DECEMBER 2023
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ABOUT THE COVER

This month's cover is inspired by the feature article, "Challenges and Opportunities of Increasing Materials Circularity: A Focus on Critical Metal Recovery from Electronic Waste." The article, which begins on page 19, looks at waste printed circuit boards as a major secondary source of critical materials that can be reused to manufacture new electronic products. Cover designed by Cheryl M. Geier, TMS Senior Graphic Designer.

About *JOM: The Magazine*:

This print publication is excerpted from the publication of record, *JOM*, which includes both The Magazine and The Journal sections. *JOM: The Magazine* includes news and insights about TMS, its members, and the professions it serves. To access the publication of record, visit www.tms.org/JOM.

About TMS:

The Minerals, Metals & Materials Society (TMS) is a professional organization that encompasses the entire range of materials science and engineering, from minerals processing and primary metals production to basic research and the advanced applications of materials. Learn more at www.tms.org.

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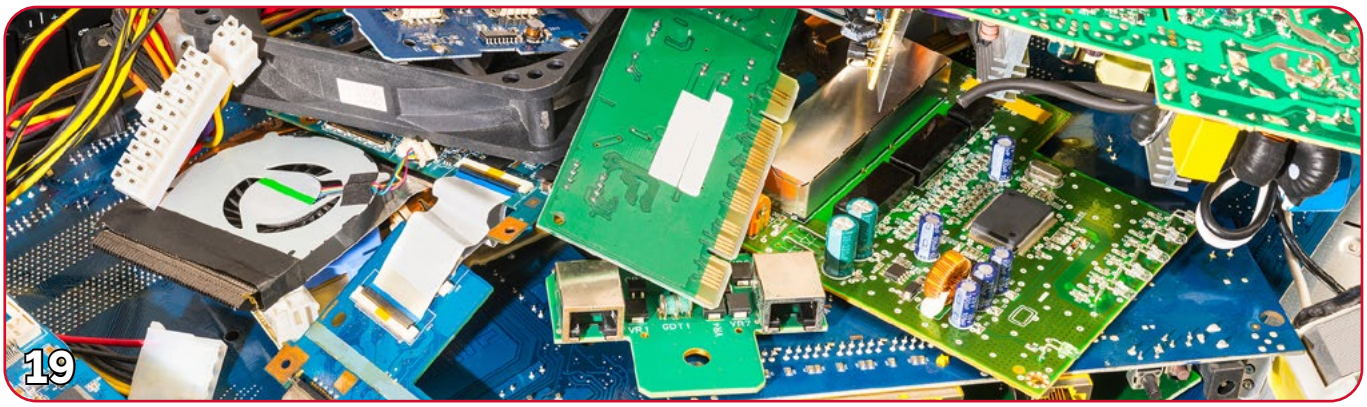

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IN THE FINAL ANALYSIS

JOM THE MAGAZINE

> *"Effective philanthropy requires a lot of time and creativity—the same kind of focus and skills that building a business requires."*
>
> —Bill Gates

When I began my TMS career in 1984, my tools as an editor were an IBM Selectric typewriter and a red pen. Today, I write this column using Microsoft Word running on Windows 11. Almost all of my meetings are held via Microsoft Teams. In a year, Microsoft Copilot will probably draft "In the Final Analysis" without me asking. No one wonders how Bill Gates and Paul Allen became very, very, very, very wealthy from founding and building Microsoft. By the turn of the millennium, Bill and then-wife Melinda founded and built something arguably as notable: The Bill & Melinda Gates Foundation to improve global health, education, libraries, and the U.S. Pacific Northwest.

Working on a much smaller scale than the Gates Foundation, the TMS Foundation is also doing its part to make the world a better place by encouraging materials professionals and students to excel in the field. TMS members know this well, as they are now receiving appeals and encouragement to participate in our 2023 fundraising campaign. This column fits in that category.

To understand why we give today, let's look back many yesterdays. . . . 2023 marks the 30th anniversary of the establishment of the TMS Foundation. The founders were J. Keith Brimacombe, the 1993 TMS President, and Lionel ("Kim") Kimmerling, the 1994 TMS President. They led many equally passionate volunteers. As Keith described it in the March 1994 *JOM*:

> *Very high on the priority list was the nurturing of young people, especially through the establishment of the TMS Foundation. It was time that TMS had a mechanism whereby we could facilitate the funding of activities such as scholarships, student design competitions, young professional development, and university curricula in the materials field. With the expert guidance of Kim Kimerling, who undertook the task of organizing the foundation, it now exists and funding is being received from the solicitations that were made. The foundation has three goals. The first is student support through scholarships and other initiatives. Second is curriculum development in materials science and engineering, with a special emphasis on design. . . . The third thrust is the support of young professionals. . . . Our goal in the first year is to raise in the vicinity of $100,000, and I am confident we will reach that goal.*

Keith was masterful in setting a compelling vision and pragmatic in laying out a pathway to reach it. There's good reason why so many awards are named in his honor. While we did not meet our goal of raising $100,000 in Year One, we did reach and better that goal in 1997, raising almost $120,000. That would remain the TMS Foundation's highwater mark for more than a decade as we had to learn the many practicalities of successful fundraising. Our down years helped us hone our philanthropic acumen, focus our governance, and modernize our fundraising practices. In 2013, the TMS Foundation again surpassed the $100,000 fundraising threshold. Over the next ten years, the TMS Foundation would not raise less that $120,000 in any given year. More typically, fundraising exceeded $200,000 per year. Twice, fundraising passed $500,000.

I thought of Keith as I read Lynne Robinson's "A Chance to Give Back—Twice" in this issue. She quotes Carl Cady, current TMS Foundation Chair, who says, "The focus of the TMS Foundation Board of Trustees is to grow the endowment so the Foundation is self-sustaining and can continue to fund activities that enable and encourage our next generation of members to participate in the Society." I read his words as reflecting decades of consistent vision, leadership, and purpose. . . . Your gift this month will certainly help advance that tradition.

James J. Robinson
Executive Director

James Robinson

"Working on a much smaller scale than the Gates Foundation, the TMS Foundation is also doing its part to make the world a better place by encouraging materials professionals and students to excel in the field."

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JOM TECHNICAL TOPICS

JOM THE MAGAZINE

Find peer-reviewed technical articles covering the full range of minerals, metals, and materials science and engineering in the December issue of *JOM:* The Journal. Each issue features several technical topics presenting a series of related articles compiled by guest editors. A preview of December technical topics and articles are listed below. TMS members can log in to www.tms.org/Journals for full access to technical articles from *JOM:* The Journal and additional TMS journals.

Article information is current as of October 3, 2023.
For the most up-to-date article listing, visit www.tms.org/JOM.

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Additive Manufacturing for High Temperature Energy Systems: Harvesting Material Data and Modeling

Editors: **Isabella van Rooyen**, Pacific Northwest National Laboratory; **Xiaoyuan Lou,** Purdue University; **Kumar Sridharan,** University of Wisconsin-Madison**; Subhashish Meher,** Pacific Northwest National Laboratory; **Yi Xie,** Purdue University
Sponsors: Additive Manufacturing Committee and Nuclear Materials Committee

"Pulsed Laser Additive Manufacturing for 316L Stainless Steel: A New Approach to Control Subgrain Cellular Structure," **Houshang Yin,** et al.

"Reactive Synthesis in Additive Manufacturing of an Ultrahigh Temperature MoSiB Alloy," **Zahabul Islam,** et al.

"Microstructure and Temperature Dependent Indentation Response of Additively Manufactured Precipitation-Strengthened $Al_{0.3}Ti_{0.2}Co_{0.7}CrFeNi_{1.7}$ High Entropy Alloy," **Mohan Sai Kiran Kumar Yadav Nartu,** et al.

"Microstructure, Mechanical Properties and Oxidation Behavior of Refractory Multi-Principal Element Alloys by Laser Remelting and Conventional Manufacturing," **Visharad Jalan,** et al.

"Microstructure and Residual Stress in Functionally Graded 316L Stainless Steel/Inconel 625 alloys Fabricated by Direct Energy Deposition," **Xinchang Zhang,** et al.

"Microstructural Characterization of the Transition in SS316L and IN625 Bimetallic Fabricated Using Hybrid Additive Manufacturing," **Christopher J. Bettencourt,** et al.

Advanced Functional and Structural Thin Films and Coatings

Editors: **Nugehalli Ravindra,** New Jersey Institute of Technology; **Adele Carradò,** University of Strasbourg; **Karine Mougin,** Mulhouse Materials Science Institute; **Ramana Chintalapalle,** University of Texas-El Paso; **Gerald Ferblantier,** University of Strasbourg
Sponsor: Thin Films and Interfaces Committee

"Influence of Concentration of Potassium Hydroxide in Electrolyte on Formation of Hydroxyapatite Coatings on Titanium," **O.V. Tkachuk,** et al.

"Inorganic Capping Layers in RDL Technologies: Process Advantages and Reliability," **Emmanuel Chery,** et al.

"Fabrication and Performance Evaluation of Schottky Diode Device Fabricated Utilizing Ultrathin Silver Nanowires-PEDOT:PSS Composite Electrode," **Amna Mir,** et al.

"A Comparative Study of the Electrochemical and Microstructural Characteristics of Optimized Electroless Ni-P-SiO_2 Nanocomposite Coatings Using a Sulphamate Bath on Brass Alloy," **Narges Mahdavi,** et al.

