview of these emerging research opportunities, along with challenges and opportunities for the materials community in the areas of instrumentation, cyberinfrastructure, education, and workforce development.