

# **ASPE/euspen 2016 Summer Topical Meeting on Dimensional Accuracy and Surface Finish in Additive Manufacturing**

Raleigh, North Carolina, USA  
27 – 30 June 2016

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## Welcome and Opening Remarks

Tuesday, June 28, 2016, 08:45 AM - 09:00 AM

Session Chair: John S. Taylor, Lawrence Livermore National Laboratory

## Session I

### Industrialization of Additive Manufacturing

Tuesday, June 28, 2016, 09:00 AM - 10:40 AM

Session Chairs: John S. Taylor, Lawrence Livermore National Laboratory and

Ola L. A. Harrysson, North Carolina State University

- 1. Industrialization of Additive Manufacturing: Past, Present, and Exciting Future\***  
Herderick, E. C. (GE Corporate Supply Chain and Operations)
- 2. Reproducibility of the Dimensional Accuracy: Investigations for Fused Deposition Modeling**  
Knoop, F.; Lieneke, T.; Schoepner, V. (University of Paderborn) . . . . . 3
- 3. Dimensional Tolerances for Additive Manufacturing: Experimental Investigation of Manufacturing Accuracy for Selective Laser Melting**  
Lieneke, T.; de Groot, S.; Adam, G. A.O.; Zimmer, D. (Paderborn University) . . . . . 9
- 4. Characterization of Electron Beam Melting Process (EBM): Capability Approach**  
Dolimont, A.; Rivière-Lorphèvre, E.; Ducobu, F.; Filippi, E. (University of Mons);  
Michotte, S. (Sirris); de Formanoir, C.; Godet, S.; (Université Libre de Bruxelles). . . . . 16

## Session II

### Meeting Tolerances with Secondary Operations & Gauging

Tuesday, June 28, 2016, 11:10 AM - 12:25 PM

Session Chair: Michael M. Kirka, Oak Ridge National Laboratory and

Richard K. Leach, University of Nottingham

- 1. Laser Polishing of Additive Manufactured Steel and Titanium Components**  
Smith, B.; See, T.; Hiersemenzel, F.; Antar, M. (Manufacturing Technology Centre);  
Kaja, K. (Bruker UK Limited) . . . . . 22
- 2. Integrating Metal AM with Milling and Non-Traditional Machining to Improve Surface Properties**  
Iqebal, A. S.; Wang, Z; Bukkapatnam, S. (Texas A&M University);  
Shrestha, S.; Manogharan, G. P. (Youngstown State University) . . . . . 28
- 3. “Additive is Not an Island” – A Renishaw Solution Approach to the Control of AM Part Quality**  
McClelland, M. (Renishaw plc). . . . . 33

## Commercial Announcements & Short Notes

Tuesday, June 28, 2016, 01:55 PM - 03:25 PM

Stephen J. Ludwick (Aerotech, Inc.) and  
Seno Rekawa (Lawrence Berkeley National Laboratory)

## Technical Poster and Networking Session

Tuesday, June 28, 2016, 03:40 PM - 05:10 PM

Session Chair: Wendy L. Shearon, American Society for Precision Engineering

- 1. Evolution of Surface Texture and Cracks During Injection Molding of Fiber-Reinforced, Additively-Manufactured Injection Molding Inserts**  
Hofstätter, T.; Mischkot, M.; Pedersen, D. B.; Tosello, G.; Hansen, H. N.  
(Technical University of Denmark) . . . . . 38
- 2. Distribution and Orientation of Carbon Fibers in Polylactic Acid Parts Produced by Fused Deposition Modeling**  
Hofstätter, T.; Pedersen, D. B.; Tosello, G.; Hansen, H. N. (Technical University of Denmark);  
Gutmann, I. W. (University of Vienna); Koch, T. (Vienna University of Technology)  
Heinz, G. (Karl Landsteiner University of Health Sciences) . . . . . 44
- 3. Design of Artifact for Additive Manufacturing in the context of Aerospace Design\***  
Massey, M. D. (University of Tennessee-Knoxville); Kirka, M. M.;  
Dehoff, R. R.; Babu, S. (Oak Ridge National Laboratory)
- 4. Surface Finish Metrology of Additive Manufactured Components**  
Reese, Z.; Taylor, J. S.; Evans, C. J. (University of North Carolina-Charlotte) . . . . . 50
- 5. Surface Finish Inspection by X-ray Computed Tomography in FDM Parts**  
Ruiz-Huerta, L.; Castro-Espinosa, H. A.; Caballero-Ruiz, A.  
(Universidad Nacional Autónoma de México) . . . . . 55
- 6. Correlation Between Building Parameters, Mechanical Properties and Building Time In**  
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(Universidad Nacional Autónoma de México) . . . . . 60
- 7. Computed Tomography Aided Porosity Comparison Between ABS Filaments and FDM Manufactured Pieces**  
Ruiz-Huerta, L.; Hernández-Contreras, A.; Caballero-Ruiz, A.; Almanza-Arjona, Y. C.  
(Universidad Nacional Autónoma de México) . . . . . 66
- 8. Raster Analysis and Mechanical Behavior Prediction by FEM of FDM Process**  
Ruiz-Huerta, L.; Sánchez-Balanzar, L.; Caballero-Ruiz, A.; Velázquez-Villegas, F.  
(Universidad Nacional Autónoma de México) . . . . . 72
- 9. Information-Rich Approach to Non-Destructive Non-Contact Measurement Planning, Inspection and Verification for Additive Manufacturing**  
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### City Club Raleigh

