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Comparison of calculated and experimental Ms temperatures for a wide range of steels

Al Alloys



issolution of Mg2Si precipital in Alloy A6401

Nickel



Variation in solidus temperature over 1000 compositions within alloy 718 specification

Ti and TiAl Alloys

2.5 Ti64/4V × [Ma] 1 [395:Wa] + [1962McG] 0.5 0.5 0.0 0 200 400 600 800 1000 1200 1400 1600 Temperature, *C

Linear expansion vs Temperature for Ti-6AI-4V

High Entropy Alloys



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Oxides



Ternary liquidus projection in oxide systems

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About the Cover

From the article "Dual-beam Irradiation Stability of Amorphous Silicon Oxycarbide at 300°C and 500°C" by Qing Su et al., shown is a transmission electron microscopy (TEM) image of a cross-sectional sample consisting of a 300 nm thick amorphous SiOC film (top, right) sitting on a SiO₂/Si substrate (bottom, left). The SiO₂ portion of the substrate is 300 nm thick. The very top of the sample shows some of the adhesive used in making the cross-section. The entire sample was subjected to a 3 keV He implantation of $2.0x10^{17}$ He/cm² while being simultaneously irradiated with 500 keV Kr ions to a dose of $1.4x10^{16}$ Kr/cm². The total dose received was 19.7 dpa. No crystallization, He bubble or void formation, or segregation are observed in the SiOC portion of the sample, suggesting dual-beam irradiation stability at 500°C. However, the Si substrate contains numerous nanoscale He bubbles and defect clusters.

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About JOM:

The scope of *JOM* (ISSN 1047-4838) encompasses publicizing news about TMS and its members and stakeholder communities while publishing meaningful peer-reviewed materials science and engineering content. That content includes groundbreaking laboratory discoveries, the effective transition of science into technology, innovative industrial and manufacturing developments, resource and supply chain issues, improvement and innovation in processing and fabrication, and life-cycle and sustainability practices. In fulfilling this scope, *JOM* strives to balance the interests of the laboratory and the marketplace by reporting academic, industrial, and government-sponsored work from around the world.

About TMS:

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

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GUIDE THE FUTURE OF TMS: SUBMIT NOMINEES FOR THE 2022 TMS BOARD OF DIRECTORS



TMS is now accepting nominations for the following Board of Directors positions for the 2022–2025 term:

- Presidential Rotation (encompasses three successive oneyear positions: Vice President, President, and Past President)
- TMS Director/Chair, Membership & Student Development

Find complete job descriptions and qualifications for each office, as well as the Nominee Statement Form and nomination instructions, at:

www.tms.org/BoardNominations

SUBMIT YOUR NOMINATIONS BY JANUARY 15, 2021.

FOR MORE INFORMATION

Contact Deborah Hixon, TMS Awards Program Administrator, at hixon@tms.org.

JOM, Vol. 72, No. 11, 2020 https://doi.org/10.1007/s11837-020-04412-0 © 2020 The Minerals, Metals & Materials Society

in the final analysis

"Volunteering is the ultimate exercise in democracy. You vote in elections once a year, but when you volunteer, you vote every day about the kind of community you want to live in."

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—Unknown

Even in a year disrupted by COVID-19, there is an unbreakable rhythm and cadence to a professional association such as TMS. It is a routine as steady and predictable as the metronomic publication of a monthly journal or the orchestration of conducting an annual meeting. One of the whole notes in the TMS sheet music is the annual election of new members to sit on the TMS Board of Directors. The election process begins with the submission of candidates for open Board positions by January 15th and ends the subsequent August 15th, when the President declares the slate of candidates elected.

The election of Board members is a notable event as TMS is a membership organization. The Board represents all TMS members. The membership empowers the Board of Directors with broad authority to act on behalf of the membership and to represent member interests. The Board creates committees, sets strategies and policies, approves how the financial assets are employed, and delegates responsibilities to volunteer bodies and staff. They also contract an executive director to manage the headquarters and run the business enterprise.

Our TMS Board consists of 14 volunteers, each of whom serves three-year terms. There are three individuals in the Presidential Cycle, one Financial Planning Officer, five Technical Division Chairs, and five Functional Area Directors. For the coming election cycle, five positions are open and nominations are solicited for two of those positions. (The other three positions are chairs of Technical Divisions; they are elected but bypass the nomination step.) The two positions for which nominations are solicited are Presidential Cycle and Membership and Student Development Director.

The Board nomination process can be confusing as it is rigorous out of necessity. All details are on the TMS website—look under the "About" tab of the main menu. While the process is well documented, there are urban legends about submitting a Board nomination that are simply not factual. A few of these are myths that I can dispel:

- Someone has to nominate you for a Board position. No, any member can self-nominate.
- *Only a Vice Chair can apply for a Functional Area Director position.* No, any member can apply.
- *If you are not selected the first time, you'll never be selected.* No, the Society is working hard to encourage multiple exceptional candidates for each position every year. Not everyone can be picked at once, so please don't be discouraged and submit again.
- *Presidential Cycle candidates are selected based on an industry-government-academia rotation.* No, there is no rotation.
- A candidate for the Presidential Cycle must have past Board service. No, TMS Board experience is not required.
- Only friends of the Executive Director can be selected for the Presidential Cycle: No, no, no. Granted, I'm a convivial guy and I do think of all Past Presidents with whom I've worked on friendly terms.