"Effect of Current Type and Density on Tribological Properties of Electrodeposited Ni-Co/MWCNT Nanocomposite Coatings," **Ramazan Karslioglu,** et al.

"Metal/Polymer/Metal Sandwich Systems—An Overview," **Adele Carrado,** et al.

Characterization of Interactions between Materials and External Fields

Editor: **Zhiwei Peng**, Central South University
Sponsor: Materials Characterization Committee

"Crystallization Behavior of Calcium Silicate-Based Mold Flux under the Electropulsing Treatment with Different Pulse Duty Cycle," **Wanlin Wang,** et al.

"Microwave-Intensified Separation of Boron and Iron from Ludwigite Ore Based on Impedance Matching," **Lei Ye,** et al.

"Phase Equilibria of Ti-bearing Electric Furnace Slags in the CaO-MgO-SiO_2-13%Al_2O_3-50%TiO_2 System," **Jianfa Jing,** et al.

"Phase and Structure Optimizations of MoS_2 Concentrate Pellets with Al_2O_3-SiO_2 Additives During Oxidative and Volatilizing Roasting Process," **Guanghui Li,** et al.

"Experimental Investigation of TiO_2 Pigment Production by Electrodialysis Process from Ilmenite Concentrate," **Amirhossein Meysami,** et al.

"Thermodynamic Analysis and Experiment on the Conversion of Niobium Ferrite to Pyrochlore," **Xin Peng,** et al.

"Cooling Rate of Hot Stamping Dies by Constructed Cooling Temperature Trend Model," **Yuhang Zhang,** et al.

"Carrier Transport Enhancement by Doping Rubidium in $Cu_{0.5}Tl_{0.5}$-1223 Superconducting Phase," **Anila Kanwal,** et al.

Composite Materials for Sustainable and Eco-Friendly Material Development and Application

Editors: **Brian Wisner,** Ohio University; **Ioannis Mastorakos,** Clarkson University; **Muralidharan Paramsothy,** NanoWorld Innovations; **Simona Murph,** Savannah River National Laboratory
Sponsor: Composite Materials Committee

"Phyto-Synthesis and Characterization of *Parthenium*-Mediated Iron Oxide Nanoparticles and an Evaluation of their Antifungal and Antioxidant Activities and Effect on Seed Germination," **Rajiv Periakaruppan,** et al.

"Calculation of f-CaO Hydration Ratio in Steel Slag Based on Mathematical Model of Hydration Expansion of Steel Slag–Cement Cementitious Materials," **Taiyue Chen,** et al.

"Preparation, Characterisation, and Properties of Anti-erosion Grouting Materials from Industrial Solid Waste," **Yifan Gao,** et al.

"Composite Fayalite with 5% Laterite Soil and Iron Sand: Structural Properties and Band Gap Calculation Based on Theoretical Kubelka–Munk, Taylor Expansion, and Self-Consistent Field Method," **Heryanto Heryanto,** et al.

"*Ocimum tenuiflorum*-Assisted Fabrication of Iron-Oxide Nanoparticles and Its Use in Wastewater Treatment of the Textile Industry," **Rajiv Periakaruppan,** et al.

"Effect of Thermo-Processing on The Microstructure, Impact Abrasion Wear, and Corrosion Resistance Properties of TiC Reinforced Al Added High Mn Steel Matrix Composite," **Renuprava Dalai,** et al.

"A Study of the Damage Mechanism and Microstructures of Aeolian Sand Concrete Specimens Undergoing Salt-Freezing Effects," **Wei Dong,** et al.

"Bio-based Copolyesters from *p*-Hydroxybenzaldehyde: Synthesis, Characterization and Thermo-Mechanical Properties," **Huan Wang,** et al.

"Selective Removal of Lead (II) Ions from Wastewater with Fabricated ZnO-PVA Membrane," **Hafiza Mehwish Rasheed,** et al.

"One-Step Binding and Wrapping Fragmented Natural Microcrystalline Graphite Via Phenolic Resin into Secondary Particles for High-Performance Lithium-Ion Battery Anode," **Yu Ma,** et al.

"Synthesis and Characterization of Hybrid Nanocomposites based on Poly(2-chloroaniline) / Zinc Oxide Nanofiller for Antibacterial Studies Against *Escherichia coli* and *Bacillus subtilis*," **Mirza Nadeem Ahmad,** et al.

"Effect of Mg on Compression Property of Porous Zn Alloys Fabricated by Low-Temperature Reactive Sintering Powder Metallurgy Approach," **Donghui Yang,** et al.

"Degradation of High-Density Polyethylene (HDPE) Film by Bacterial Consortium," **Hong Zhang,** et al.

"Investigation of Reusing Copper Converter Slag Residue with the Flash Sintering Method," **Zeynep Çetinkaya**

"Synthesis and Characterization of *Phyllanthus acidus*-Assisted Iron-Oxide Nanoparticles for the Removal of Heavy Metals from Wastewater," **Rajiv Periakaruppan,** et al.

"Nickel Nanoparticles Loaded in Smart Crosslinked Organic Polymer Microgels/Hydrogels: A Review," **Muhammad Afif,** et al.

"Mechanical And Degradation Studies on The Biodegradable Composites of a Polylactic Acid Matrix Reinforced by Tricalcium Phosphate, and ZnO Nanoparticles for Biomedical Applications," **Muzamil Hussain,** et al.

"Exploring a Sustainable Approach to Antioxidant Potential of Iron Oxide Nanoparticles Synthesized Using *Citrus sinensis* Peel Extract," **Mosleh Mohammad Abomughaid**

"Effect of Bioceramic Reinforcement on Mechanical and Machinability Behaviour of Az31 Magnesium Alloy Composites," **A. Saravanakumar,** et al.

"Mechanism of Deep-Sea Microbial-Mediated Synergistic Synthesis of Ferromanganese Oxidation Products Process for Heavy Metal Ion Adsorption," **Shunliang Liu,** et al.

"Facile Synthesis of CoO/Sm2O3@UiO-66-NH2/NF Composite as Efficient Photocatalysts for Oxygen Evolution Reaction," **Muhammad Kashif,** et al.

Environmental Stability of Materials and Coatings at High Temperatures

Editors: **Vilupanur Ravi**, Cal Poly Pomona; **Kinga Unocic**, Oak Ridge National Laboratory; **Steven Raiman**, University of Michigan; **Bai Cui**, University of Nebraska; and **Wenjun Cai**, Virginia Tech
Sponsor: Corrosion and Environmental Effects Committee

"Corrosion Behavior of $Fe_{81}Cr_{19}$, $Fe_{49}Co_{49}V_2$, and $Co_{72}Fe_4Mn_4Nb_4Si_2B_{14}$ Alloys in Simulated Venusian Environment," **Yuankang Wang,** et al.

"Microstructure and Early-stage Oxidation Behavior of Co-Cr-Cu-Fe-Mn-Ni High-Entropy Alloys," **Jonathan Apell,** et al.

"High Temperature Corrosion of Ni-Cr Alloys Exposed to Calcium Oxide," **Nicholas Ury,** et al.

Identification of Anisotropic Constitutive Models for Complex Loading Paths

Editors: **Myoung-Gyu Lee**, Seoul National University; **Daniel R. Coughlin**, United States Steel Corporation
Sponsor: Shaping and Forming Committee

"Development of a Deep Learning Model for Capturing Plastic Anisotropy-Texture Linkage," **Taejoon Park,** et al.

"Identification of Plasticity and Fracture Models for Automotive Extruded Aluminum Parts Using Finite Element Model Updating Algorithm," **Jung Yun Won,** et al.

"Simulation-Free Identification of the Reduced Hosford-Coulomb Ductile Fracture Criterion for the Nimonic Sheets Assisted by the Virtual Fields Method," **Chanyang Kim,** et al.

"Multi-interpolation Method to Linearize Stress Path in Cruciform Specimen for In-plane Biaxial Test," **Jinjae Kim,** et al.

"Rate-Dependent Hole-Expansion Experiments on Plastically Anisotropic Sheets," **Carter J. Fietek,** et al.

Microstructures and Mechanical Behavior of High-entropy Materials

Editors: **Peter Liaw**, University of Tennessee; **Jongun Moon**, University of Tennessee; and **Jamieson Brechtl**, Oak Ridge National Laboratory

"Investigation on the Tension-Compression Asymmetry of CoCrFeNiAl high-entropy Alloy under the Influence of Twining Boundary Spacing," **Qiaoyun Tang,** et al.

"Machine Learning Based Hardness Prediction of High-Entropy Alloys for Laser Additive Manufacturing," **Wenhan Zhu,** et al.

"Molecular Dynamics Simulation for Nanoindentation on Nano-Laminated Dual-Phase CoCrFeMnNi High-Entropy Alloy," **Peiwen Liu,** et al.

"Microstructure and Mechanical Properties of AlCoCrFeNi High-Entropy Alloy-Reinforced Ti-Al Metallic-Intermetallic Composites," **Enhao Wang,** et al.

"Effect of Post Welding Treatment on Corrosion Behavior of Laser and Gas Tungsten Arc-Welded $(Fe_{50}Mn_{30}Co_{10}Cr_{10})_{99}C_1$ Interstitial High Entropy Alloy," **Sushil Yebaji,** et al.

