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A Preview of the U.S. Air Force Research Laboratory Additive Manufacturing Modeling Challenge Series

Michael Groeber, Edwin Schwalbach, William Musinski, Paul Shade, Sean Donegan, Michael Uchic, Daniel Sparkman, Todd Turner, and Jonathan Miller

Challenge Series Overview

The Air Force Research Laboratory (AFRL) Additive Manufacturing (AM) Modeling Challenge Series is a portion of a larger program focused on including material heterogeneity within design systems for AM. The overall interest is to be able to predict, locally resolved, the internal structure and resultant performance of metallic components produced by AM. The challenge problems themselves are formulated similar to the successful Sandia Fracture Challenge, which has executed three such challenges.

The scope of each challenge problem was discussed and outlined at a workshop with more than 30 members representing AFRL, NASA, the aerospace industry, academia, and the U.S. Department of Energy. An advisory panel consisting of community leaders in AM process modeling, material performance modeling, and automated design methods was tasked with consolidating discussion points and making recommendations for challenge problem statements. These recommendations were used by AFRL researchers to finalize the challenge problem statements and accompanying data packages. Each challenge will be comprised of a problem statement, a calibration data package, an input data package, and an answer submission template.

Eligibility

Challenge problems are open to academia, small and large businesses, and national laboratories, both in the United States and internationally. Data packages will be publicly released by AFRL and made available to participants. Contact information will be required for accessing data packages to allow for challenge updates to be communicated, but does not obligate participation. Submissions will be kept private during grading by AFRL researchers, but will be shared anonymously as an aggregate after grading. Only AFRL will know the identity associated with each submission at any time. An exception to this is when a participant is selected as a Top Performer in one of the challenges, that participant must agree to openly associate their identity with the submission. Participants will be informed of their submission's grade/quality and can see other submissions in an anonymous form in a debrief document or journal article. Participants interested in having their submission graded, but not considered for an award, may discuss with AFRL regarding inclusion in the anonymous aggregate. Any questions regarding eligibility to participate or accept awards can be addressed to AFRL through the challenge participation site.

Schedule

Challenge problems and data packages are scheduled to be released on May 1, 2018. Any modifications to that date will be posted at the challenge participation site. The planned deadline for submissions through the participation site is October 31, 2018. Any modifications to that date will be posted on the participation site and communicated to all registered participants. AFRL will grade submissions and announce Top Performers approximately four months after the submission deadline, tentatively planned for March 1, 2019. A workshop will be held to debrief participants on the results and to honor Top Performers.

Logistics

Problems and data packages will be posted at the Materials Data Facility website, **www.materialsdatafacility.org. The participation site** for the AFRL AM Modeling Challenge Series is **https://doi.org/10.18126/M2MG92.** Data packages will carry unlimited data rights to the participants with proper citation. Submission will be the property of the corresponding participant and not circulated by AFRL. AFRL is requesting rights to use the submissions in derivative work, but will not distribute any portions of the submissions directly without approval of the corresponding participants. It should be noted that AFRL is not setting any constraints on the modeling approaches allowed by participants. Any additional information available in literature can be utilized by participants, but should be reported with the submission.

Awards

Challenge problems will have an associated monetary and/or resource award to be issued to Top Performers. Exact details of the breakdown of prize money/resources is under development and award amounts will be communicated through the challenge participation site.

Challenge Problem Statements

Challenge problems are divided into one of two categories and one of two scales. The first two challenges are within the Processing-to-Structure category, and the second two challenges are within the Structure-to-Properties category, indicating what information is provided and what information is to be simulated/predicted. In each category, one challenge focuses on macroscopic/aggregate behavior and the other focuses on microscopic/local behavior. Figure 1 shows the builds designed by AFRL for the challenges and will be referenced throughout the descriptions of the challenges in this article. Additional details of each challenge and exact reporting requirements will be available in the problem statement of the challenges.