TMS has enjoyed, and continues to enjoy, fantastic volunteer leadership. A part of the reason is that we have a good process by which to select our leaders. The bigger reason is that we have benefited, year in and year out, from the efforts of volunteers who are endlessly generous with their time, talent, treasure, and thoughts to make TMS work for the good of the order and the good of the members. If you are ready to help this group benefit from your insights, nomination packages are due January 15, 2021.



Number 11

November 2020



James J. Robinson Executive Director

"While the process is well documented, there are urban legends about submitting a Board nomination that are simply not factual."

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Do you have business or industry news of interest to the minerals, metals, and materials community? Submit your announcement or press release to Kaitlin Calva, JOM Magazine Managing Editor, at kcalva@tms.org for consideration.

In Case You Missed It: Business News from the Field

Redwood Recycles Battery Materials

Carson City, Nevada, USA: Redwood Materials Inc., a startup founded by Tesla Inc. co-founder J.B. Straubel, is developing processes to recycle battery materials for reuse in new batteries and has begun recycling scrap from Panasonic coming out of Gigafactory Nevada. Redwood plans to refine its recycling process on cellphone batteries in preparation to handle electric car batteries. Straubel seeks to lower battery costs by reducing the use of raw materials and believes Redwood can reach half the price of mined materials within 10 years. The company expects to expand to 200 employees by the end of 2020.

Researchers Shape Alloy Micro-Crystals

Birmingham, U.K.: Researchers at the University of Birmingham and the University of Greenwich used high-speed x-ray imaging to record the formation of micro-crystals as alloys cool and solidify under a magnetic field, and then developed



Chelveston, U.K.: GE Renewable Energy, in collaboration with engineering company Wykes, began development of an innovative battery energy storage system in the United Kingdom. GE Renewable Energy will deliver the 25 MW multiple hour duration energy storage systems to be integrated with Wykes' 60 MW solar photovoltaic (PV) plant at the Chelveston Renewable Energy Park. The site also has 26 MW of wind energy, with Wykes intending to use the storage to add another 60 MW of solar capacity, taking total renewable capacity to 146 MW. The site will be the first British direct-DC-coupled solar deployment where the solar and batteries share a common set of power conversion equipment. (Photo courtesy GE Renewable Energy.)

a mathematical model to predict whether microcrystals would form and what shape they would have. The ability to shape the growth of the micro-crystals will impact industrial-scale processes, such as the removal of iron from recycled aluminum. In related research, a technique was invented using magnets and a temperature gradient to remove iron that makes the material brittle and limits its applications. The invention was patented by the University of **Birmingham Enterprise** and supported by the Midlands Innovation Commercialisation of Research Accelerator.

Ivanhoe Partners with China's CNMC in Africa

Vancouver. Canada: Ivanhoe Mines announced a strategic partnership agreement with state-owned China Nonferrous Metal Mining (CNMC) to explore opportunities in Africa and pursue the objective of becoming a leading supplier of critical materials for clean energy. The strategic partnership will provide significant opportunities for collaboration on mineral exploration, mine planning, development and acquisition of mineral projects, logistics, and smelting. Ivanhoe is developing the Kamoa-Kakula copper project and former Kipushi Mine joint ventures in the Democratic Republic of the Congo and the Platreef joint venture in South Africa.

Steelmaker Implements Green Equipment

Salzgitter, Germany: Salzgitter Flachstahl GmbH acquired what is being called the world's most powerful, hightemperature hydrogen electrolyzer. It has a rated electrical output of 720 kW and is expected to produce at least 100 tons of green hydrogen from renewable electricity by the end of 2022. The new equipment is part of the GrInHy2.0 project, which aims to develop a carbon-neutral, hydrogenbased steelmaking process. The effort brings together Salzgitter; hydrogen electrolyzer manufacturer Sunfire; and steel industry partners Paul Wurth SA and Tenova SpA.

Kyoto University Announces First PGM-HEA

Kyoto, Japan: Kyoto University, in cooperation with multiple institutes in Japan, reported the first high-entropy alloy (HEA) to consist of all six platinum group metals, known as PGM-HEA. The researchers also showed that PGM-HEA electrochemically catalyzes ethanol oxidation reactions highly efficiently. To test its usefulness, PGM-HEA was applied to electrochemical ethanol oxidation reactions, which are used for portable power applications such as smartphones. The higher catalytic performance could provide a new strategy for higher fuel efficiency.

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young professional technical notes

This occasional feature highlights the scientific interests and professional accomplishments of a young TMS member who has contributed to the technical content of the current issue of JOM as an author. advisor, or guest editor. The development of this feature is a special project of the TMS Young Professionals Committee. For additional information contact Kaitlin Calva. JOM Magazine Managing Editor, at kcalva@tms.org.

Jan Steglich on Driving A Career in Aluminum Recycling Forward

Kaitlin Calva

"I love the recycling spirit," said Jan Steglich, TRIMET Aluminium SE, coauthor of the October 2020 *JOM* paper, "Dross Formation in Aluminum Melts During the Charging of Beverage Can Scrap Bales with Different Densities Using Various Thermal Pretreatments."

"From my point of view, our globalized world makes it more and more obvious that we have to handle our resources in an environmentally sustainable manner."

As a project engineer in TRIMET's R&D Department, Steglich currently works on cast alloy development, technical customer support, and assisting TRIMET's plants with aluminum recycling technologies. Before joining TRIMET, he studied recycling engineering at RWTH Aachen University. "The *JOM* paper is essentially an extended abstract of my Ph.D. work about the dross formation mechanisms of solid residues on aluminum beverage can scrap with various thermal

pretreatments," Steglich explained.