**Tuesday, June 28, 2016, 6:30 PM – 9:00 PM, Wells Fargo Building – 28th Floor, 150 Fayetteville Street**  
(A short 5-10 minute walk from the Marriott) – Dress Code: Business Casual

The Networking Dinner is atop the 28th floor of the Wells Fargo Building at the City Club Raleigh. See the fabulous view of Raleigh while enjoying fun, food and fellowship. Plan to take the walk from the Marriott to the Wells Fargo Building along Fayetteville Street, a vibrant, active area of the city.

\* No Abstract Available

## Session III

### Design for Additive Manufacturing

Wednesday, June 29, 2016, 08:30 AM - 10:35 AM

Session Chair: David B. Pedersen, TU Denmark and  
Stephen J. Ludwick, Aerotech, Inc.

- 1. Entry Points for Metal Additive Manufacturing in Precision Equipment**  
Peijnenburg, A. T.; Wijnstok, C.; Oosterhuis, G. (VDL Enabling Technologies Group);  
Vanloffelt, M. (3D Systems) . . . . . 81
- 2. Dimensional Accuracy of Printed End Effector**  
Wijnstok, C.; Oosterhuis, G. (VDL Enabling Technologies Group);  
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- 3. Lattice Structure Topology Optimization for Lightweight Additive  
Manufactured Design: Experimental Validation and Dimensional Accuracy**  
Cheng, L.; To, A. C. (University of Pittsburgh); Belski, E.; Ludwick, S. J. (Aerotech, Inc.);  
Oskin, J. (Oberg Industries) . . . . . 93
- 4. Designing for Color in Additive Manufacturing**  
Eiriksson, E. R.; Luongo, A.; Frisvad, J. R.; Pedersen, D. B.;  
Aanæs, H. (Technical University of Denmark) . . . . . 98
- 5. Precision Locating of Additively Manufactured Parts Using  
Embedded Kinematic Couplings**  
Penny, R. S.; Hart, A. J. (Massachusetts Institute of Technology) . . . . . 103

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### In Situ Process Metrology 1

Wednesday, June 29, 2016, 11:05 AM - 11:55 AM

Session Chair: Ola L. A. Harrysson, North Carolina State University and  
Edward D. Herderick, GE Corporate Supply Chain and Operations

- 1. Powder Bed Layer Geometry**  
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- 2. In-Situ Monitoring in Additive Manufacturing Using Contact Image Sensors**  
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(Technical University of Denmark) . . . . . 114

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### In Situ Process Metrology - 2

Wednesday, June 29, 2016, 01:25 PM 03:05 PM

Session Chair: Ola L. A. Harrysson, North Carolina State University and  
Edward D. Herderick, GE Corporate Supply Chain and Operations

- 1. In Situ Surface Metrology of Laser Powder Bed Fusion Processes Using Fringe Projection**  
Zhang, B.; Ziegert, J. C.; Davies, A. D. (University of North Carolina - Charlotte) . . . . . 119
- 2. In-Situ Temperature Measurement During the Electron Beam Melting Process of Inconel 718**  
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(Oak Ridge National Laboratory) . . . . . 125
- 3. Quality Control by Artificial Vision of Additively Manufactured Objects in the Arcam Q10 Electron Beam Melting Process**  
Paquit, V.; Dehoff, R. R.; Kirka, M. M. (Oak Ridge National Laboratory) . . . . . 126
- 4. In-Process Sensing for Laser Powder Bed Fusion\***  
Kelly, S. M.; Boulware, P. C.; Cronley, L.; Firestone, G.; Marchal, J.; Reichert, C. (EWI)

## Session VI

### Functional Assessment of AM Components

Wednesday, June 29, 2016, 03:35 PM - 05:15 PM

Session Chair: David J. Bate, Nikon Metrology and  
Gerrit Oosterhuis, VDL Enabling Technologies Group