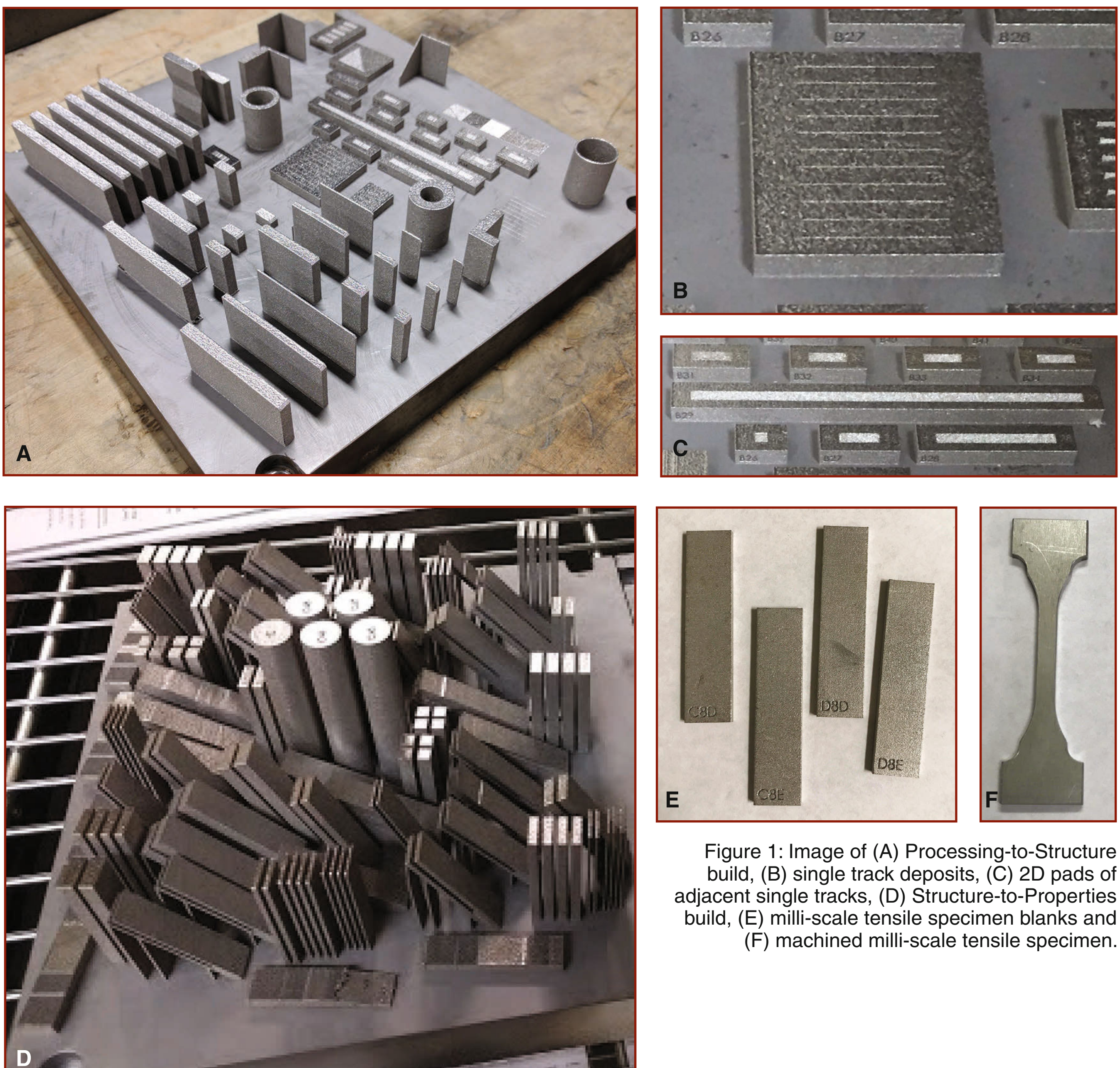

Figure 1: Image of (A) Processing-to-Structure build, (B) single track deposits, (C) 2D pads of adjacent single tracks, (D) Structure-to-Properties build, (E) milli-scale tensile specimen blanks and (F) machined milli-scale tensile specimen.

Residual Stress and Distortion Challenge

Participants will be asked to predict residual stresses and distortions that develop during AM processing. The build in Figure 1A contains calibration and validation specimens. Residual stress measurements on vertical walls of multiple thicknesses and lengths will be made by hole drilling and energy dispersive diffraction (EDD). Additionally, surface position measurements will be made by coordinate measuring systems and laser scanning to quantify macroscopic distortions. The vertical wall measurements, along with their processing history (i.e. scan paths, laser power and speed, layer thicknesses and times), will be provided as calibration data for models.

The same processing information will be provided in the input data package for geometries where the participant will not have the residual stress and distortion measurements. These objects are intersecting walls and cylinders seen in Figure 1A. Participants will be asked to predict the in-plane and out-of-plane stress state at select locations in these objects, as well as the macroscopic deviation from the intended geometry at select locations.

