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Where We've Been and Where We'll Go

A *JOM* Roundtable on Key Issues in Additive Manufacturing

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The importance of materials science and engineering to additive manufacturing (AM) was an emerging topic of exploration when *JOM*: The Magazine published the article, "Layers of Complexity" in its November 2014 issue. Through interviews, case studies, and a roundtable of experts, the future potential of the field was examined from a variety of angles. Many of the perspectives offered were energized and optimistic, although also realistic about the challenges facing widespread deployment of AM.

Much has changed since then and interest in the capabilities of AM has increased exponentially. On the fifth anniversary of that article's publication, it seemed fitting to assemble another expert panel to reflect on those changes and developments, while also looking forward to how AM will continue to impact the materials science and manufacturing landscape.

Background image by Santosh Rauniyar and Kevin Chou, "Melt Pool Analysis and Mesoscale Simulation of Laser Powder Bed Fusion Process (L-PBF) with Ti-6Al-4V Powder Particles", *JOM*, 71, 3, 2019.

Meet the Roundtable Panel

Allison M. Beese, associate professor at Pennsylvania State University, sits on the TMS Content Development and Dissemination Committee and the Additive Manufacturing Committee. She is the recipient of the 2018 AIME Robert Lansing Hardy Award.

David L. Bourell, the Temple Foundation Professor at University of Texas at Austin, is the founding chair of the Additive Manufacturing Committee and teaches the Additive Manufacturing Materials and Processes half-day workshop at multiple TMS events. He is a 2011 TMS Fellow.

Mohsen Seifi is the director of Global Additive Manufacturing Programs at ASTM International and adjunct assistant professor at Case Western Reserve University. He is a member of the Additive Manufacturing and Mechanical Behavior of Materials Committees.

AM Breakthroughs and Setbacks

Beese: One of the key breakthroughs has been the integration of real-time sensing equipment within AM machines, combined with the application of machine learning to process the resulting data. Eventually, the use of real-time sensors, along with understanding of the process-structure-property relationships, will have the potential to result in real-time process monitoring and correction.

Bourell: Also significant is the adoption of AM by large, multinational companies, including Hewlett Packard. This is already impacting performance and value. In addition, custom product design is making a renaissance. Examples include Gillette's custom razor handles, Mini Cooper's auto components, Dr. Scholl's custom insoles, and Deutsche Bahn's integration of AM to facilitate rapid production and distribution of legacy spare parts.

Beese: I am personally very excited about the potential for designing functionally graded materials to be fabricated via AM. This is an area that my colleague at Penn State, Zi-Kui Liu, and I have been working on. If we can understand phase formation in AM while mixing metals or metal alloys, we could eventually spatially tailor properties, such as strength, stiffness, thermal conductivity, or magnetic permeability within a single component by deliberately depositing different combinations of alloys at different locations within the component.

AM offers a huge opportunity for alloy design. New materials that precipitate out desired phases or grain morphologies/textures during AM could be designed to provide high strength, good ductility, or other properties we would like to see within components.

Bourell: Use of metals AM for consistent, reliable structural parts is among the hottest areas in materials these days. In the last five years, I am excited that serious researchers are studying low-cost AM technologies, such as binder jetting and materials extrusion. Producing service parts on these machines will have significant positive impact on part cost and AM adoption. Major challenges for service part manufacture are consistency and reliability of microstructure and properties; reduction of time/effort cost in post-processing, including removal or elimination of support structures; and full exploitation of the design freedom AM offers.

Workforce Readiness

Seifi: In 2017, ASTM conducted a virtual workshop to gather expert input on education and training gaps. Some major takeaways included the need for better understanding of process-property relationships, such as AM-specific defect mechanisms and impacts on mechanical properties; gaps in information sharing and collaboration among industry, academia, and professional societies; and a need for more hands-on training opportunities. Most courses are offered online only, due to cost and/or safety concerns, and do not give participants firsthand experience to discover AM strengths and limits.

Beese: People who design the AM machines, as well as those who use them, should be aware of the range of science and engineering considerations involved in making components. However, educational programs often cannot cover everything relevant to the AM process. Also, since the technology continues to evolve and advance, it's challenging to keep course content updated to reflect the current state of the art. So, courses and programs need to constantly evolve.

Seifi: A major difficulty is that the community does not have a good program to teach standards or to show the big picture of how AM connects with other related disciplines. AM encompasses materials science, mechanical engineering, computer science, and other areas, and is closely tied to Industry 4.0 disciplines such as big data, robotics, and the Internet of Things. The boundaries between AM and these disciplines are disappearing, and it is important to take this into account.

