Proceedings

ASPE 2015 Spring Topical Meeting

Achieving Precision Tolerances in Additive Manufacturing

April 26-29, 2015

American Society for
Precision Engineering

P.O. Box 10826, Raleigh, NC 27605-0826
(919) 839-8444 | Fax (919) 839-8039
Technical and Poster Sessions

Session I
Welcome & Opening Remarks & Plenary I
Monday, April 27, 2015, 8:30 AM - 10:30 AM
Session Chair: John S. Taylor, Lawrence Livermore National Laboratory and
Shawn P. Moylan, National Institute of Standards and Technology

1. Digital Photonic Production... Opportunities and Challenges in Gas Turbine
   Manufacturing
   Khanna, M. (Siemens Energy, Inc.) ......................................................... 3

2. Progress In Additive Manufacturing
   Herderick, E. C. (GE Aviation) .......................................................... 4

3. Flexible Manufacturing with an Additive Process Chain: Design, Production
   and Surface Finish
   Uhlmann, E.; Rethmeier, M.; Graf, B.; Kersting, R.; Bergmann, A. (Fraunhofer-Institute
   for Production Systems and Design Technology (IPK)) .......................... 5

Session II
Plenary 2
Monday, April 27, 2015, 11:00 AM - 12:30 PM
Session Chair: Thomas A. Dow, North Carolina State University and
Richard K. Leach, University of Nottingham

1. Typical Requirements for Precision Mechanical Parts in Relation
   to Additive Manufacturing
   Peijnenburg, A. T; Oosterhuis, G.; Goudsmit, F. -W. (VDL Enabling Technologies Group) ........... 10

2. Considerations for AM Modelling in the Context of Topology Optimization
   van Keulen, F.; Ayas, C. (Delft University of Technology) .......................... 15

3. 3D Systems’ Perspective on the Future of Additive Manufacturing
   Moussa, K.; Nguyen, H.; Tummala, P; McDonough, J. (3D Systems Corporation) .................... 17

Commercial Session
Monday, April 27, 2015, 2:00 PM - 3:30 PM
Session Chairs: Vivek G. Badami, Zygo Corporation and
Pete J. Fitsos, Lawrence Livermore National Laboratory
Session III
Design and Optimization
Tuesday, April 28, 2015, 8:30 AM - 10:35 AM
Session Chair: Thomas R. Kurfess, Georgia Institute of Technology and Antonius T. Peijnenburg, VDL Enabling Technologies Group

1. Complexity Isn’t Necessarily Free: Opportunities and Challenges in Additive Manufacturing
Jared, B. H.; Boyce, B.; Battaile, C. C.; Lim, H.; Tran, H. D.; Robbins, J.; Clark, B. W.; Blacker, T. D. (Sandia National Laboratories) .................................................. 22

2. Analysis and Optimization of the Dimensional Accuracy for FDM Parts Manufactured with ABSM30
Knoop, F.; Schoeppner, V. (University of Paderborn) ........................................... 26

Wang, X.; Biyikli, E.; To, A. C. (University of Pittsburgh) ........................................ 32

4. Long-Term Positioning Effectiveness of Additive Manufactured-Monolithic Double Compound Notch Type Flexure Stage
Lee, C.-B.; Tarbutton, J. (University of South Carolina); Lee, S. K. (Gwangju Institute of Science & Technology) ............................................................... 36

5. Features and Tolerances in Additive Manufacturing – an Extension to the AMF File Format

Session IV
In-Process Sensing
Tuesday, April 28, 2015, 11:05 AM - 12:45 PM
Session Chair: Ola L. A. Harrysson, North Carolina State University and Stephen J. Ludwich, Aerotech, Inc.


2. In Situ Monitoring of Laser Powder Bed Fusion Additive Manufacturing Using Digital Fringe Projection Technique

3. Current State and New Developments of Quality Monitoring
Leggett, P. (Concept Laser, Inc.) ............................................................................. 53

4. Dimensional Accuracy of Large and Complex Ti-6Al-4V Component Made via Electron Beam Melting
Bauza, M. B.; Bhogaraju, R. (Carl Zeiss Industrial Metrology); Kirka, M. M.; Richardson, B. S.; Love, L; Lowe, L. E.; Dehoff, R. R. (Oak Ridge National Laboratory) .......... 54
Session V
Modeling and Microstructure
Tuesday, April 28, 2015, 2:15 PM - 3:55 PM
Session Chair: Howard A. Kuhn, University of Pittsburgh and Bradley H. Jared, Sandia National Laboratories

1. Modeling the Metal Additive Manufacturing Process at the Scales of the Part and the Powder

2. Study on Additive Manufacturing of Inner Contoured Tools
   Uhlmann, E.; Bergmann, A.; Gridin, W. (Fraunhofer-Institute Production Systems and Design Technology (IPK)) ................................................................. 59

3. Mechanical and Microstructure Attributes of Inconel 718 Processed via Electron Beam Melting
   Kirka, M.; Dehoff, R. R. (Oak Ridge National Laboratory); Medina, F (Arcam AB); Sames, W. (Texas A & M University) ................................................................. 66

Session VI
Characterization of Surface Finish
Tuesday, April 28, 2015, 4:25 PM - 5:40 PM
Session Chair: Vivek G. Badami, Zygo Corporation and Marcin B. Bauza, Carl Zeiss Industrial Metrology

1. Physical Processes Linking Input Parameters and Surface Morphology in Additive Manufacturing
   Taylor, J. S. (Lawrence Livermore National Laboratory) ................................................................. 70