Nanostructured Biomaterials

Editor: **Roger Narayan**, North Carolina State University

"Curcumin-Laden Crosslinked Chitosan–PVA Films: The Synergistic Impact of Genipin and Curcumin on Accelerating Wound Closure," **Reteesha Ramdani,** et al.

"A Comprehensive Study on Extracellular Green Synthesis, Antibacterial Activity and Process Design of Metallic Nanoparticles from *Botryococcus braunii* Microalga," **Anıl Tevfik Koçer,** et al.

"A Novel Magnetization-Modified Attapulgite as an Excellent Adsorbent for Tetracycline in Water," **Jiuling Wang,** et al.

"Properties and Effects of a Drug-Loaded Haemostatic Sponge," **Lusha Wang,** et al.

"An In-Vivo Study on Nanostructured Ti Dental Implant Produced by Caliber Rolling and Surface Modification by SLActive," **Mohammadreza Sadrkhah,** et al.

"Antimicrobial Evaluation of Metal Microneedles Made by Local Electrodeposition-Based Additive Manufacturing on Metal-Coated Substrates," **Gregory Sachan,** et al.

Pyrometallurgical Techniques Towards Emissions Reductions

Editors: **Mohamed Elzohiery,** Guardian Industries; **Will Hannemann,** Glencore Technology
Sponsor: Pyrometallurgy Committee

"Effect of H_2 on the Distribution of Phosphorus in Gaseous Reduction of Hematite Ore," **Edson Kugara Chiwandika,** et al.

"Removal of C, Si, Mn, S and P in Iron Melt under Hydrogen Plasma," **Ramesh Kumar,** et al.

"Sticking Behavior During the Reduction Process in a Gas–Solid Fluidized Bed with an Inclined Agitator," **Chuanfu Li,** et al.

"Efficient Leaching Arsenic and Recovering Antimony from High Arsenic Soot," **Zeyu Xiao,** et al.

"Study on the Application of Straw Carbon as Reductant in the Recovery of Iron from High-Iron Red Mud," **Xiaofei Li,** et al.

"Phase Evolution and Recovery Rate of Sb in Lead-silver Slag Treated via Melting-fuming Method," **YingYing Shen,** et al.

"Optimization of Gas-Solid Co-Reduction Conditions for Deep-Sea Polymetallic Nodules," **Fan Li,** et al.

View More Technical Articles

JOM regularly publishes additional articles that fit within the scope of the journal, but not within the scope of a particular technical topic. Read these in the "Technical Articles" section of *JOM* on Springer.

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TMS MEMBER NEWS

JOM THE MAGAZINE

Share the Good News!

Contact Kelly Zappas, *JOM: The Magazine* editor, at kzappas@tms.org to share your professional accomplishments. Please note that only news submitted by current TMS members will be considered.

Babak Raeisinia Featured in Smarter Every Day Series

Babak Raeisinia, co-founder and head of applications and partnerships for Machina Labs, was featured in Destin Sandin's YouTube series, Smarter Every Day. Sandin is an engineer and science communicator who produces educational videos on his YouTube channel. In a recent video as part of a manufacturing series, Sandin visited the Los Angeles-based Machina Labs and talked to Raeisinia and Machina Labs chief executive officer, **Edward Mehr,** along with several other employees. This video provided a deep dive into Machina Lab's incremental sheet forming process or, as they call it, Roboforming™. Currently, Machina Labs primarily works on sheet forming, but through innovation they hope to move into robotic craftsmanship. To learn more, watch the whole video "ROBOFORMING: The Future of Metalworking?" on **www.youtube.com/SmarterEveryDay**.

Raeisinia is a member of the lead expert team for the new Office of Naval Research (ONR) sponsored TMS science and technology accelerator study on digital manufacturing, which includes potentially game changing manufacturing technologies such as Machina's Roboforming. He is also part of the organizing committee for TMS's Digital and Robotic Forming 2024, co-located at the TMS Specialty Congress 2024, which will take place from June 16–20, 2024, in Cleveland, Ohio. Make plans to attend or learn more about this meeting at **www.tms.org/RoboticForming2024**.

TMS Aluminum Courses Convene in the Kingdom of Bahrain

In September 2023, attendees met for two TMS Aluminum Courses: the 2023 Anode Technology for the Aluminum Industry Course (Anode 2023) and the 2023 Control of Potline Scrubber and Fugitive Emissions for Aluminum Smelters Course (PSFE 2023). These courses were held concurrently in Manama, Kingdom of Bahrain, and featured four days of expert instruction, collaboration, and tours of the Aluminium Bahrain B.S.C. (Alba) Plant.

Anode 2023 was a practical, operations-focused course which built on the success of previous iterations and presented topics in the development of anodes, such as rodding and fume control with an emphasis on operational aspects and theoretical lectures. Five experts were engaged in organizing and instructing this course: **Les Edwards** (Lead Instructor), Rain Carbon Inc.; **Christopher Kuhnt,** Rain CII Carbon LLC; **Stephen Lindsay,** Alcoa/Hatch; **Alan Tomsett,** Rio Tinto Pacific Operations; and **Barry Sadler,** Net Carbon Consulting Pty Ltd.

Attendees of the Anode 2023 and PSFE 2023 courses gather in Manama, Kingdom of Bahrain. *Photo courtesy of Aluminium Bahrain B.S.C. (Alba).*

PSFE 2023 focused on providing a complete, intensive overview of the latest techniques for controlling and reducing emissions from the aluminum smelting process. The curriculum featured in-depth presentations from these experienced instructors: **Stephan Broek** (Lead Instructor), Kensington Technology Inc.; **Stephen Lindsay,** Alcoa/Hatch; **James Metson,** The University of Auckland; **David Wong,** Atmolite Consulting Pty Ltd.

Both courses included tours to the state-of-the-art Alba plant, one of the world's largest aluminum smelters, which produces aluminum products in the form of Standard and Value-Added Products.

Learn more about the TMS Aluminum Courses at **www.tms.org/AluminumCourses**.

Anode 2023 and PSFE 2023 participants tour the Aluminium Bahrain B.S.C. (Alba) plant. *Photo courtesy of Aluminium Bahrain B.S.C. (Alba).*

Journal of Sustainable Metallurgy Seeks Topical Collection Submissions

The *Journal of Sustainable Metallurgy* is seeking submissions for the topical collection, "Reaction Kinetics Study of Ferrous and Non-ferrous Materials Using Hydrogen and Biomass," guest edited by **Xue Feng Dong** and **Paul Zulli** from the ARC Research Hub for Australian Steel Innovation at the University of Wollongong, Australia. This topical collection is dedicated to advancing understanding of reaction kinetics of ferrous and nonferrous materials under metallurgical conditions with hydrogen and biomass. It will present the latest research outcomes from the study of reaction kinetics in various fluid–solid systems found in the metallurgical industry.

The scope will cover experimental analysis and measurements, numerical modelling, process evaluation, and reactor design, ultimately to enable quantitative analysis of kinetics. Specifically, this collection will assemble manuscripts from different perspectives, including reviews on hydrogen and biomass applications, optimal design of fluid–solid systems, theoretical model development, quantification of reaction rates and parameters, exploration of reaction mechanisms, experimental measurements and observations, analysis of morphology change and phase transformations, and future developments in process control technology. Results from laboratory and/or pilot scale studies and industrial trials are welcome.

Submissions are due **January 31, 2024,** through **www.editorialmanager.com/sume.** After logging in, choose "Submit New Manuscript," and then select article type "Thematic Article." When reaching the "Additional Information" screen, indicate that you are submitting for the topical collection "Reaction Kinetics Study" from the list of options. Author instructions and additional journal details are available at **www.springer.com/40831**.

TMS Supports Letter to State Leaders Regarding Strengthening Domestic MSE Degree Programs

As of September 2023, TMS is a signatory of a letter developed by the Essential Minerals Association that expresses the views of many U.S. colleges, universities, and engineering professional societies about the critical shortage of college graduates in geological and engineering disciplines required to meet the necessary quantity of minerals essential to the transition to clean and renewable technologies. The fields of mineral exploration, extraction, and processing struggle to hire qualified engineers and scientists, which limits these industries from innovating, achieving production targets, and strategic objectives, due to the mass retirement of the baby boom generation and the lack of students entering relevant degree programs. In addition, the number of accredited mining and mineral development programs at U.S. universities has drastically decreased over the last forty years.

The solution to the problem laid out in this letter is to strengthen domestic degree programs, including through the Mining Schools Act of 2023 (S. 912) and its companion bill, H.R. 2685. TMS and the universities and professional societies who support this letter encourage the timely passage of both bills.

Read the whole statement at **www.tms.org/CurrentIssues**.

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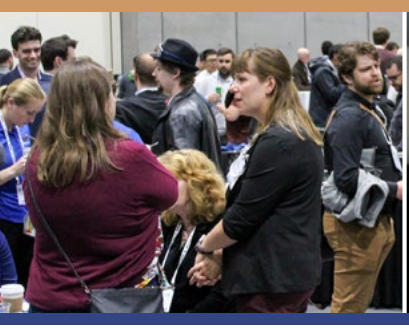
GET READY FOR THE MAIN EVENT: TMS2024

Kelly Zappas



Strong technical programming, an active exhibition, and a collection of networking, social, and professional development events will come together under one roof for the TMS 2024 Annual Meeting & Exhibition (TMS2024), March 3–7 in Orlando, Florida, USA. The TMS Annual Meeting is the Society's biggest event of the year—regularly attracting more than 4,000 minerals, metals, and materials scientists and engineers from around the world.