Despite being so energy intensive, Steglich believes that aluminum production "plays a vital part in the transition from fossil fuels to renewable energies. Aluminum electrolysis can serve as a virtual battery to stabilize the power grid during periods of volatile renewable energy ratios," Steglich said. As a light metal, aluminum is essential for improving efficiency in the transportation industry, through strategies like lightweighting and e-mobility. "Furthermore, we are constantly working on making our recycling furnaces as

energy efficient as possible, for example, by innovative melting techniques and hybrid energy systems to lower our carbon footprint."

In fact, Steglich counts his work in nonferrous metallurgy recycling at TRIMET as one of his career highlights; the family-owned operation provides both exciting challenges as well as opportunities for career development. Additional highlights include a voluntary internship at a foundry in South Africa, which also afforded him the opportunity to learn about the culture.

Outside of gaining "a deep insight into aluminum recycling" during his Ph.D. work at RWTH Aachen, Steglich notes that economic factors, such as the limited availability of rare earth elements and related recycling efforts, have also served as a driving force in his career. He has also had the good fortune of meeting several individuals who have helped foster his career both as a student and a professional. "These people have in common that they encourage interest, promote knowledge, and have a positive spirit."

"It is absolutely vital for you to surround yourself with positive people whom you like to work and you can trust," he added.

Also, attending the TMS Annual Meeting & Exhibition has helped Steglich make connections, explore technical issues, and move his work forward. "It is a fantastic opportunity to meet experts in their fields and to improve research by discussing problems, results, and ideas," he said, noting that it is important to "stay curious, and never assume to understand a problem in all its details."

To others just starting out in their engineering careers, Steglich recommends: "Follow your interest and do what you love, because then you are passionate about it and you might be spending a lot of your life on that."



Jan Steglich is pictured above equipping beverage can scrap bales with thermocouples together with a team from the AMAP P5 Recycling Project.

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Aspiring for More in an Unprecedented Year: The TMS Foundation in 2020

Garry Warren



Late in 2019 (the good old days!) I told the Board of Trustees of the TMS Foundation that we faced a challenging year in 2020. Little did I know how true that would be, nor did I realize how broad an

impact the pandemic would have on our lives. Currently, young professionals and students are dealing with unprecedented challenges and roadblocks to their career paths—a path they must continue to follow to keep science and engineering strong as the world emerges from the impacts of the pandemic. Part of the mission of the TMS Foundation is to provide some assistance to these young professionals to help them achieve their professional goals.

For many students, the COVID-19 pandemic has only increased the uneasiness surrounding their academic careers. Whether they need a hand paying for tuition or a boost of confidence, the TMS Foundation is there to help. Receiving a scholarship through the TMS Foundation can provide students with critical financial assistance,

Fast Facts About the TMS Foundation Support the 2020 Year-End Appeal

Deadline: December 31, 2020

Employer Match: Register The Minerals, Metals & Materials Society for an employer match with your company. TMS (EIN: 25-1484913) is a qualified 501(c)3 tax-exempt organization.

Donate Online: To donate online, use our contribution form at www.TMSFoundation.org/Contribute, which now includes the convenient option to donate through PayPal. You can also take advantage of our automatic, monthly contribution option.

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

Questions? Contact TMS Foundation staff at TMSFoundation@tms.org or 1-724-776-9000 for more information or to discuss your donation personally. valuable recognition, and opportunities to connect with professionals in their field. Many young professionals in TMS have benefitted from programs funded by the TMS Foundation, including the TMS Division Scholarships, Young Leaders Professional Development Awards, Early Career Faculty Fellow Award, Young Leaders International Scholars Awards, and several others. (You can find details on all of the programs supported by the TMS Foundation in the Awards and Outreach section of www.TMSFoundation .org.) But the need is still great, especially now. Beginning this year and for the next three years the Foundation will focus on expanding programs aimed at young professionals and students, those who are in very vulnerable stages of their careers. I'm asking all TMS members to help us accomplish this goal. With your help, I know we can achieve a great deal.

Have you been the beneficiary of a TMS scholarship? A Young Leaders Award? An International Scholar Award or Early Career Faculty Fellow Award? If you have benefited from the Foundation in the past, please consider making a gift to the Foundation this year. When you do, send a note letting us know what that award meant to you at the time. We would like to hear your stories. Obviously, we love large donations, but no gift is too small. If only 25% of the membership (that's about 3,000 people) gave \$100 each that would add \$300,000 to the Foundation each year! Another \$300K would be sufficient, for example, to endow about seven additional Young Leaders Awards every year!

Like so many, I've been bingeing old and new programs on TV during the pandemic. *Star Trek* and its spinoffs are some of my favorites, in part because the plots often hinge on some new or critical material (transparent aluminum, dilithium crystals, etc.). But without the elements of diversity and optimism embedded in *Star Trek*, I doubt I would have found that series quite so seductive. The September issue of *JOM*: The Magazine included several excellent articles on diversity (recommended reading if you haven't already). One of the articles discussed the difference between being a "bystander" or an "upstander." I think that analogy is very appropriate here. Don't be a bystander, rather be an upstander for the TMS Foundation and send a donation this year! YOU can "make it so!"

Garry Warren is Chair of the TMS Foundation Board of Trustees and is a member of the Gold Society for lifetime giving and the 1871 Legacy Circle.