2. Characterization of the Optical Surface of Additively Manufactured Lenses
   Browar, A. E. M.; Green, W. E.; Burns, S. J.; Ellis, J. D. (University of Rochester) ................................. 72

3. Multi-scale Areal Curvature Analysis of Fused Deposition Surfaces
   Bartkowiak, T. (Poznan University of Technology); Lehner II, J. T.; Hyde, J.; Wang, Z.; Brown, C. A. (Worcester Polytechnic Institute); Pedersen, D. B.; Hansen, H. N. (Technical University of Denmark) .................................................. 77

Session VII
Process Validation and Optimization
Wednesday, April 29, 2015, 8:30 AM - 10:35 AM
Session Chair: Edward D. Herderich, GE Aviation and Hans N. Hansen, Technical University of Denmark

1. Quality Optimized Additive Manufacturing Through Measuring System Analysis
   Uhlmann, E.; Bergmann, A. (Fraunhofer-Institute for Production Systems and Design Technology (IPK)); John, P; Kashveko, V.; Gerlitzky, G. (IWF TU Berlin) ........................................... 83

2. Testing Workpieces for Selective Laser Sintering
   Galovskyy, B.; Hausotte T. R. (Friedrich-Alexander Universität Erlangen-Nürnberg) ................................. 89
3. Predicting Color Output of Additive Manufactured Parts
Eiriksson, E. R.; Pedersen, D. B.; Aanaes, H. (Technical University of Denmark) ........................................ 95

4. Progress toward Standardized Additive Manufacturing Test Artifacts
Moylan, S. P. (National Institute of Standards and Technology) ............................................................... 100

5. Material Certification Through a Synergistic Experimental Monitoring and
Microstructure Modeling Approach
Elwany, A.; Karaman, I.; Arroave, R. (Texas A&M University) ............................................................... 106

Session VIII
CT Metrology of AM Components
Wednesday, April 29, 2015, 11:05 AM - 12:00 PM
Session Chair: Shawn P. Moylan, National Institute of Standards and Technology and
Richard K. Leach, University of Nottingham

1. Effects of X-ray Interactions and CT Algorithms on the Capability of X-ray
CT Metrology of Additive Manufactured Parts
Bate, D. J. (Nikon Metrology) ................................................................. 110

2. Assessing Additive Manufacturing Processes with X-Ray CT Metrology
Villarraga-Gómez, H.; Smith, S. T. (University of North Carolina-Charlotte);
Lee, C.-B.; Corbett, T.; Tarbutton, J.; (University of South Carolina) .......................................................... 116

Session IX
Convergence to Tight Tolerances
Wednesday, April 29, 2015, 1:30 PM - 4:15 PM
Session Chair: John S. Taylor, Lawrence Livermore National Laboratory and
Andreas Fischer-Ludwig, Siemens Energy, AG

1. New Opportunities for Part Fidelity Using Hybrid AM + CNC
Jones, J. (Hybrid Manufacturing Technologies) ................................................................. 122

2. Post-Process Machining of Additive Manufactured Stainless Steel
Lane, B. M.; Moylan, S. P.; Whitenton, E. P. (National Institute of Standards & Technology) ........... 123

3. Challenges in Tolerance Transfer for Additive Manufacturing
Ameta, G. (Washington State University); Moylan, S. P.; Witherell, P;
Lipman, R. (National Institute of Standards & Technology) ................................................................. 129

4. Laser Polishing of Laser Additive Manufactured Surfaces Made from
Inconel 718 and ASTM F75
Ross, I.; Kumstel, J.; Bremen, S.; Willenborg, E. (Fraunhofer Institute
for Laser Technology ILT). ................................................................. 136

5. Shape Adaptive Grinding (SAG) of Complex Additively Manufactured Parts
Beaucamp, A. T.; Namba, Y. Y (Chubu University); Charlton, P.; Jain, S;
Graziano, A. A. (Zeeko Ltd.) ................................................................. 141

6. Spatial Accuracy of Embedded Surface Coloring in Color 3D Printing
Pedersen, D. B.; Hansen, H. N.; Eiriksson, E. R. (Technical University of Denmark) .................. 147
Poster Session

Monday, April 27, 2015, 3:45 PM - 5:15 PM

Session Chair: Thomas A. Dow, North Carolina State University and Marcin B. Bauza, Carl Zeiss Industrial Metrology

1. In-situ Monitoring of Dimensional Accuracy in Additive Manufacturing by Layerwise Detection of Geometric Errors
   Aminzadeh, M.; Kurfess, T. R. (Georgia Institute of Technology) ........................................ 151

2. Preliminary Study of Corona-Assisted Additive Manufacturing Process of Piezoelectric Thermopolymer
   Lee, C.-B.; Mahamud, R.; Farouk, T.; Tarbutton, J. (University of South Carolina) .................. 155

3. Hydrogen Molecule Induced Surface Cross-linking for Enhancing Mechanical Stability of Printed Organic 3D Structure *

4. X-Ray Computed Tomography for the Characterisation of Pores in an Additive Manufacturing Process
   Maskery, I. (University of Nottingham) ................................................................. 159

5. Model - Support Material Interaction Inspection by X-ray Computed Tomography in FDM Additive Manufacturing Process

6. Dimensional Metrology of Complex Inner Geometries Built by Additive Manufacturing
   Villarraga-Gómez, H.; Smith, S. T. (University of North Carolina-Charlotte); Lee, C.-B.; Tarbutton, J. (University of South Carolina); Charney, S. P. (Carl Zeiss Industrial Metrology) ............................................. 164

* No Abstract Available