This will be the first TMS annual meeting held in Orlando since 2015 and the first ever to take place at the Hyatt Regency Orlando. The setting is a different one from our most recent Orlando meeting, because it will not take place on Walt Disney World® property. Instead, the venue is located in Orlando's popular International Drive Entertainment District, which offers shopping, attractions, and a variety of dining options. International Drive is only 15 minutes from the Orlando International Airport; close to Universal Orlando, SeaWorld® Orlando, and Disney resorts; and just 20 minutes from downtown Orlando and other neighborhoods. The venue is also different from TMS2023 in San Diego, California, because attendees will not need to travel between a hotel and convention center. At TMS2024, all events will take place within the hotel complex.

This article provides an overview of the technical programming and networking event information available at *JOM*'s press time. Please visit the TMS2024 website at www.tms.org/TMS2024 to view the latest updates on the conference, to search programming and events plans, to reserve housing, and to register for TMS2024.

PREVIEW TECHNICAL PROGRAMMING

What interests you most? Is it materials for sustainability, energy technologies, or extreme environments? Artificial intelligence and data-enabled materials science? Processing for tailored performance? The TMS2024 technical program features more than 90 symposia planned in 11 technical tracks, exploring these topics and more.

This year's technical tracks are:

- Additive Manufacturing
- Advanced Characterization Methods
- Biomaterials
- Data-Driven and Computational Materials Design
- Electronic, Magnetic, and Energy Materials
- Light Metals
- Materials Degradation and Degradation by Design
- Materials Synthesis and Processing
- Mechanics of Materials
- Nuclear Materials
- Special Topics

Symposia and technical topics are developed by volunteer TMS leaders working in more than 30 technical committees, ensuring that programming comes from TMS members and is based on the interests of members working in industry, academia, and national laboratories.

SEARCH THE PROGRAM AND EVENTS CALENDAR

A Preliminary Program and Events Calendar is now available that allows users to search technical programming, committee meetings, social and networking events, and individual presentations planned for TMS2024. Use the dropdown menus for a broad search or type in a technical keyword (ex. aluminum, characterization) or event type (ex. committee, reception, student) for a more refined search. This popular tool, introduced last year, lets you find topics of interest quickly. New for this year is the ability to log in to the site and save your search results for future reference.

Please note that this tool is meant only to provide preliminary information on programming and events; the TMS2024 app will be available in February to allow you to build an official at-meeting schedule.

HONORARY SYMPOSIA

Five distinguished TMS members will be recognized at special honorary symposia, sponsored by TMS technical divisions and held as part of the TMS2024 Technical Program. Plan to join your fellow TMS members at these sessions.

Wole Soboyejo will be honored by the TMS Structural Materials Division at the symposium, **Materials Science for Global Development—Health, Energy, and Environment.** This symposium will provide an opportunity for participants to discuss the current interest and progress in advanced structural and functional materials that are relevant to global challenges and international development.

The TMS Functional Materials Division (FMD) will honor **Victorino Franco** at the symposium, **Advanced Soft Magnets and Magnetocaloric Materials.** This honorary symposium will cover several aspects of soft magnets and magnetocaloric materials, from novel material design to prototyping and validation.

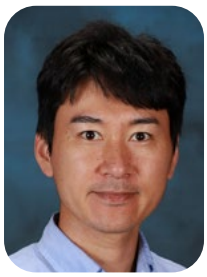
The FMD will also honor **Uday B. Pal** with the **High Temperature Electrochemistry** symposium. This symposium will cover a broad range of topics related to the fundamentals and applications of high-temperature electrochemistry.

The TMS Light Metals Division will honor **Anil K. Sachdev** at **An Atoms to Autos Approach for Materials Innovations for Lightweighting**. This symposium will focus on how microstructure can be engineered to address challenges related to lightweight product design and manufacturing.

Takashi Nakamura will be honored by the TMS Extraction & Processing Division at the **Process Metallurgy and Environmental Engineering** symposium. This symposium will review the history of the research on the physical chemistry of smelting and recycling processes for nonferrous metals such as copper, lead, and zinc, and on the environmental issues related to the circulation of nonferrous metals.

FRONTIERS OF MATERIALS SYMPOSIA

Two symposia at TMS2024 will explore hot or emergent technical topics, organized by recipients of the TMS Frontiers of Materials Award. This award offers selected early-career professionals an opportunity to present symposia in topic areas that are novel, exciting, or not covered by existing TMS programming. In return, TMS2024 attendees benefit from the chance to explore future growth areas at the frontiers of materials research.



Takaaki Koyanagi, Oak Ridge National Laboratory, will host the symposium **Novel Ceramics Processes for Nuclear Applications.** This special session will bring together scientists and engineers to discuss opportunities and needs for key enabling materials processing for application in nuclear energy systems. As part of the session, Koyanagi will deliver the keynote presentation, "Development of Next-Generation Silicon Carbide Composites for Nuclear Energy."

The symposium **Physics-Informed Machine Learning for Modeling and Design of Materials and Manufacturing Processes** will be organized by **Pinar Acar,** Virginia Polytechnic Institute and State University. This event will feature presentations on modeling, multi-scale modeling, and the design of materials and manufacturing processes across different length scales (ranging from the atomistic scale to the macro-scale) using physics-informed machine learning techniques. Acar will deliver the symposium's keynote presentation, "Inverse Design for Crystal Plasticity Model Identification via Physics-Informed Neural Networks."

TMS2024 PROCEEDINGS

TMS2024 attendees in most registration classes receive free online access to the complete collection of proceedings publications. Before the meeting, preregistered attendees will receive information on how to download proceedings content. The following titles are planned:

- *Advances in Pyrometallurgy: Furnace Containment*
- *Characterization of Minerals, Metals and Materials 2024: Process–Structure–Property Relations and New Technologies*
- *Composite Materials: Sustainable and Eco-Friendly Materials and Application*
- *Energy Technology 2024: Carbon Dioxide Management and Other Technologies*
- *Light Metals 2024*
- *Magnesium Technology 2024*
- *Materials Processing Fundamentals 2024: Iron and Steel Production*
- *Rare Metal Technology 2024*
- *TMS 2024 153rd Annual Meeting & Exhibition Supplemental Proceedings*

SPOTLIGHT ON THE EXHIBITION

The TMS2024 Exhibition provides a venue for companies to recruit new talent and connect with influential purchasers and for attendees to meet new suppliers and discover new products. This year's exhibit will focus on products and services that support the most popular themes of the meeting, including:

- Additive manufacturing and 3D printing laboratory
- Melt processing, casting and recycling of aluminum
- Digital and robotic manufacturing
- Employee recruitment
- Software and publishing
- Testing and characterization, including mechanical behavior
- Thermo/mechanical processing equipment

Explore offerings in these areas and more when you visit the exhibit hall at TMS2024. The exhibition will be held at the Hyatt Regency Orlando—the same venue as other meeting programming and events—and will host two receptions that invite all attendees to enjoy appetizers, drinks, and networking with colleagues, exhibitors, and poster presenters. The exhibit hall will also be the location for the 2024 TMS Bladesmithing Competition, a display of blades forged by student teams from around the world and a consistently popular attraction at the TMS Annual Meeting & Exhibition.

New exhibitors are being added regularly; visit www.tms.org/TMS2024/Exhibit to view the most up-to-date floorplan and exhibitor list.

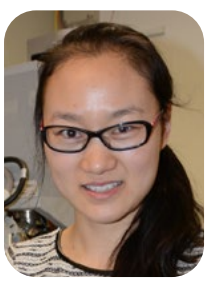
DIVISION LUNCHEON LECTURES

The TMS technical divisions will come together throughout the week at TMS2024 to enjoy camaraderie, celebrate award recipients, and hear about important topics relevant to their work at the Technical Division Luncheons. These events will feature the following invited speakers.

Structural Materials Division/Functional Materials Division Luncheon

Featuring Talks by the 2023 FMD and SMD Young Leaders Professional Development Award Recipients






Speakers: Jing Du, Penn State University; **Arun Kumar Mannodi,** Purdue University; **Dong Liu,** University of Bristol; and **Christopher Zenk,** Friedrich-Alexander-Universität

Extraction & Processing Division/ Materials Processing & Manufacturing Division Luncheon

Speaker: Dierk Raabe, Max-Planck Institut für Eisenforschung GmbH

Light Metals Division Luncheon

Speaker: Gregg Whigham, Aluminum Dynamics LLC

The presentations are free to all TMS2024 attendees, but you must purchase a ticket to these events to receive lunch. The cost per ticket is $75 and can be purchased through the TMS2024 registration form.

PREVIEW STUDENT EVENTS

TMS2024 will offer a number of competitions and events geared toward graduate and undergraduate student participants. Learn more about these activities—including the Bladesmithing Competition, Materials Bowl, student poster contest, student career forum, and more—in the Student Events section of www.tms.org/TMS2024 and in the article, "Prepare for Bladesmithing, Materials Bowl, and Student Poster Competitions at TMS2024," in the November 2023 issue of JOM: The Magazine.