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FOUNDATION

THE TMS FOUNDATION IN FOCUS

2019 Annual Report



A LETTER FROM TMS FOUNDATION LEADERSHIP

After experiencing a period of revitalization and celebrating our 25th anniversary, 2019 was a refreshing year for the TMS Foundation. In March 2019, the TMS Foundation Board of Trustees adopted a new signature program statement: *The TMS Foundation supports students and young professionals with meaningful financial assistance and impactful careerbuilding experiences.*

While securing the future of our professions has always been at the heart of the TMS Foundation's mission, this signature program statement commits us to an even sharper focus on supporting the next generation of leaders in the field.

To celebrate the kick-off of this renewed focus, the TMS Foundation got a fresh, new look and a redesigned website. Along with this was a campaign inviting past donors and TMS members to reacquaint themselves with the TMS Foundation and take a more active role in supporting students and young professionals.

And it's clear that our donors believe in our work. From November 2019 through the end of December 2019, we conducted our annual year-end appeal, which raised \$88,342. Over the course of the entire year, \$349,582 was raised by a total of 321 generous donors, 69 of whom were new to the Foundation family.

So, while 2019 proved to be an exciting year of change for the TMS Foundation, we look forward to the many new opportunities ahead to expand our impact.

Sincerely,



Harry WWarren

Garry W. Warren Chair, TMS Foundation Board of Trustees Member, TMS Foundation Gold Society

2019 FOUNDATION BOARD OF TRUSTEES

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"The TMS annual meetings helped me grow professionally through formal presentations of my research work, participation in several technical and functional committees, organizing symposia, establishing connections with the top researchers in the field, and involvement in young professional activities. I am very grateful to the TMS Foundation for funding the Young Leaders International Scholar Award."



—**Fadi Abdeljawad**, 2019 TMS/JIM Young Leaders International Scholar

THE TMS FOUNDATION IN FOCUS 2019 Annual Report



OUR MISSION

The TMS Foundation supports students and young professionals with meaningful financial assistance and impactful career-building experiences. To learn more about the mission, vision, and history of the TMS Foundation, visit the About section at www.TMSFoundation.org.

OUR PROGRAMS

STUDENTS

By supporting scholarships, travel grants, and educational enrichment programs for students, the TMS Foundation helps remove barriers to education while encouraging a deeper involvement in the greater materials community.

EARLY CAREER PROFESSIONALS

The TMS Foundation offers professional recognition awards, opportunities for presenting work and developing symposia, and leadership development programs through its support for professionals at this key stage in their career development.

ESTABLISHED PROFESSIONALS

Awards supported by the TMS Foundation encourage diversity within the professions, outstanding mentors or educators, and distinguished achievements, helping to boost prestige within the fields.

OUTREACH INITIATIVES

The TMS Foundation also supports the *Materials Explorers*[™] high school outreach program and the TMS Bladesmithing Competition for college students, as well as student participation in the Electronic Materials Conference and the ASM Materials Camps.

2019 FOUNDATION BOARD OF TRUSTEES

The financial information below provides two perspectives on the TMS Foundation's performance in 2019:

- Donations, inclusive of new endowments
 being established
- Program expenditures, including all gifts issued through the Foundation



2019 TMS FOUNDATION PROGRAM EXPENDITURES



The TMS Foundation is a unit of The Minerals, Metals & Materials Society (EIN: 25-1484913), which is a qualified 501(c)3 taxexempt organization. Official registration and financial information may be obtained from the Pennsylvania Department of State by calling toll-free, within Pennsylvania, 1-800-732-0999. Registration does not imply endorsement.



THE TMS FOUNDATION IN FOCUS 2019 Annual Report

THANK YOU TO OUR 2019 DONORS

In addition to special donor groups such as the **40/40 Club** for young professionals and the **1871 Legacy Circle** for individuals who have provided for the TMS Foundation through planned giving, the TMS Foundation celebrates its donors through its **Lifetime Giving Honorific Societies** and the **Annual Giving Honor Roll**. With their generous contributions to the TMS Foundation, our donors are making a significant and permanent impact on the future of the minerals, metals, and materials professions.

To view current members of both honor rolls, visit www.TMSFoundation.org/HonorRolls.



"Your commitment to the TMS Foundation reflects your passion to introduce young people to the materials science and engineering community and to sustain them in the profession throughout their formative years."

-Garry Warren, at the 2020 Donor Appreciation Dinner



www.TMSFoundation.org 1-724-776-9000 TMSFoundation@tms.org TMS Foundation 5700 Corporate Drive Suite 750 Pittsburgh, PA 15237



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The Minerals, Metals & Materials Society

2019 TMS ANNUAL REPORT



A LETTER FROM TMS LEADERSHIP

Dear TMS Members,

3716

Looking back at 2019—as the year 2020 draws to a close—feels a bit like looking through a time capsule from a now-distant era.

In 2019, we held two broad-appeal conferences—the TMS 2019 Annual Meeting & Exhibition and Materials Science & Technology 2019. Together, these two events attracted more than 7,000 in-person attendees from around the world. In addition, we held four faceto-face specialty conferences, organized four on-site courses, and were developing plans for many more events that would bring our community together for technical exchange, networking, and camaraderie in the coming year.

While 2020 caused us to alter many of these plans, you'll also see in this report the types of projects that continue to move along, despite a global pandemic. You'll see the growth in impact factors for TMS journals. You'll hear about the release of new TMS studies. And you'll see who makes up the membership of our minerals, metals, and materials community.