- 1. Effect of the Surface Finish on the Corrosion Resistance of Direct Metal Laser Sintered Ti6Al4V**  
Xu, Y.; Lu, Y.; Brown, C. A.; Sisson, R. D. (Worcester Polytechnic Institute) . . . . . 127
- 2. The Effect of Laser Scan Strategy on Distortion and Residual Stresses of Arches made with Selective Laser Melting**  
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- 3. Anisotropic Tensile Testing of Additively Manufactured Parts with Varying Interior Raster Geometries by Low-Cost Fused Filament Fabrication Machines**  
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- 4. X-ray Computed Tomography for Additive Manufacturing: Accuracy of Porosity Measurements**  
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- 5. Assessing the Structural Integrity of Additive Manufactured Metal Parts with X-Ray CT**  
Villarraga-Gómez, H.; Ramsey, A. (Nikon Metrology); Seifi, M.; Lewandowski, J. (Case Western Reserve University); Uchiyama, Y. (Nikon Corporation) . . . . . 151

## Session VII

### Characterization of Surface Topography

Thursday, June 30, 2016, 08:30 AM - 10:35 AM

Session Chair: Christopher J. Evans, University of North Carolina at Charlotte

John S. Taylor, Lawrence Livermore National Laboratory

#### 1. Towards an Additive Surface Atlas

Thompson, A.; Senin, N.; Leach, R. K. (University of Nottingham) . . . . . 156

#### 2. Areal Surface Texture Parameters on Surface

Pagani, L.; Scott, P. J. (University of Huddersfield) . . . . . 162

#### 3. Preliminary Study Toward Surface Texture as a Process Signature in Laser Powder Bed Fusion Additive Manufacturing

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#### 5. On the Metrology of Surfaces Produced by Laser Melting of Powders

Lemoine, A.; Mancini, M. P.; Velez, J. A.; Brown, C. A. (Worcester Polytechnic Institute) . . 174

## Session VIII

### CT Metrology

Thursday, June 30, 2016, 11:05 AM - 12:45 PM

Session Chair: Christopher A. Brown, Worcester Polytechnic Institute and

Richard K. Leach, National Physical Laboratory, UK

#### 1. Practical Methods of Correcting X-ray CT Scans

Bate, D. J. (Nikon Metrology) . . . . . 180

#### 2. A Systems Approach to Quantifying Uncertainty in X-ray Systems for Metrology

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#### 3. Inspection of Embedded Internal Features in Additively Manufactured Metal Parts Using Metrological X-ray Computed Tomography

Kim, F. H.; Moylan, S. P. (National Institute of Standards and Technology);  
Villarraga-Gómez, H. (Nikon Metrology, Inc.) . . . . . 191

#### 4. A New Scatter Correcting Technology for Industrial mini- and microCT of Large Multimaterial or Highly Absorbing Samples\*

Telesz, S. (GE Oil & Gas Digital Solutions)

\* No Abstract Available

## Session IX

### Metrology Instruments

Thursday, June 30, 2016, 01:55 AM - 03:35 PM

Session Chair: Jason Fox, National Institute of Standards and Technology  
and Herminso Villarraga-Gómez, Nikon Metrology, Inc.

- 1. Computed Tomography to Evaluate Large Area Projection  
Micro-Stereo-Lithography (LAP $\mu$ SL)**  
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- 2. Assessment of Dimensional Measurement Tools to Measure Additively  
Manufactured Metallic Parts**  
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- 3. Investigating the Capability of Microfocus X-Ray Computed Tomography  
for Areal Surface Analysis of Additively Manufactured Parts**  
Townsend, A.; Blunt, L. A.; Bills, P. (University of Huddersfield). . . . . 206
- 4. Effect of Rough Metal AM Surfaces on Laser Scanner Accuracy\***  
Srinivasan, H.; Harrysson, O. L. A.; Wysk, R.; Ambekar, R. (North Carolina State University)

## Session X

### Development of AM Processes

Thursday, June 30, 2016, 04:00 PM - 05:40 PM

Session Chair: Michael M. Kirka, Oak Ridge National Laboratory  
Ola L. A. Harrysson, North Carolina State University

- 1. Dimensional Accuracy and Machine Variability of Titanium Parts Manufactured  
using the EOS Direct Metal Laser Sintered (DMLS) Process**  
Mitchell, W. F.; Reutzler, E. W.; Merdes, T. A.; Lang, D. C.  
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- 2. Characterization of Additive Manufacturing Materials  
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Koch, R. D.; Van Slyke, S. E.; (Honeywell FM&T) . . . . . 216
- 3. Metals Additive Manufacturing and Equipment Experience  
from a Process Engineering Viewpoint\***  
Griffith, B. E. (Honeywell FM&T)
- 4. A Holistic Approach to Metals Processed Through Electron Beam Melting**  
Kirka, M. M.; Dehoff, R. R.; Lee, Y.; Okello, A.;  
Dinwiddie, R. B. (Oak Ridge National Laboratory). . . . . 220

**No Host Closing Reception, 06:00 PM – 06:30 PM – 8:00 PM,**

**Clouds Brewing Co., 126 N. West Street**

The is your opportunity to talk about what you've learned and make connections.

\* No Abstract Available