



## A Workshop on: The Frontiers of Mechanistic Data-Driven Modeling for Additive Manufacturing

October 24-26, 2018

### **Venue**

Neue Materialien Fürth GmbH  
Dr.-Mack-Straße 81, Technikum 1, 6th Floor  
Fürth, Germany

### **Workshop Goal**

The National Academies of Sciences, Engineering, and Medicine is organizing a workshop to explore the frontiers of mechanistic data-driven modeling for additive manufacturing.

The workshop will examine approaches to and challenges with the following:

- Measuring and modeling process monitoring and control;
- Developing models to represent microstructure evolution, alloy design, and part suitability;
- Modeling phases of process and machine design; and
- Accelerating product and process qualification and certification.

To address these four topics, the workshop will convene leading additive manufacturing experts in online monitoring, science of materials and mechanics, optimization and controls, and qualification and certification, as well as experts from relevant mathematics, statistics, and data science communities, from both the United States and the European Union.

A rapporteur who is not a member of the committee will be appointed to create a written summary (a "Proceedings") of workshop presentations and discussions.

## AGENDA

--- Day 1 Oct 24 ---

- 9:00am**      **Welcome from the Co-Chairs**  
*Carolin Körner, Co-Chair, Friedrich-Alexander University Erlangen-Nürnberg*  
*Wing Kam Liu, Co-Chair, Northwestern University*
- 9:20am**      **Opening Comments from the Sponsors**  
*Allen Roach, Sandia*  
*Richard Ricker, NIST*
- 9:40am**      **Opening Comments from the Academies**  
*Michelle Schwalbe, Board on Mathematical Sciences and Analytics*  
*Erik Svedberg, The Materials and Manufacturing Board*
- 10:00am**      **Session 1: Measurements and Modeling for Process Monitoring and Control**

### Session 1 Questions:

- How can systems be measured in real time?
- What measurements are required to do quantification during AM?
- How can the precision of a measurement be certified?
- How can measured data be employed to understand the full state of a system?
- What mathematical and statistical methods could be applied to additive manufacturing? How can resources from other disciplines be integrated?
- Sensing: What can be measured in-situ and in-line? What are the main challenges of coaxial and off-axis sensing in terms of accuracy, frequency, and spatial and temporal resolution?
- Process and product quality: What is the correlation between process signature and product defects? How does the probability of detecting flaws connect with the qualification of an additively manufactured item?
- Transfer learning and scaling up: How can models and solutions be used to transfer knowledge from machine to machine and from lab to lab? How does this change depending on the material and geometry selected to make a part?
- Performance and economic evaluation of in-situ monitoring: What are the impacts of false positives and false negatives? What are the economic advantages of in-situ monitoring?
- From monitoring to feedback control: What are the challenges of moving from monitoring to feedback control?

- 10:00am**      **Introduction to Session 1**  
*Bianca Colosimo, Polytechnico Milano\**

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\* Session lead

**10:10am Measurement Science for Process Monitoring and Control**  
*Jarred Heigel, National Institute of Standards and Technology*  
(15min presentation, 15min discussion)

**10:40am Break**

**11:00am Process Simulation as a Complement of Process Monitoring**  
*Daniel Reznick, Siemens* (15min presentation, 15min discussion)

**11:30pm Lunch**

**12:30pm Panel Discussion**

- Brief self-introductions and statements of research interests (30 min total; 5 min each)
- Open discussion, lead by Bianca Colosimo (60 min)

*Panelists:*

*Bianca Colosimo, Polytechnico Milano*

*Ben Dutton, Manufacturing Technology Centre*

*Jarred Heigel, National Institute of Standards and Technology*

*Daniel Reznick, Siemens*

*Kilian Wasmer, Empa*

*Amit Surana, United Technologies Research Center*

**2:00pm Break**

**2:30pm [Session 2: Developing Models to Represent Microstructure Evolution, Alloy Design, and Part Suitability](#)**

**Session 2 Questions:**

- How does the AM community develop and validate computer models that use measured material property data and build parameters to predict the location-dependent state of as-built and post-processed components?
- How does the AM community develop and validate computer models that connect the location-dependent state of a part to its performance?

**2:30pm Introduction to Session 2**  
*Lyle Levine, National Institute of Standards and Technology\**

**2:35pm Measurements for Additive Manufacturing of Metals**  
*Lyle Levine, National Institute of Standards and Technology*  
(15min presentation, 15min discussion)

**3:05pm Break**

**3:30pm Predicting Material State and Performance of Additively Manufactured Parts**

*Kyle Johnson, Sandia National Laboratories*  
(15min presentation, 15min discussion)

**4:00pm Panel Discussion**

- Brief self-introductions and statements of research interests (30 min total; 5 min each)
- Open discussion, lead by Lyle Levine (60 min)

*Panelists:*

*Lyle Levine, National Institute of Standards and Technology*

*Eric Jäggle, Max Planck Institute*

*Kyle Johnson, Sandia National Laboratories*

*Christian Leinenbach, Empa*

*Deniece Korzekwa, Los Alamos National Laboratory*

*Annett Seide, MTU Aero Engines*

*John Turner, Oak Ridge National Laboratory*

**5:30pm Conclude Sessions**

**6:30pm Dinner on Your Own**

**--- Day 2 Oct 25 ---**

**9:00am Recap of Day 1; Major Themes and Overview for the Day**

Session 1: Bianca Colosimo (15min)

Session 2: Lyle Levine (15min)

**9:30am [Session 3: Modeling Aspects of Process and Machine Design](#)**

**Session 3 Questions:**

- How can processing and post-processing be changed to drive part and manufacturing performance to a predetermined goal (e.g., target state and production rate)?
- How can modified machine instructions bring about the desired process changes?
- What new methods or techniques need to be developed to run the AM process so control signals can be included?
- How can part-process planning be optimized?
- What new methods or techniques (for hybrid and/or autonomous machines) need to be developed to conduct the steps rapidly enough to monitor and control the process (e.g., decision making/machine learning algorithms)?