RESERVE YOUR ROOM

Attendees can book rooms now at the Hyatt Regency Orlando with OnPeak, the official TMS housing provider, through the TMS2024 website. Those who book through TMS receive the following benefits:

- **Discounted Room Rates**: TMS and onPeak have negotiated discounted rates on hotel rooms for TMS2024 attendees.
- **Significantly Reduced Resort Fees**: All hotel guests are charged a resort fee of $38 per day, but that fee is reduced to $8 per day when you book through TMS and onPeak. This resort fee includes access to the property's fitness center, discounts on spa treatments and merchandise, and two I-Ride trolley tickets.
- **Discounts on Dining and Parking**: Receive a 10% discount at three of the resort's on-site eateries: B-Line, Descend 21, and Fiorenzo's. You'll also receive a 50% discount on self-parking if you bring a car to the hotel.
- **Complimentary WiFi**: Stay connected with complimentary internet access in your guest room.
- Also, guests who book by December 15 will be entered in a drawing for the chance to stay in one of the hotel's metropolitan suites free during the meeting. Visit the Housing section of www.tms.org/TMS2024 to reserve your room today.

REGISTER TODAY

Registration is now open for TMS2024. TMS members save 20% on meeting registration, so be sure to renew your membership before you register for the conference to lock in the discounted member registration rate. In addition, anyone who registers before **January 31** will also receive a 10% discount on meeting registration.

Visit www.tms.org/TMS2024 to register today, and plan to join your TMS colleagues in Orlando in March.

WHY TMS2024?

When asked to define the most important reasons to attend a TMS Annual Meeting, repeat attendee and 2024 TMS President Brad Boyce named three things: networking, learning, and sharing.

"It's great to meet colleagues from around the world who are sharing similar experiences," said Boyce in a video interview that explores the benefits of attending the TMS Annual Meeting.

"I've learned so much from the TMS annual meetings," Boyce continued. "Every year I come to these meetings with an open mind, and I realize how much more the field is doing that I didn't appreciate before I attended. I see where the field is going, and I meet other practitioners and I get inspired to go do better at my own work."

Visit www.tms.org/TMS2024 to watch the full video and to gain the perspective of one TMS member on how TMS2024 can benefit you and your career.

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Getting to Know the Incoming 2024 TMS Board Members

Kelly Zappas

In 2024, two new members will join the TMS Board of Directors for three-year terms. This month, *JOM* talks with our new leaders about their past experiences as TMS members and active volunteers and their hopes for the Society's future.

These new board members will begin their term at the end of the TMS 2024 Annual Meeting & Exhibition (TMS2024) in Orlando, Florida, March 3–7.

Dan Miracle
Presidential Cycle

Dan Miracle, a senior scientist in the Materials and Manufacturing Directorate of the Air Force Research Laboratory, will begin his three-year term in the TMS presidential cycle. He'll serve as vice president in 2024, as president in 2025, and as past president in 2026.

Miracle began his involvement with the Society when he gave his first technical talk at a TMS meeting in Pittsburgh, Pennsylvania, in October 1980, shortly after receiving his B.S. degree. However, it took him a long time to realize just how essential it is for materials scientists and engineers to come together to discuss their recent results and new ideas.

"While the publishing outlets associated with TMS have been very important in my career, without a doubt I've benefited most from attending the regular and specialty meetings organized through TMS," said Miracle. "The professional relationships, the partnerships, and the new ideas produced at these meetings have been foundational in helping advance my career."

For Miracle, TMS has always offered a good balance of basic and applied content, and the volunteer-led, 'bottom-up' approach to programming appealed to him. "Together, these features soon drew me in as a member of the technical committees, where the ability to contribute to the Society and our profession has kept me active for many years," he said.

As Miracle's career has progressed, so has his interest in contributing to TMS. He previously served

> *"I hope to contribute to the continued growth of TMS to address new needs and opportunities, so that we remain a highly inclusive society where global materials practitioners come together to envision, define, and enable the future."*
> **–Dan Miracle**

on the TMS Board of Directors as the chair of the TMS Structural Materials Division. "From my previous time on the TMS Board of Directors, I found that TMS is a well-organized, well-run, forward-looking professional organization. I also learned that it's not easy to maintain this position in a changing world, and I'm motivated to help TMS continue to flourish and grow as a vibrant and engaging society," he said.

"Most of all, I'm looking forward to working together with the talented volunteer leaders and passionate TMS staff and leadership that ensure that TMS runs smoothly," Miracle said. "I hope to contribute to the continued growth of TMS to address new needs and opportunities, so that we remain a highly inclusive society where global materials practitioners come together to envision, define, and enable the future."

Robert Maass
Program Director

Robert Maass is head of the Materials Engineering Department and a member of the directorate at the Federal Institute of Materials Research and Testing (BAM) in Berlin, Germany. At TMS2024, he will also step into the role of Program Director on the TMS Board of Directors. Maass first learned the value of TMS programming while earning his Ph.D. in materials science from the École Polytechnique Fédérale de Lausanne (EPFL) in Switzerland.

"I had the privilege of being in a very international group during my time as a graduate student in Switzerland," said Maass. "It was completely normal that fore-front results would be presented to our international peers at TMS meetings, which always have been a hot spot for structural materials research."

From there, he said, a colleague suggested he attend a technical committee meeting. "It was an eye opener," said Maass. "I realized that if I want to, I can get involved and contribute, learn, and lead. So, TMS became much more than just a meeting to go to, but a part of my personal and professional development. As of today, this is what makes TMS so unique and inclusive."

TMS, he said, is a place where he learns about the newest topics on the horizon, meets the best scientists in his field, and learns to take responsibility for the community in different service roles.

"I really encourage young peers to take advantage of getting engaged," said Maass. "It is a very rewarding experience and throughout my journey at TMS, I had the luck of learning from the best: my two programming chair predecessors, Brad Boyce and Tim Rupert."

Joining the Board of Directors, he said, is a natural consequence of having been involved in different committees. "There comes the point at which you either step down to give space for others," he said, "or you have to take more responsibilities. I love TMS, and therefore there was only one option."

> *"Programming is the heart of all TMS meetings. Fore-front topics and high-quality programming is what has brought the world together at our meetings."*
> **–Robert Maass**

His hope is that his continued involvement with TMS will also help to promote the Society in Europe, where he currently lives after many years in the United States, and to allow him to meet outstanding leaders in the field.

"Immersion in TMS is a fantastic way to lead, give back, and learn," he said.

Maass will give back by leading programming for the Society. He looks forward, specifically, to building up the TMS Fall Meeting, where he believes the Programming Committee will play a central role in creating a strong new identity for our Society at that event.

"Programming is the heart of all TMS meetings," he said. "Fore-front topics and high-quality programming is what has brought the world together at our meetings. Looking forward, this will remain our core mission, but I am also committed to strengthening our young scientists' opportunities, developing innovative programming items, and improving our communication with the technical committees."

Nominations Now Open for 2025-2028 TMS Board of Directors

TMS is now accepting nominations for two positions on the 2025–2028 TMS Board of Directors. The open positions are the Presidential Rotation and the Membership Diversity and Development Director/ Chair. Nominations will be accepted until **January 15, 2024**. Additionally, positions for three division chairs (Light Metals, Materials Processing & Manufacturing, and Structural Materials) are open on the 2025–2028 Board of Directors, but nominations for these positions are developed directly through the technical divisions.

Applicants' packages for the two open positions will be considered by the Society's Nominating Committee, which will then recommend a candidate for each position to the Board of Directors. If approved by the Board of Directors, these endorsed candidates will be presented to the general membership for approval by July 2024.

To access complete job descriptions and qualifications for each office, as well as the Nominee Statement Form and nomination instructions, visit www.tms.org/BoardNominations. For additional information, contact Deborah Hixon, TMS Awards Program Manager, at **hixon@tms.org**.

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TMS FOUNDATION

A Chance to Give Back—Twice

Lynne Robinson

Carl Cady

There's a good story to tell about the TMS Foundation during its 2023 year-end appeal—a story of growth, enthusiasm, and service. Carl Cady, TMS Foundation Board of Trustees Chair, is happy to share it as he encourages TMS members to donate to the Foundation as an important way to support their profession.

"The focus of the TMS Foundation Board of Trustees is to grow the endowment so the Foundation is self-sustaining and can continue to fund activities that enable and encourage our next generation of members to participate in the Society," he said. "I am excited by the growth of the Foundation's programs. We were able to expand the TMS Family Care Grant program from 20 to 30 grants offered in 2023 and have added five Young Leaders Professional Development Awards—one for each TMS technical division—to the next awards cycle. I'm looking forward to a future in which we have further flexibility to provide opportunities that would benefit our membership."

While donating to the TMS Foundation is a very direct way to support the profession, making that gift in honor of a colleague provides another avenue to give back by raising awareness of potential role models in the field. That was a motivator behind the $50,000 donation that Garry Warren, 2011 TMS President and Past Chair, TMS Foundation Board of Trustees, made in honor of Stanley Howard, 2016 TMS President, who passed away in 2021.

"It was a joy to work with Stan," said Warren. "Not only was he one of the smartest people I've ever met, but he was level-headed, even-tempered, a good listener, a skilled diplomat, and possessed an enviable sense of humor. He was always a calm voice of reason and had a unique ability to foresee problems or consequences to some course of action that a committee or the Board of Directors was contemplating. That was emblematic of his

Interested in Honoring a Colleague?

Simply check the Tribute box on the donation form and complete the information on the person you wish to honor. If you would like to discuss your donation personally, please contact the TMS Foundation staff at **TMSFoundation@tms.org**.

willingness to help others, which he did with great frequency.