Yes, some things have changed dramatically since 2019, and our annual report for 2020 will likely look much different than this one. But be assured that some things won't change, no matter the circumstances. This includes TMS's commitment to its members and to moving science and engineering advances forward.

So look back with us over the successes of the year that has passed, as we continue to work towards success in 2020 and beyond.

Sincerely,



James C. Foley 2019 TMS President





WHO WE ARE



*Percentages may not add up to 100% due to rounding.

OUR IMPACT FACTORS: NEW JOURNALS ACHIEVE INDEXING STATUS

TMS journals continued their upward Impact Factor (IF) trend with the release of the 2019 Journal Citation Reports (Clarivate Analytics, 2020). The chart shown here demonstrates the progress of Impact Factors for JOM, Journal of Electronic Materials (JEM), Metallurgical and Materials Transactions A (MMTA), and Metallurgical and Materials Transactions B (MMTB). It also shows the addition of TMS's newest journals—Integrating Materials and Manufacturing Innovation (IMMI) and Journal of Sustainable Metallurgy (JSM)—which received their first Impact Factors for 2019.

For more key metric information on TMS journals, read "Impact Factors and Other Key Metrics Released for All Six TMS Journals" in the September 2020 issue of *JOM*.



OUR STUDIES

Three TMS studies were released in 2019, offering influential technology reports and accelerator studies to the public at no charge.



Next-Generation Materials Genome Initiative Workforce Organized by TMS on behalf of the U.S. National Science Foundation

Creating the



Metamorphic Manufacturing: Shapina the Future of **On-Demand** Components Organized by TMS on behalf of the Office of Naval Research and the Lightweight Innovations for Tomorrow Manufacturing Institute



Verification and Validation of Computational Models Associated with the Mechanics of Materials Organized by TMS on behalf of the U.S. National Science Foundation

OUR CONFERENCES AND EVENTS

TMS held two large, multidisciplinary annual conferences, as well as more focused specialty conferences, workshops, and short courses. The following are 2019 events in which the Society had ownership, sponsorship, and/or management interest:





2019 TMS BOARD OF DIRECTORS

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2019 FINANCIAL REVIEW

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2019 Operating Revenues by Program Area



2019 Operating Expenses by Program Area



REVENUE	% Total	otal		
Membership	6%	6% \$533,442		
Publications	38%	\$3,185,085		
Events	51%	\$4,366,700		
Other	5%	\$431,800		
TOTAL REVENUES		\$8,517,027		
EXPENSES				
Membership	4%	\$346,767		
Publications	12% \$950,262			
Events	38% \$3,128,159			
Volunteer Support	9%	9% \$780,717		

Marketing	5%	\$425,174
Studies	8%	\$678,511
Operations	24%	\$2,027,623
TOTAL EXPENSES		\$8,337,213
		te fel
EXCESS OPERATIONS		\$179,814



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Latest TMS Study Raises Value of Simulations



Ann Ritchie

Computational modeling is attracting interest from organizations that are beginning to see cost and time savings when the simulations are shown to be reliable through the practice of verification and validation (V&V) and the related practice of uncertainty quantification (UQ). TMS recently released the second publication in a series of science and technology accelerator studies that delivers V&V and UQ guidance. Accelerating the Broad Implementation of Verification & Validation in Computational Models of the Mechanics of Materials and Structures provides expert analysis, insights, recommendations, and action plans on developing trustworthy computational models.

To provide definitions of some key terms, verification can be described as the process of determining that the computed quantities of interest (QOI) are sufficiently accurate, while validation encompasses the process of determining the degree to which a model is an accurate representation of physical reality, from the perspective of the intended uses of the model. Uncertainty quantification encompasses the process of quantifying uncertainties associated with model calculations of physical QOI.

The U.S. National Science Foundation's Division of Civil, Mechanical, and Manufacturing Innovation's Mechanics of Materials and Structures program funded this latest TMS study, which seeks to help broaden the practice of V&V and UQ. Simulations could potentially reduce the costs and time to develop new products and manufacturing procedures, but sufficient V&V and UQ must ensure the simulations deliver trustworthy results. Fields such as nuclear engineering, aerospace, and biomedical engineering have long been practicing V&V and seeing the benefits.

Study Process

The latest V&V study builds upon the analysis and recommendations presented in the first study, *Verification and Validation of Computational Models Associated with the Mechanics of Materials*, that TMS published in 2019. This second installation of the series seeks to explain the underlying concepts and accelerate the widespread implementation of the techniques and practices within the mechanics of materials and structures (MOMS) and related communities.

TMS convened an internationally recognized team of 12 experts to develop the final report, chaired by William Oberkampf, Virginia Polytechnic Institute and State University. A team of equal caliber was formed to write the recommended practices section of the report, chaired by William Rider, Sandia National Laboratories.

"Organizations, both private and public, want to use computational simulation in design, decision making, and risk assessment. They want to better understand how you assess the credibility or reliability of simulations," Oberkampf said.

"The opportunity to engage with this body of experts and tackle this important problem was too good to pass up," added Rider. "The whole study was expertly led by TMS, who set up an environment and approach to this challenge that assisted us greatly. It was a joy to work on."