- 9:30am**      **Introduction to Session 3**  
*Tahany El-Wardany, United Technologies Research Center*
- 9:40am**      **Current State of Commercial Powder-Bed Additive Machines –  
Improvements Needed to Minimize Build-to-Build Variability’**  
*Ade Makinde, General Electric Global Research Center, with support from  
Johannes Henrich Schleifenbaum, Fraunhofer Institute for Laser Technology,  
and Shoufeng Yang, KU Leuven*  
(15min presentation, 15min discussion)
- 10:10am**      **Break**
- 10:30am**      **Modeling Challenges and Opportunities at the Part-Level**  
*Jian Cao, Northwestern University, with support from Ranadip Acharya, United  
Technologies Research Center, and Mustafa Megahed, ESI Group*  
(15min presentation, 15min discussion)
- 11:00am**      **Panel Discussion**
- Brief self-introductions and statements of research interests (30 min total; 5 min each)
  - Open discussion, lead by Tahany El-Wardany (60 min)
- Panelists:*  
*Tahany El-Wardany, United Technologies Research Center\**  
*Ranadip Acharya, United Technologies Research Center*  
*Jian Cao, Northwestern University*  
*Ade Makinde, General Electric Global Research Center*  
*Mustafa Megahed, ESI Group*  
*Johannes Henrich Schleifenbaum, Fraunhofer Institute for Laser Technology*  
*Michael Schmidt, Friedrich-Alexander University Erlangen-Nürnberg*  
*Shoufeng Yang, KU Leuven*
- 12:30pm**      **Lunch**
- 1:30pm**      **Session 4: Accelerating Product and Process Qualification and  
Certification**

**Session 4 Questions:**

- How can each part be built so as to be identical and conformant, within standard tolerances and without individual inspections?
- What new standards, methods, or techniques need to be developed to certify a part built with additive manufacturing?

- 1:30am**      **Introduction to Session 4**  
*Paolo Gennaro, Precicast Additive\**
- 1:35pm**      **Process Qualification and Technological Validation, from Casting to Additive**  
*Paolo Gennaro, Precicast Additive*  
(15min presentation, 15min discussion)
- 2:05pm**      **Modelling and Simulation**  
*Michel Delanaye, GeonX*  
(15min presentation, 15min discussion)
- 2:35pm**      **Break**
- 3:00pm**      **Panel Discussion**
- Brief self-introductions and statements of research interests (30 min total; 5 min each)
  - Open discussion, lead by Paolo Genaro (60 min)
- Panelists:*  
*Paolo Gennaro, Precicast Additive*  
*Vincent Paquit, Oak Ridge National Laboratory*  
*Jens Telgkamp, AIRBUS Operations GmbH*  
*Michel Delanaye, GeonX*  
*David Teter, Los Alamos National Laboratory*  
*Richard Ricker, National Institute of Standards and Technology*
- 5:00pm**      **Conclude Presentations and Discussions**
- 5:30pm**      **Tour of Nuremberg**
- 7:30pm**      **Dinner**  
*Trödelstube*  
*Located at Trödelmarkt 30, 90403 Nuremberg*

**--- Day 3 Oct 26 ---**

- 9:00am**      **Recap of Day 2; Major Themes and Overview for the Day**  
Session 3: Tahany El-Wardany (15 min)  
Session 4, Paolo Gennaro (15 min)

- 9:30am Breakout Groups**
- [Measurements and Modeling for Process Monitoring and Control](#)
  - [Developing Models to Represent Microstructure Evolution, Alloy Design, and Part Suitability](#)
  - [Modeling Aspects of Process and Machine Design](#)
  - [Accelerating Product and Process Qualification and Certification](#)
- 12:00pm Lunch (with Breakout Groups)**
- 1:00pm Breakout Groups Report Back**
- 2:30pm Final Comments from Co-Chairs and Sponsors**  
*Carolin Körner, Co-Chair, Friedrich-Alexander University Erlangen-Nürnberg*  
*Wing Kam Liu, Co-Chair, Northwestern University*  
*Sponsors Representative*
- 3:00pm Adjourn Workshop**

**Thank you to our U.S. sponsors (the National Nuclear Security Administration, Los Alamos National Laboratory, Sandia National Laboratories, and the National Institute of Standards and Technology), our E.U. hosts (Friedrich-Alexander University Erlangen-Nuremberg, Department of Materials Science, Chair of Materials Science and Engineering for Metals (WTM)), and our planning committee and sponsor organization representatives (shown below) for making this workshop possible.**

**PLANNING COMMITTEE**

- Carolin Körner, Friedrich-Alexander University Erlangen-Nürnberg (co-chair)
- Wing Kam Liu, Northwestern University (co-chair)
- Tahany El-Wardany, United Technologies Research Center
- Ade Makinde, General Electric Global Research Center
- Mustafa Megahed, ESI Group
- Celia Merzbacher, Consultant
- Nancy Reid, University of Toronto
- Jens Telgkamp, AIRBUS Operations GmbH
- Karen Willcox, University of Texas at Austin

**REPRESENTATIVES FROM SPONSORS**

- Lyle Levine, National Institute of Standards and Technology
- Richard Ricker, National Institute of Standards and Technology
- R. Allen Roach, Sandia National Laboratories
- Shawn Dirk, Sandia National Laboratories
- David Teter, Los Alamos National Laboratory
- Jonathan King, National Nuclear Security Administration
- Jay Edgeworth, National Nuclear Security Administration