"On a personal note, I could always count on him –no matter what! Friendships that last for 40+ years are a precious gift, and I am so pleased to make this donation in his honor," Warren continued. "A gift to the Foundation is one of a few ways a TMS member can not only honor a colleague, but also help demonstrate that each of us depends on mentors and friends throughout our careers."

Cady expressed his gratitude for Warren's gift and its intention. "Garry's generosity shines a light on an activity that Stan championed as a devoted Foundation Trustee," he said. "It's also a great example of another way TMS members can 'pay it forward' by tangibly recognizing and expressing gratitude to those people who helped or inspired you."

Whatever donation opportunity members choose, Cady emphasized that every gift goes directly to programs that support the next generation of minerals, metals, and materials professionals in meaningful ways. "I truly believe that every donation we receive returns to our membership tenfold," he said. "I thank everyone who has given to our Foundation or is considering a donation this year. By investing in the people who are shaping the future of our profession, you are making both TMS and the fields it serves that much stronger."

Give to the 2023 Year-End Appeal

Deadline: December 31, 2023

Donate Online: Use our online contribution form at **www.TMSFoundation.org/Contribute**.

Donate by Mail: Mail your donation to the TMS Foundation at 5700 Corporate Drive, Suite 750, Pittsburgh, PA 15237.

Questions? E-mail the TMS Foundation staff at **TMSFoundation@tms.org** or call us at 1-724-776-9000.

The Impact of Your Gift

The TMS Foundation supports students and early career professionals with meaningful financial assistance and impactful career-building experiences. Since its inception, the TMS Foundation—and the donors who support it—have made a difference in hundreds of careers and lives by conferring the following scholarships, grants, and awards:

387
Student Scholarships
Since 1994

512
Early Career Support Awards
Since 1996

121
Family Care Grants
Since 2017
Supported in collaboration with TMS

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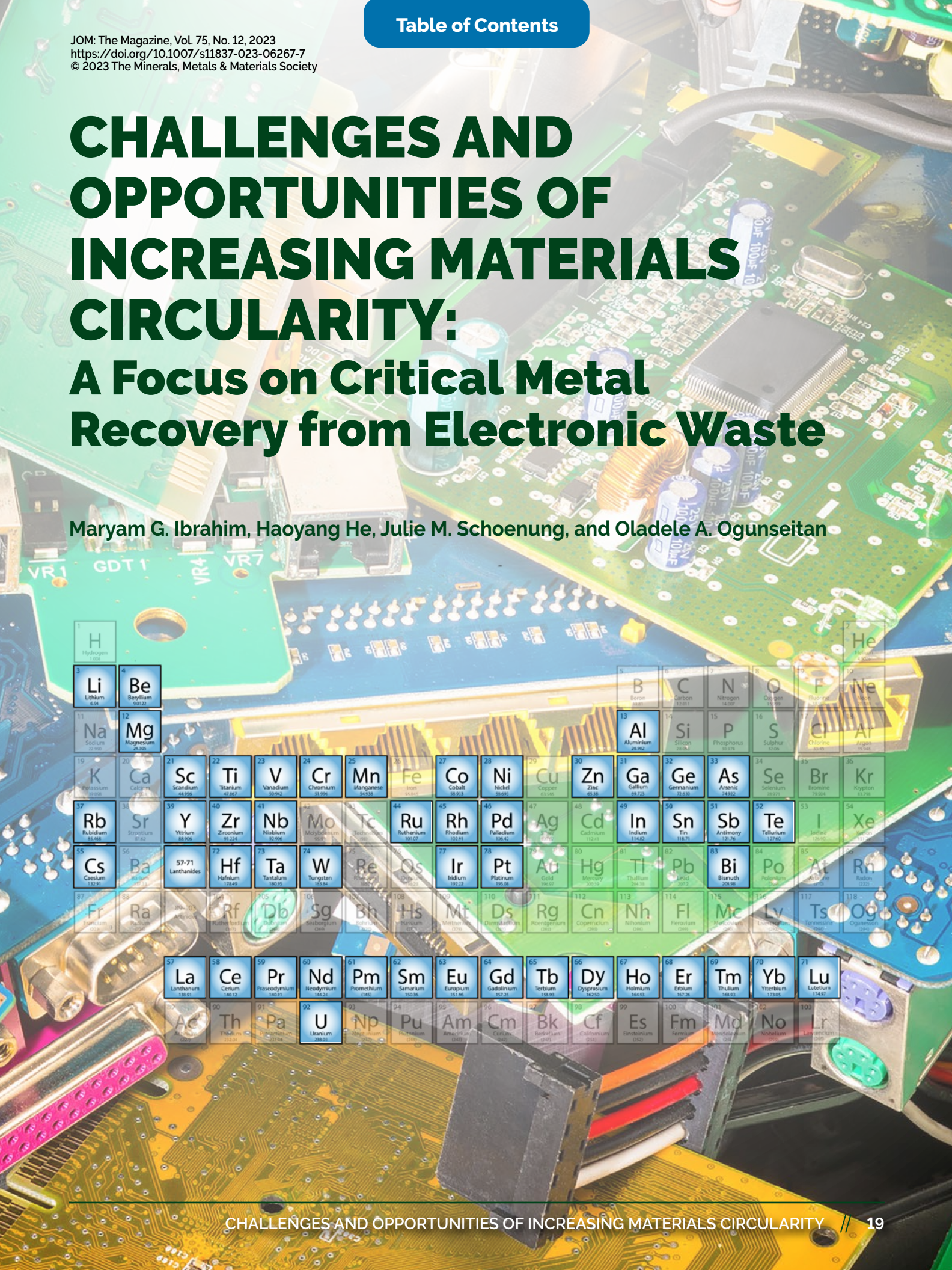
CHALLENGES AND OPPORTUNITIES OF INCREASING MATERIALS CIRCULARITY:

A Focus on Critical Metal Recovery from Electronic Waste

Maryam G. Ibrahim, Haoyang He, Julie M. Schoenung, and Oladele A. Ogunseitan



Editor's Note: This article is a summary of the authors' response to the 2023 Circular Economy Request for Information: Challenges and Opportunities of Increasing Materials Circularity, a call for information issued by the U.S. Department of Energy's Advanced Materials & Manufacturing Technologies Office (AMMTO) in March 2023. Information can be found at **www.energy.gov/eere/ammto/2023-circular-economy-request-information-challenges-and-opportunities-increasing**.

Recycling domestic waste printed circuit boards (WPCBs) to recover critical metals not only offers high economic value, but also facilitates the establishment of a circular supply chain that avoids fraught reliance on international sources of newly mined metals.

The Urgent Need for a Secure Supply Chain for Critical Materials

The world confronts unprecedented challenges in coordinating responses to emergent conditions including global climate change, population growth, and international security. These challenges have also stimulated rapid advances in software technologies. Among them is the development of artificial intelligence (AI) designed to support predictive and responsive strategies for processing and interpreting "big data." Yet, such software advances rely on hardware technologies, for which the supply of critical materials needed to sustain their manufacture and production at scale is increasingly uncertain.

The currently unsustainable supply chain of critical materials led to the recent circular economy request for information issued by the U.S. Department of Energy's Advanced Materials and Manufacturing Technologies Office (AMMTO). In this context, critical materials are defined as high-priority metals and semimetals with specific technological applications, and the susceptibility to supply chain constraints resulting from factors such as scarcity, price volatility, declining ore grades, and environmental burden.

Critical metals have proven to be un-substitutable in various cutting-edge applications due to their unique structural and functional properties. Specifically, the innovative use of critical metals such as cobalt, lithium, nickel, and rare earth elements (REEs) dysprosium, terbium, and neodymium, have enabled technologies with enhanced electrical, mechanical, thermal, magnetic, and optical functions. Other materials that are designated as 'critical' include precious metals such as gold, silver, platinum, and palladium, which have broad applications across many industries.

Strategies to increase the circularity of critical materials present special opportunities for research and development to generate quantitative databases and tools, including AI for assessments of environmental life cycle and functional performance, for integrating social and ecological incentives in recycling and resource recovery, and for overcoming techno-economic barriers against the transition from a linear to a circular economy. Thus, the request from AMMTO explicitly calls for an investigation into the "potential for electronic waste (e-waste) to be a viable source of critical materials." The trend toward circularity in the electronics industry has long been a topic of research and international regulations, but major impediments remain unresolved.[1,2] This article focuses on this particular topic by emphasizing strategies to recover critical metals from e-waste.

The integration of critical metals in manufacturing has spurred technological breakthroughs and engendered industries such as electronics, automobiles, and energy capture, all of which have revolutionized the landscape of human societies in the 21st century. Advanced electronic products are now manufactured with a wide range of critical metals that are embedded in miniaturized components and consolidated circuitry. All electronic products rely on printed circuit boards (PCBs) and the various electronic components attached to them, which contain a wider variety and higher concentration of critical metals compared to any other electronic hardware component.[3]

At present, the electronic equipment sector is the largest consumer of critical metals, for which global resource demand is projected to double by 2030. Competition for the supply of newly mined critical metals cuts across various electronic manufacturers and industrial sectors, while potential secondary sources are routinely discarded as e-waste, which has become a notorious source of toxic environmental pollution. Recycling domestic waste printed circuit boards (WPCBs) to recover critical metals not only offers high economic value, but also facilitates the establishment of a circular supply chain that avoids fraught reliance on international sources of newly mined metals.