Highlights

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A strong value proposition for V&V and UQ is one of the highlights of the publication. The report's Table I, reproduced on the following page, clearly outlines value elements for the target areas of industry, government labs,

TMS Science and Technology Accelerator Studies

These TMS studies are available to download for free. Access the entire suite of TMS-led research at www.tms.org/Studies, including the two recent studies on verification and validation:

- Accelerating the Broad Implementation of Verification & Validation in Computational Models of the Mechanics of Materials and Structures (2020): www.tms.org/VVAccelerator
- Verification and Validation of Computational Models Associated with the Mechanics of Materials (2019): www.tms.org/VerificationandValidation

academia, and regulators. The list includes "faster time to market and increased profitability," and "better prediction of product quality, costs, and life," among other benefits. It also underscores the value in improved decision-making delivered by computational simulations that include rigorous application of V&V practices.

Another section of the report identifies eight key competency areas and processes for educators and academic administrators who seek to develop curricular activities that bring verification and validation in computer simulation into the classroom. Those areas include code verification; solution verification; model calibration and calibration experiments; uncertainty characterization; uncertainty propagation; model validation experiments; validation metrics; and predictive capability. The study team recognized a need to better integrate V&V and UQ at both the undergraduate and graduate levels and have presented strategies in the report for improving training and multidisciplinary curricula.

Recommended Practices

The Recommended Practices section of the report offers highly valuable guidance and detailed instruction on how to stimulate implementation. Figure 1 of this section, also shown on the following page, illustrates an overarching framework made up of six major process steps. The report outlines five to ten recommended tasks for each of the

VALUE ELEMENT	Industry	Government Labs	Academia	Regulators
Faster time to market and increased profitability	x			
Supports risk/failure mitigation and understanding	x	x		x
Better prediction of product quality, costs, and life	x			
Reduces physical testing	x	x	x	x
Improves governmental decision making		x		x
Needed when full-scale tests are not feasible	x	x		x
Assesses and elevates the value of artificial intelligence (AI) techniques			x	
Improves the value and versatility of predictive models	x	x	x	x
Supports assessment of safety and reliability for complex systems	x	x		x
Accelerates regulatory process approval	x	x		x
Enhances the utility and reproducibility of shared data	x	x	x	x

Table I. Summary table of the value proposition elements for V&V and associated stakeholder groups.

six major process steps. Those tasks involve a variety of stakeholders and contributors, including code/software developers; experimentalists; funding organizations/resource gatekeepers; modelers; numerical analysts; regulators and/ or customers; and users of the models and/or computational/ simulation analysts.

Important to the Recommended Practices section is the synthesis of engagement between experts in V&V, and material science and engineering. The two disciplines are both challenging and required lengthy technical conversations to reach an understanding between the two bodies of experts.

"The document records how these two communities intersect and how to apply the combined best practices. It is also a 'one-stop shop' for how to do a great V&V activity specifically applied to material science," Rider explained. "Finally, it includes guidance on professional education and growing a V&V community internal to material science."

TMS applied strategies to bridge these technical and cultural gaps. A mix of experts from the two communities were invited to work on the expert team while remaining aware of the existing cultural differences of their team members. The technical report needed to represent crosscultural interactions so that readers of varied expertise and backgrounds would be able to understand each other's perspectives and work together on V&V concepts and

implementation. In addition to the mixed teams, the content development and editing phases of the report entailed a review of language to be understood at the novice level, as well as to engage readers who possess some V&V and UQ experience.

"What has been created is an advance in both areas of V&V and materials science with boundless opportunity for new breakthroughs once the unified research begins to be conducted. The V&V is an engine of continual improvement for whatever field it is applied... it helps optimize research investments," Rider said.

Outcomes

George Spanos, principal investigator, and Michael Rawlings, co-principal investigator, both from TMS, coordinated the study team, recommended practices team, and development of the publication. The project ran from late 2019 to late 2020, overlapping with the start of the COVID-19

pandemic. The study team pivoted to complete the work during virtual sessions and through a combination of discussions, note capture, chat, and other collaboration tools. "I was extremely impressed with their level of commitment and follow through," said Spanos. "I think this was due to a combination of their inherent professionalism and their realization of the importance of this topic and the study to the relevant science and engineering communities."

Practitioners of both simulation work and experimental work will find value in the report. Spanos, for example, trained as a materials scientist and conducted predominantly experimental work during his research career. He was impressed by the V&V experts on the study team.

"I never before delved into the detailed aspects of V&V, which I now know to be critical to developing and implementing predictive computational models and simulations that are trusted to give accurate predictions. Knowing what I know now, from being on the inside of this study and report, if I were still in my old career as a section head back at the Naval Research Laboratory, I would make reading this report a must for myself and the researchers who worked in my section," Spanos said.

Verification and validation offers the potential to make a significant impact on the development of advanced materials systems and structures. The reliability and confidence in simulation will increase as more private and public organizations begin to accelerate their implementation of these practices.

"These are the building blocks you use to answer the

Meet the Study Team





Figure 1. In this simplified V&V flow chart, gray boxes represent key process steps. Modified from ASME V&V 10-2006 (R2016).1

> question, 'why should I believe your simulation.' By broadening its use, I hope this study makes an impact in the materials and structures field," Oberkampf said.

Endnotes

1. R2016. The American Society for Mechanical Engineers. Guide for Verification and Validation in Computational Solid Mechanics, (New York, NY: ASME, 2006), https://www.asme.org/ products/ codes-standards/v-v-10-2006-guide-verification-validation.