ASTM recently launched an Education and Workforce Development (E&WD) program through the ASTM AM Center of Excellence (CoE) with three phases. In phase 1, we assessed AM community needs by analyzing the global activity landscape and developing a workforce workshop. We identified needed skills for the AM workforce, gaps in workforce development activities, and the role of stakeholders. In phase 2, the AM CoE developed a roadmap to guide the development and implementation of the E&WD program and a strategy for designing and developing courses that capitalizes on partner expertise. We are now in phase 3, training the workforce by convening a series of workshops in conjunction with the large events such as biannual ASTM F42, Additive Manufacturing Technologies Committee standardization week in conjunction with ISO TC261. This three-phase approach of needs assessment, planning, and program execution provides a good example for the community to follow in developing training programs.

Beese: Societies and universities are offering short courses to introduce people to AM. For example, Penn State has created a master's degree program in additive manufacturing and design, which was designed to educate the future AM workforce, providing a deep dive into the multidisciplinary aspects of AM. This program also provides a hands-on lab course to give participates experience in building parts with AM, heat treating them, and characterizing them.

The Current Standards Landscape

Beese: A challenge with standardization is the number of variables that go into each build, which includes not only the prescribed variables, such as laser power, scan speed, layer height, or powder/wire feed rate, but also things that the machine operator does not necessarily control. For example, scan strategy, which is typically selected by the machine and not the user, directly impacts the thermal history within a component being built. Additionally, if the laser calibration differs between builds, or drifts with time, the processing conditions actually used may be different than those intended.

Finally, many machines are not truly open, which may make sense from a business standpoint, but from a scientific standpoint, we need to be able to alter parameters and monitor the process to develop the fundamental science understanding needed to advance or more widely adopt AM.

Seifi: Currently, it can take anywhere from one to three years for a new standard to be developed due to the nature of consensus-based development of standards, which is too slow to keep up with the rapid pace of AM technology. Standardization and R&D work are often disconnected from one another, which can lead to duplication of work as multiple industry stakeholders independently address the same challenges. Ultimately, this slows down the development of the field and increases the time to market for new technologies because foundational knowledge is not being shared.

There are several interconnected efforts to address these challenges. ASTM created Committee F42 on AM Technologies that is now working collaboratively with ISO to develop AM standards. The AM CoE has also begun conducting R&D specifically focused on standard gaps.

We encourage organizations to contribute to the acceleration of standardization by looking for opportunities to share pre-competitive research and participate in round-robin studies that could benefit the whole field.
— Mohsen Seifi, ASTM International

Accelerated AM standards development is the central focus area of the AM CoE. America Makes, one of the Manufacturing USA institutes, outlined the most critical AM standards gaps identified by the community and assigned responsibility to fill those gaps to specific organizations, including ASTM. We are addressing these gaps. A roadmap detailing the AM CoE's R&D efforts and plans will be available to the community in 2019—Through the first round of R&D projects, we have been able to contribute in filling 13 standards gaps from the America Makes roadmap and enhance 16 existing standards.

We encourage organizations to contribute to the acceleration of standardization by looking for opportunities to share pre-competitive research and participate in round-robin studies that could benefit the whole field. Individuals with AM expertise can also participate on standards developing organization (SDO) technical committees, like ASTM's F42.

Bourell: We are much further along today than five years ago. This includes strong programs within ASTM and ISO, the creation of pathways for joint development of standards within ASTM/ISO, and the creation of the Additive Manufacturing Standardization Collaborative (AMSC) with contributions from ANSI and America Makes. The challenge now is to maintain a collaborative spirit and write the identified standards.

A key issue that persists in the adoption of AM is qualification and certification both with respect to the adoption of known alloys into additively manufactured components and also as a barrier to the design, development, and adoption of completely new alloys.
— Allison M. Beese, Pennsylvania State University

Qualification and Certification

Beese: A key issue that persists in the adoption of AM is qualification and certification both with respect to the adoption of known alloys into additively manufactured components and also as a barrier to the design, development, and adoption of completely new alloys.

Seifi: ASTM is always looking at current progress in qualification and certification. According to an internal landscape analysis we did in early 2019, although third-party certification serves a critical role in AM, there are not yet any full-fledged AM certification programs addressing the wide range of AM materials, parts, and processes. Those programs that exist typically focus on specific AM parts in select industries, leaving organizations to conduct internal qualfciation processes on their own. The most critical barrier to improving this situation is the complexity of AM itself—it is difficult for any single organization to cover the full range of AM parts and address all related qualification needs.

Beese: The key properties that need to be qualified vary with application. Traditionally, in the cases of both qualification and material certification, certain properties are verified within a given lot of material. For example, if properties like strength, ductility, or fatigue life were being qualified for a traditionally processed metal ingot, the corresponding test specimens, typically defined by ASTM or ISO standards, would be extracted from material within the same lot, and tested. However, this cannot be done in AM. New testing need to be defined.