Limitations of Current Technologies for Resource Recovery from E-Waste

Existing technologies for recycling WPCBs do not operate at the scale necessary to ensure full circularity because of a constellation of environmental, technical, and economic limitations.[4]

The current methods, initially designed for the recovery of base metals like copper and a limited range of precious metals (such as gold), involve mechanical processing, high-temperature smelting, and chemical leaching. Unfortunately, these methods yield a low recovery rate of critical metals, while generating toxic emissions. For example, it is estimated that the pre-

processing of WPCBs by mechanical size reduction and physical separation (i.e., gravity, magnetic, and electrostatic methods) results in a total dissipative loss of 30% in the initial volume of feed materials.[5] During this process, precious metals (gold, silver, palladium) and critical metals (cobalt, tantalum, nickel) are dissipated as fine dust and airborne particulates.

The extraction of metals from e-waste predominantly takes place in copper smelters, where operating temperatures often exceed 2,000˚C. Although this method is effective in reducing the volume of hazardous e-waste, it has thermodynamic limitations to targeted resource recovery. For example, critical metals cobalt, gallium, germanium, yttrium, tantalum, and tungsten and REEs do not readily dissolve in liquid copper and are either gasified and lost as particulates in the fume exhaust or accumulate in the slag phase.[5]

Additionally, large volumes of sulfur dioxide emissions, mixed metal oxides, persistent organic pollutants, and particulate matter are released during the various stages of smelting and subsequent refining processes. Chemical leaching methods require large volumes of highly corrosive and volatile reagents such as cyanide and halides, which produce toxic fumes, spent solvents, and complex sludge waste. There is an urgent need to develop improved methods for extracting critical metals from WPCBs to incentivize efficient resource recovery at an industrial scale.

The Potential and Promise of Cryogenic Milling of E-Waste for Resource Recovery

Preliminary data from laboratory-scale studies support the potential viability of cryogenic milling as a more environmentally sustainable alternative to the existing-waste recycling methods. This waste beneficiation route simultaneously functions as an efficient strategy for synthesizing large quantities of nanoparticles with superior structural and functional properties, while promising to fill the gap in the increasing demand for nano-based technologies.

During cryogenic milling, materials are mechanically milled at temperatures below -150°C, which is maintained by a continuous flow of liquid nitrogen and/or liquid argon. This technique hinges on the emergent properties of materials at below-zero temperatures to promote cold embrittlement, early fracture, and rapid grain refinement.[6] Specifically, materials such as amorphous polymers, ceramics, and metals with body-centered cubic (BCC) or hexagonal close-packed (HCP) lattice structures undergo ductile to brittle phase changes as they reach specific glass transition temperatures.[7] The BCC metals of interest include lithium, tantalum, niobium, and tungsten; while HCP metals of potential interest include cadmium, titanium, and cobalt. Other metals with face-centered cubic (FCC) crystalline lattices lose substantial plasticity and form mobile dislocations that lead to grain refinement.[7,8] Examples of metals that exhibit FCC lattice structures include copper, aluminum, silver, gold, and nickel.

Milling at cryogenic temperatures effectively suppresses recrystallization, cold welding, and agglomeration of particles, which would otherwise occur with room-temperature mechanical milling. In this regard, cryogenic milling is suitable for processing complex heterogeneous waste into recyclable elements and generates different classes of nanomaterials based on the length of milling time. Initial disassembly of electronic components should not be necessary because explosive materials can be safely milled below their ignition temperature. The consolidation of particles within a tightly closed system further reduces the risk of environmental pollution from fugitive dust.

Cryogenic milling of WPCBs aligns with safe-by-design strategies because it may be configured as a stand-alone process and does not require multiple phases and steps.[9] Thus, occupational and environmental health concerns are minimized due to suppression of the reactivity of materials at cryogenic temperatures, in comparison with current methods of e-waste management encumbered by contamination and hazardous emissions associated with the thermal degradation of polymers, halogenated flame retardants, and toxic metals.

Cryogenic milling of e-waste can be leveraged as a strategic approach to sustainable resource management by synchronizing the principles of green chemistry and materials circularity, thereby avoiding side effects that have compromised regrettable solutions to resource recovery technologies.

The recovery of critical metals from WPCBs can unlock an untapped economic potential by producing valuable resources while reducing the environmental and social pressures of processing e-waste and extracting primary material resources.

Next Steps

In the context of a circular economy, the mining of e-waste is a reliable opportunity to support U.S. industries with a sustainable secondary source of raw materials. The recovery of critical metals from WPCBs can unlock an untapped economic potential by producing valuable resources while reducing the environmental and social pressures of processing e-waste and extracting primary material resources. Much research and development work remains, and the necessary regulatory infrastructure needs to be implemented to support a strategic transition from the current linear economy of WPCBs to circularity.

First, existing national policies can benefit from incentives and enforcement to ensure that most if not all e-waste generated is collected from consumers, and international regulations that govern the transboundary movements of e-waste need to be strengthened. In the U.S., the Department of Justice's contract with UNICOR (the Federal Prison Industries program), in an initiative to collect and recycle e-waste through the federal prison system, can serve as an opportunity to pilot procedures for critical metals recovery.

Second, research is needed to ensure the cost-effectiveness of relatively new approaches such as cryogenic milling of e-waste to emphasize targeted recovery of critical metals.

Third, the marketability of recycling processes should consider the optimal level of purity in recovering critical metals to incentivize implementation and scale-up by industry.[7] In the case of nanotechnology, the properties of marketable nanoparticles should be pre-defined for the intended applications.[5] Recycling and resource recovery operations also need to be monitored routinely to protect workers and the environment by eliminating or reducing potentially toxic emissions.

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About the Authors

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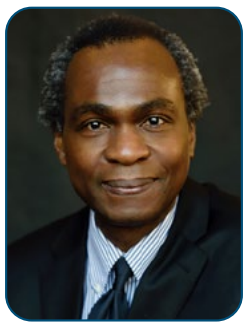
Haoyang He is currently working as a postdoctoral scholar in Professor Julie M. Schoenung's research laboratory in the Department of Materials Science and Engineering at the University of California, Irvine.

Julie M. Schoenung is department chair and distinguished professor in the Department of Materials Science and Engineering and co-director of the World Institute for Sustainable Development of Materials (WISDOM) at the University of California, Irvine. In 2021, she was inducted as a TMS Fellow.



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JOM: The Magazine, Vol. 75, No. 12, 2023
https://doi.org/10.1007/s11837-023-06268-6

In Case You Missed It:

BUSINESS NEWS FROM THE FIELD

Do you have business or industry news of interest to the minerals, metals, and materials community?

JOM THE MAGAZINE

Submit your announcement or press release to Kelly Zappas at kzappas@tms.org.

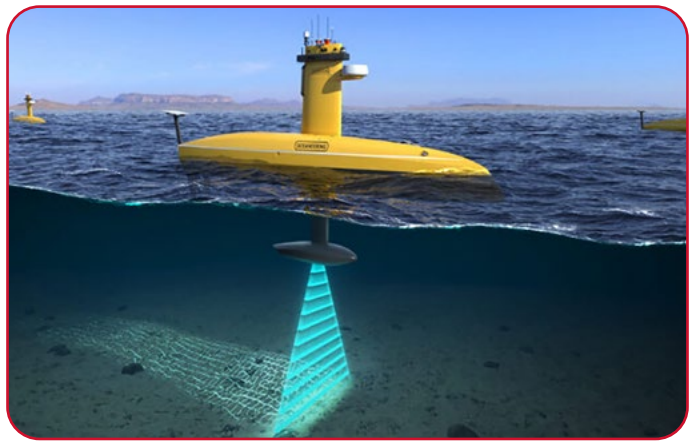
London, United Kingdom: Rio Tinto and H2 Green Steel signed a multi-year agreement for the supply of high-grade direct reduction iron ore pellets from Rio Tinto's Iron Ore Company of Canada (IOC). In addition, Rio Tinto will purchase and on-sell a portion of the surplus low carbon hot briquette iron (HBI) made by H2 Green Steel during their ramp-up of their steelmaking capacity. The direct reduction pellets will provide a large portion of the iron ore supply at H2 Green Steel's Boden, Sweden, plant. This plant is expected to begin operations in 2025, processing direct reduction pellets into HBI and making steel through electric arc furnaces using green hydrogen. (Pictured: Rio Tinto's IOC iron ore mines in Canada. Photo Credit: Rio Tinto)

REMADE Obtains New Technology License

Rochester, New York, USA: The REMADE Institute announced a new technology license which involves a technological innovation capable of removing metallic impurities from recycled aluminum melts, thus improving the quality of the aluminum and allowing for it to be used in more diverse applications. This technology was developed as part of the ongoing REMADE project, "Selective Recovery of Elements from Molten Aluminum Alloys," led by TMS member Subodh Das.

Fives Group Designs Cold Rolling Mill

Paris, France: The Fives Group has designed a cold rolling mill which enables the rolling of ultra-thin strips of electrical steel. The DMS 20Hi EcoMill was supplied to Xinyu, of the Baowu Group, and allows steelmakers to roll strips down to their minimum thickness without breaking while maintaining surface quality and flatness. The DMS 20Hi EcoMill's latest developments include increased rolling speed and strip tension, advanced roll gap lubrication for high product quality, enhanced fume extraction, better strip wiping efficiency, and more.