> Top row, left to right: Marisol Koslowski, Purdue University: William Rider, recommended practices chair. Sandia National Laboratories: William Oberkampf, study team chair, Virginia Polytechnic Institute and State University; and Kiran Solanki, Arizona State University. Bottom row, left to right: Arif Masud, University of Illinois Urbana-Champaign; David Fullwood, Brigham Young University; and Krishna Garikipati, University of Michigan. Not pictured: Sankaran Mahadevan, Vanderbilt University; David McDowell, Georgia Institute of Technology; Paris Perdikaris, University of Pennsylvania; Celia Reina, University of Pennsylvania; and Mike Tonks, University of Florida



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TMS meeting headlines

Meeting dates and locations are current as of September 1. For the most up-to-date list of TMS-sponsored events, visit www.tms.org/Meetings.

Other Meetings of Note

The 11th International Conference on Molten Slags, Fluxes and Salts (MOLTEN 2021) February 21–25, 2021 Seoul, South Korea

TMS Materials Innovation Briefings: Focus on Pittsburgh May 12, 2021 Cranberry Township, Pennsylvania, USA

Solidification Course 2021 May 30–June 4, 2021 Villars-sur-Ollon, Switzerland

The 12th International Conference on Magnesium Alloys and their Applications (Mg 2021) June 15–18, 2021 Montreal, Canada

5th International Congress on 3D Materials Science (3DMS 2021) June 29–July 2, 2021 Washington, D.C., USA

Liquid Metal Processing & Casting Conference (LMPC 2021)

September 19–22, 2021 Philadelphia, Pennsylvania, USA

Materials in Nuclear Energy Systems (MiNES 2021)

September 19–23, 2021 Pittsburgh, Pennsylvania, USA

World Congress on High Entropy Alloys (HEA 2021) November 14–17, 2021 Charlotte, North Carolina, USA

TMS2021

150th Annual Meeting & Exhibition March 14–18, 2021 Orlando World Center Marriott Orlando, Florida, USA Registration Opens Soon! www.tms.org/TMS2021

- TMS will celebrate 150 years of bringing together engineers, scientists, business leaders, and other professionals in the minerals, metals, and materials fields for a comprehensive, crossdisciplinary exchange of technical knowledge at the TMS 2021 Annual Meeting & Exhibition (TMS2021).
- The All-Conference Plenary session will feature Anne Lauvergeon, founder/CEO of ALP, chair of École des Mines de Nancy, and former CEO of Areva SA.
- Book housing at the Orlando World Center Marriott for a stay at the convenient, self-contained resort where all in-person TMS2021 technical programming, exhibit, and social functions will be held.



April 18–22, 2021 Hyatt Regency Lake Tahoe Lake Tahoe, Nevada, USA Register by March 5, 2021 www.tms.org/ICME2021

- Register now for the 6th World Congress on Integrated Computational Materials Engineering and join leading researchers and practitioners to share the latest knowledge and advances in the field.
- Confirmed plenary speakers at press time include Bita Ghaffari, Ford Motor Company; Andrea Rovinelli, Argonne National Laboratory; Peter Voorhees, Northwestern University; and Charles H. Ward, Air Force Research Laboratory, among others.



July 25–30, 2021 The Ohio State University Columbus, Ohio, USA Discount Registration Deadline: June 11, 2021 www.tms.org/ICTP2021

- The 13th International Conference on the Technology of Plasticity (ICTP 2020) brings together colleagues across industry, academia, and government to discuss all aspects of metal forming science and technology.
- Eight keynote speakers will present their latest improvements and innovations covering the focal points of global issues, simulation, materials, and innovation.
- Sign up for the optional visit to the National Museum of the U.S. Air Force and technical tour of laboratories at The Ohio State University. Tours can be selected at registration.



September 12–16, 2021 Seven Springs Mountain Resort Seven Springs, Pennsylvania, USA www.tms.org/Superalloys2021

- Registration is open for the 14th International Symposium on Superalloys (Superalloys 2021). All accepted manuscripts are published in the *Superalloys 2020* proceedings, and access is included in the registration fee.
- Watch the Superalloys 2021 Preview webinar series to explore the meeting's topics. On-demand videos are on the TMS Webinar Library: www.tms.org/WebinarLibrary



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call for papers

JOM is seeking contributions on the following topics for 2021. For the full Editorial Calendar, along with author instructions, visit www.tms.org/EditorialCalendar.



May 2021

Manuscript Deadline: December 1, 2020 Topic: 8th European Conference on Renewable Energy Systems (By Invitation Only)

Scope: This special topic will publish invited papers presented at the 8th European Conference on Renewable Energy Systems. The areas of coverage will include energy materials, optoelectronic materials, semiconducting, compounds, alloys, and composites of potential use in energy applications. In addition, submissions related to synthesis and characterization of materials for energy conversion, solar energy, wind energy, fuel cells, and energy storage materials are included.

Editors: Shadia Ikhmayies and Hilal Kurt **Sponsor:** Invited

Topic: Adaptive Metallurgical Processing Technologies for Strategic Metal Recycling

Scope: The demand for strategic metals has enabled many new technologies for recycling of complex materials. In the meantime, traditional metallurgical processes also need to be adapted to address techno-economic barriers. This special topic is open to researchers from both industry and academia in areas of strategic metal recycling. Papers providing perspective on technical challenges or broader materials science challenges toward sustainability are also welcome.