Additionally, standard characterizations or specimen geometries are not yet agreed upon to certify materials. Due to the complexity of components made by AM, standards must be defined for a range of potential situations.

Seifi: Standards provide the foundation of qualification and certification programs. Without strong standards, it is impossible to complete qualification and certification procedures. For this reason, supporting the development of high-priority standards is crucial to accelerating progress in these areas. Additionally, existing qualification and certification programs could receive support to work in a coordinated manner—for example, by creating a third-party framework for them to follow for quality assurance.

TMS Community Support and Involvement

Bourell: In the past five years, TMS has made enormous strides including creating the Additive Manufacturing Committee, hosting several hundred presentations at the TMS Annual Meeting & Exhibition each year, and growing the TMS/AM community to more than 400 participants.

Seifi: TMS's studies on the materials genome/informatics and integrated computational materials engineering (ICME) have already made a positive impact on the community. America Makes is currently using an AM genome derived from the concept of the materials genome, and the AM industry increasingly uses informatics and ICME. These concepts will be critical to expanding AM into the Industry 4.0 concept, which includes big data, simulation, and system integration. TMS could further support these activities by conducting additional studies, holding expert workshops and symposia, and pursuing other activities that help promote these areas and increase the body of knowledge.

Beese: The TMS short course on Additive Manufacturing Materials and Processes workshop exposes participants to AM processes for different material classes, talks about the modeling approaches being used for AM, and introduces the methods and metrics for evaluating structure and properties of additively manufactured materials.

The Additive Manufacturing Committee meets at both the TMS Annual Meeting & Exhibition and the Materials Science & Technology conference, providing an opportunity to shape future conferences. A suggestion is that TMS could facilitate a networking opportunity following the meeting to encourage further discussion. Newer participants would particularly benefit from the opportunity to interact with colleagues beyond technical sessions.

TMS members can get involved in the AM Committee, present their work at the annual meeting, and submit articles to *JOM*. Each year, *JOM* devotes an issue to AM.

Bourell: The rapid growth of AM is due in part to materials researchers "jumping on the bandwagon." To the degree that researchers bring their existing expertise into the field and apply it to address challenging problems in the AM field, we all benefit. I would encourage materials researchers to jump in to start making contributions.

> *Also significant is the adoption of AM by large, multinational companies, including Hewlett Packard. This is already impacting performance and value.*
>
> **— David L. Bourell, University of Texas at Austin**

A TMS Timeline of Leadership in AM

Additive Manufacturing (AM) is one of the fastest growing technical topics at the TMS Annual Meeting & Exhibition, with standing-room-only crowds routinely attracted to the keynote sessions. Beyond annual meeting programming, TMS has played a significant leadership role in advancing additive manufacturing knowledge and application over the last five years.

2015

JOM began focusing its March issue to additive manufacturing and related topics. Several manuscripts associated with these special topics have become highly cited articles.

The Additive Manufacturing Materials and Processes half-day workshop has been held at multiple events since 2015 including the annual meeting. With lead organizer David Bourell, this introductory course has taught more than 300 participants since it was first introduced.

2016

The Additive Manufacturing Committee has grown to become one of the largest technical committees at TMS since being established in 2016. It remains the only TMS committee that bridges all five technical divisions.

2018

2018 TIME

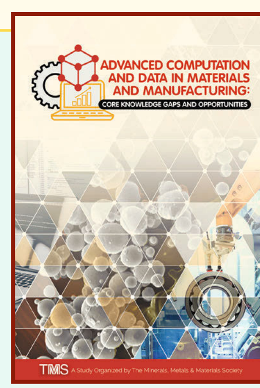
Technological Innovation in Metals Engineering

The Technological Innovations in Metals Engineering (TIME 2018) conference in Haifa, Israel was co-sponsored by TMS and included more than 100 presentations with additive manufacturing being a core topic. TMS will co-sponsor this conference again in 2020.

AM BENCH2018 ADDITIVE MANUFACTURING BENCHMARKS

Additive Manufacturing Benchmarks (AM-Bench) was held in 2018 and became the first in a series of events focused on validating and improving the accuracy of model predictions and developing universally accepted quantitative measurement approaches for all additive manufacturing (AM) materials and methods.

2019



A half-day course on **Additive Manufacturing Standards, Qualification, and Certification** was introduced at the 2019 annual meeting. The lead organizer, Mohsen Seifi, created this course for people in the materials community already familiar with AM processes who want to learn more about standardization, qualification, and certification efforts.

Multiple studies recently released by TMS have also underscored the pivotal role of AM in the materials and manufacturing landscape. Examples of reports that reference the importance of AM include: *Advanced Computation and Data in Materials and Manufacturing: Core Knowledge Gaps and Opportunities* and *Harnessing Materials Innovations to Support Next Generation Manufacturing Technologies.* To download these and other reports for free, go to www.tms.org/studies.

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