Aberdeen, Scotland: Oceaneering International's Subsea Robotics group announced a new Uncrewed Surface Vessel (USV) which will support remote survey work scopes. Through an agreement with Exail, Oceaneering International will purchase a DriX USV to aid deepwater geophysical and asset inspection operations, including offshore and nearshore surveys and autonomous underwater vehicle positioning. The DriX USV will support improved operational efficiencies, reduced vessel time on site, and reduced carbon emissions. (Photo Credit: Oceaneering International)

Blue Whale Materials to Build Battery Recycling Facility

Washington D.C., USA: Battery recycling company, Blue Whale Materials, has announced their plans to build a lithium battery recycling facility at Bartlesville Industrial Park in Bartlesville, Oklahoma, USA. This project is intended to aid the U.S.'s transition to a green energy economy and will help increase the domestic supply chain for materials used in rechargeable batteries. This facility will encompass 32 acres and provide 90 new jobs.

Panasonic to Make EV Batteries from Recycled Nickel

Osaka, Japan: In collaboration with U.S. startup, Redwood Materials, Panasonic will recycle minerals from used electric vehicle (EV) batteries to make new ones. This project aims to create a system where cells with reclaimed materials have equivalent cost and performance. As nickel accounts for 90% of the cathode material in Panasonic's EV batteries, it will be the primary focus of this endeavor; however, the company will also consider lithium and cobalt recycling. This project will take place at a Redwood factory in Nevada, and high-purity nickel is expected to be extracted from used batteries by 2028.

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https://doi.org/10.1007/s11837-023-06269-5

TMS MEETING HEADLINES

JOM THE MAGAZINE

Meeting dates and locations are current as of October 3, 2023.
For the most recent updates on TMS-sponsored events, visit **www.tms.org/Meetings**.

TMS 2024 Annual Meeting & Exhibition (TMS2024)

March 3–7, 2024

Orlando, Florida, USA

Discount Registration Deadline: January 31, 2024

TMS2024 will take place under one roof at the Hyatt Regency Orlando, a AAA four-diamond resort. Stay at the Hyatt for easy access to sessions, networking events, and social activities, and enjoy being steps away from all conference activities.

www.tms.org/TMS2024

TMS Specialty Congress 2024

June 16–20, 2024

Cleveland, Ohio, USA

Discount Registration Deadline: April 30, 2024

The Symposium on Digital and Robotic Forming 2024 will explore science and technology associated with numerically controlled forming methodologies that include robotics, machine learning, and/or combinations of manufacturing practices.

www.tms.org/SpecialtyCongress2024

15th International Symposium on Superalloys (Superalloys 2024)

September 8–12, 2024

Champion, Pennsylvania, USA

Manuscript Submission Deadline: January 31, 2024

Superalloys 2024 aims to highlight advances in superalloy technologies for the sustainable future. A special focus will be paid to contributions focusing on repair/refurbishment of alloys and components.

www.tms.org/Superalloys2024

TMS Fall Meeting 2024 at Materials Science & Technology (MS&T24)

October 6–9, 2024

Pittsburgh, Pennsylvania, USA

Abstract Submission Deadline: May 1, 2024

TMS Fall 2024 at the MS&T technical meeting and exhibition series is a long-standing, recognized forum for fostering technical innovation at the intersection of materials science, engineering, and application.

www.tms.org/TMSFall2024

// Other Meetings of Note

TMS 2025 Annual Meeting & Exhibition (TMS2025)

March 23–27, 2025
Las Vegas, Nevada, USA

www.tms.org/TMS2025

TMS Specialty Congress 2025

June 15–19, 2025
Anaheim, California, USA

www.tms.org/SpecialtyCongress2025

Extraction 2025 Meeting & Exhibition (Extraction 2025)

November 16–20, 2025
Phoenix, Arizona, USA

www.extractionmeeting.org/Extraction2025

TMS 2026 Annual Meeting & Exhibition (TMS2026)

March 15-19, 2026
San Diego, California, USA

www.tms.org/TMS2026

Materials in Nuclear Energy Systems (MiNES 2023)

December 10–14, 2023
New Orleans, Louisiana, USA

Co-sponsored by TMS

OTC Asia 2024

February 27–March 1, 2024
Kuala Lumpur, Malaysia

Co-sponsored by TMS

Offshore Technology Conference 2024

May 6–9, 2024
Houston, Texas, USA

Co-sponsored by TMS

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What if the materials data you need doesn't exist?

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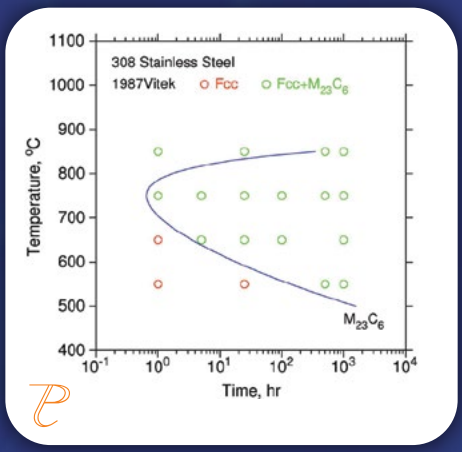
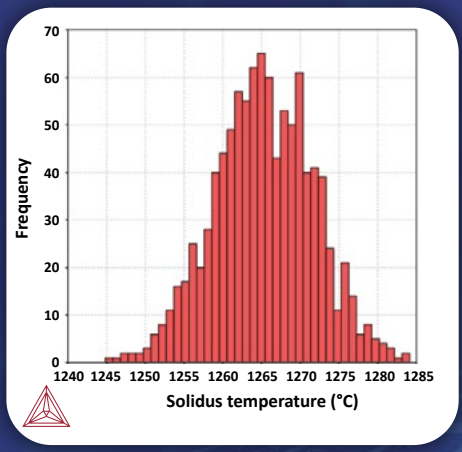


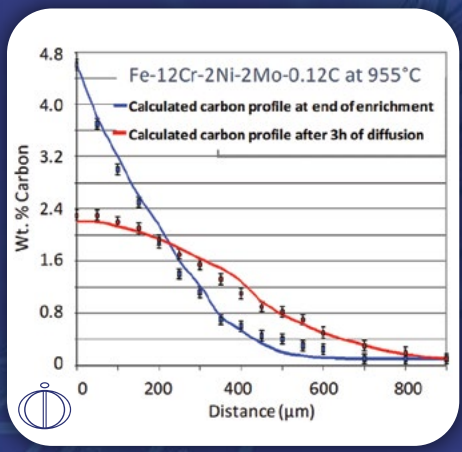
Time temperature precipitation of $M_{23}C_6$ in 308 stainless steel

Solidification



Solidus variation within Alloy 718 specification (Gaussian, n=1000)

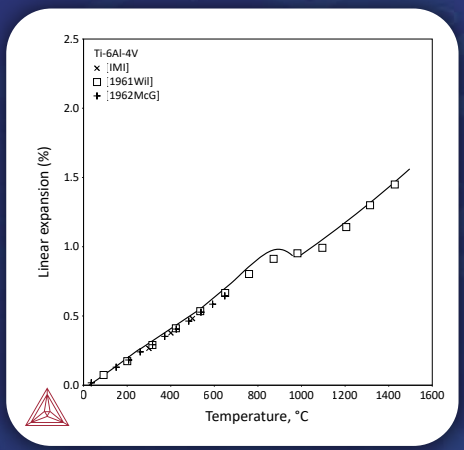
Diffusion



Carbon diffusion profile near surface during carburization of a martensitic stainless steel

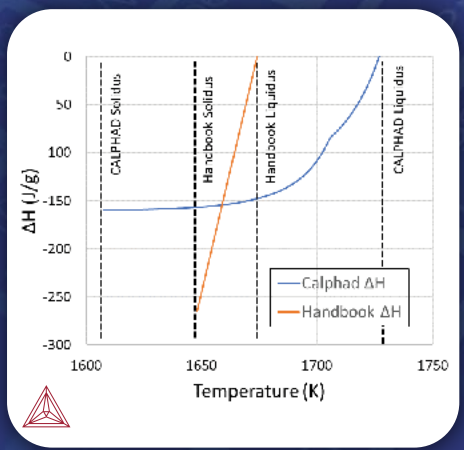
Predict a wide range of materials property data

Thermophysical Data



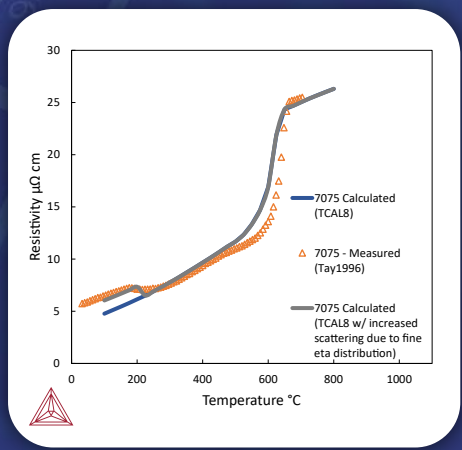
Linear expansion vs temperature for Ti-6Al-4V

Thermodynamic Properties



Calculated latent heat compared to handbook values for a specific 316L stainless steel chemistry

Electrical Resistivity



Calculated electrical resistivity of aluminum alloy 7075

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