As-Printed Microstructure Challenge

Predicting the microstructural state of material in the as-printed condition from AM processing is the focus of this challenge. The build in Figure 1A contains calibration and validation specimens. Measurements of meltpool width, depth and height will be made for single track deposits under a range of laser power and speed combinations (Figure 1B). Additionally, grain size, shape and crystallography, void volume fraction and precipitate volume fraction and size will be measured.

The single track measurements will be obtained from top surface imaging and sectioning with optical microscope (OM) and scanning electron microscope (SEM) imaging, with electron backscatter diffraction (EBSD) and energy dispersive spectroscopy (EDS). The measurements and laser processing conditions will be provided as calibration data for models. Calibration data will contain both raw images, as well as extracted numerical values.

Selected processing conditions from the single tracks were used to print two dimensional (2D) pads presented in Figure 1C, using a simple serpentine scanning strategy. The length and spacing between neighboring tracks was varied across a range of values. The exact scan path, powder size distributions, material properties and laser processing conditions will be supplied without information of resultant microstructure or pad geometry. Participants will be asked to predict meltpool geometry at various locations in the pads, as well as the local microstructure, defined by metrics like those listed as calibration data.

Macro Mechanical Performance Challenge

In this challenge, participants will be asked to predict the mechanical response of AM produced specimens. The build in Figure 1D contains calibration and validation specimens for this challenge. Stress-strain curves of ASTM E8 round bars (Figure 1D) and microstructure descriptors (i.e. grain size, shape, crystallographic texture, void v_f, etc.) will be provided as calibration data.

Measurements of microstructure will be obtained from top surface imaging and sectioning with OM and SEM imaging, with EBSD and EDS. Calibration data will contain both raw images, as well as extracted numerical values. The full stress-strain curves and key-points along the curve will be provided. In addition to the ASTM E8 specimens, a number of flat plates (Figure 1E) were printed at different thicknesses and orientations relative to the build direction. These specimens will be machined into milli-scale tensile specimens (Figure 1F). The microstructure of the plates will be collected in the same manner as the ASTM E8 samples, using the material adjacent to the gauge section of the tensile sample.

Participants will be asked to predict the stress-strain curve(s) of selected specimens being provided within the microstructure descriptors of the material.

The authors of this article are pictured, from left: William (Bill) Musinski, Sean Donegan, Paul Shade, Daniel Sparkman, Jonathan (Jon) Miller, Michael (Mike) Groeber and Edwin (Eddie) Schwalbach. Not pictured: Michael (Mike) Uchic and Todd (TJ) Turner.

Local/Micro Mechanical Performance Challenge

Participants will be asked to predict the mechanical response of AM produced specimens. The build in Figure 1D contains calibration and validation specimens. Stress-strain curves of ASTM E8 round bars (Figure 1D) and measurements of elastic constants will be provided as calibration data. Milli-scale specimens will be machined and scanned at the Advanced Photon Source at Argonne National Laboratory. The microstructure and residual stress state of a milli-scale specimen will be provided as input data. The specimen will then be loaded in-situ and the grain-level stress state will be monitored, along with the macro mechanical response. Participants will be asked to predict both the stress-strain curve of the sample, as well as the stress-state evolution of selected grains in the aggregate.

Expanded Use and Future Challenges

Model Aggregation

Following announcement of the challenge winners, AFRL will conduct studies into the ability to aggregate predictions made by participants to better predict the desired responses. This approach towards modeling follows strategies used in the weather forecasting community. During these studies, AFRL will not share the individual submissions without permission from participants and will not associate identities of the participants with the datasets. Any derivative work from the individual submissions will cite the contributions appropriately and may include the participants as collaborating authors.

Future Challenges

Additional challenges are currently being developed and will be modified as results of the first challenges become clear. Participation and quality of responses will dictate the frequency and complexity of future challenges. Future challenges are likely to address areas such as stress relief and heat treatment, as well as biaxial and dynamic loading conditions of AM samples. AFRL is also interested in suggestions from the community for future challenge ideas.

About the Authors

The authors of this article all work in the Materials & Manufacturing Directorate, Structural Materials Division, of the U.S. Air Force Research Laboratory. Michael Groeber is past chair of the TMS Advanced Characterization, Testing, and Simulation (ACTS) Committee and is a TMS ICME Committee member. Paul Shade and Michael Uchic are both ACTS Committee members and Edwin Schwalbach is a member of the Additive Manufacturing Committee. Sean Donegan and William Musinski are both TMS members.