Editor: Mingming Zhang

Sponsor: Recycling and Environmental Technologies Committee

Topic: Leveraging Materials in Topology Optimization

Scope: Topology optimization is pushing the frontiers of material design by decoupling and independently optimizing material properties and functionality. Topology optimization offers a mathematical framework to determine the most efficient material layout for prescribed constraints and loading conditions. It offers a framework for accessing unexplored and previously unachievable areas of materialproperty space. This topic will feature several invited contributions from researchers and artists innovating methods and applications of design and topology optimization for materials. **Editor:** Natasha Vermaak **Sponsor:** Invited

Topic: Microstructure Characterization: Descriptors, Data-Intensive Techniques, and Uncertainty Quantification (By Invitation Only)

Scope: Advancements in computational processing power, instrument and detector capabilities, and multi-scale modeling techniques are generating increasingly large threedimensional microstructural datasets that have facilitated the discovery of quantitative descriptors linking processing parameters to material properties. This special topic will focus on theoretical and computational developments of novel descriptors to characterize microstructural features. Papers that apply advanced statistical techniques, such as machine learning and uncertainty quantification, for collecting, analyzing, and reconstructing experimental microstructural datasets are also invited.

Editors: Srikanth Patala, Shawn Coleman, Jacob Bair, and Houlong Zhuang

Sponsors: Materials Characterization Committee, Computational Materials Science and Engineering Committee, and ICME Committee

Topic: Thermodynamic Considerations for Improved Renewable Energy Production

Scope: Municipal and industrial wastes are increasingly becoming important sources of renewable energy. However, fouling, slagging, and corrosion associated with the combustion processes of these resources are costly and threaten the long-term operation of power plants. Papers focusing on the thermodynamic modeling of problematic sulfates and chlorides in waste combustion processes are welcome. Research papers on emission control pertaining to the renewable energy industries are considered. Manuscripts intended for a broad readership are especially encouraged. **Editors:** Fiseha Tesfaye

Sponsors: Process Technology and Modeling Committee and Recycling and Environmental Technologies Committee

call for papers

June 2021 Manuscript Deadline: January 1, 2021 Topic: 100 Years of the Griffith Fracture Criteria (By Invitation Only)

Scope: While today's materials scientists know the impact of the Griffith criteria, many may not be aware of how little effect it initially had on basic and applied research. It was not until the "Space Race" in the 1950s that basic research was able to take advantage of the Griffith methodology and establish the ASTM-E-24 fracture toughness standard. This special topic will showcase the reach of the Griffith fracture criteria throughout the world today.

Editors: Megan Cordill and Jennifer Carter **Sponsors:** Nanomechanical Materials Behavior Committee and Mechanical Behavior of Materials Committee

Topic: Multiscale Experiments and Modeling in Biomaterials and Biological Materials

Scope: Manuscripts are solicited in all areas of research that use multiscale experimental or computational methods to explore biological materials (at the molecular, cellular, or tissue levels) and biomaterials (those materials which are designed to mimic or replace biological materials). **Editors:** Jing Du, Dinesh Katti, and Hendrik Heinz **Sponsor:** Biomaterials Committee

Topic: Processing-Microstructure-Property Relationships in Additive Manufacturing of Ti Alloys

Scope: This topic seeks to highlight recent advances to create a process-microstructure-property knowledge base for additive manufacturing (AM) of titanium (Ti) alloys. We also welcome developments in new feedstock materials (beyond Ti-6AI-4V and Ti-5553) that are better suited to take advantage of AM processes and their parameters, as well as the application of advanced characterization techniques in AM Ti-alloys. Both experimental and modeling submissions are encouraged, especially where modeling or theory is applied and validated experimentally. **Editors:** Rongpei Shi, Michael Gram, and Yufeng Zheng **Sponsor:** Titanium Committee

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Topic: Pyrometallurgical Processing of Secondary Resources

Scope: With the decrease of high-quality primary metal resources around the world, effective processing of secondary resources has become vital. This special topic focuses on pyrometallurgical approaches to the processing of secondary resources. The secondary resources in this context include low-grade ores, urban ores (electronic wastes, battery wastes, photovoltaic materials, and other end-of-life products), industrial byproducts and wastes, construction wastes, medical wastes, and organic resources and wastes.

Editors: M. Akbar Rhamdhani and Stuart Nicol **Sponsor:** Pyrometallurgy Committee

July 2021 Manuscript Deadline: February 1, 2021 Topic: Machine Learning in Design, Synthesis,

and Characterization of Composite Materials

Scope: Machine learning methods are enabling unprecedented advances in the area of composite materials. These methods are versatile in handling a large number of parameters and are helping in developing novel materials structures and compositions for the given application requirements. This topic is intended to cover all aspects of application of machine learning methods to the field of composite materials, including design of microstructure, synthesis condition optimization, and evaluation of properties.

Editors: Nikhil Gupta, Simona Hunyadi Murph and Ramasis Goswami

Sponsor: Composite Materials Committee

Topic: Nanomaterials and Composites for Energy Conversion and Storage

Scope: The emergence of nanostructured and composite materials has resulted in significant advancements in energy conversion and storage, such as fuel cells, photovoltaic cells, batteries, and supercapacitors. The topic scope includes the design and development of low-dimensional nanomaterials; photocatalysts and photoelectrochemical devices for solar fuel production; semiconductors nanomaterials for new-generation solar cells; computational nanomaterial science; and electrode nanomaterials for efficient energy storage systems including batteries and supercapacitors, etc. **Editors:**Yu Lin Zhong, Soumendra Basu and Ziqi Sun **Sponsor:** Energy Committee; Energy Conversion and Storage Committee

Topic: Phase Transformations during Solid-phase Welding and Processing

Scope: Papers are invited covering phase transformations and interfacial phenomena during solid-phase welding and processing.

Editors: Piyush Upadhyay and Arun Devaraj **Sponsor:** Shaping and Forming Committee



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