

AEROMAT | 2024

MARCH 12-14, 2024 | CHARLOTTE, NORTH CAROLINA

2024 ABSTRACT PROCEEDINGS

Breakthroughs in Materials
Engineering Addressing Performance,
Cost and Sustainability in Aerospace

ORGANIZED BY:



aeromatevent.org



AEROMAT 2024 ORGANIZING COMMITTEE

JULIEN BOSELLI

Conference Chair
Blue Origin

PAUL SMITH

Conference Vice Chair
Constellium

CHRISTIAN RUCKERT

Technical Chair
Airbus

MATTHIAS MIERMEISTER

Immediate Past Chair
Novelis

MEMBERS

Eli Ross UTC Pratt & Whitney	Arash Ghabchi Blue Origin	Jim Dobbs Boeing
Jeff Grabowski QuesTek Innovations LLC	Andrew Norman European Space Agency	Allen Wilson Boeing
Mike Shemkunas Boeing	Michael Neidzinski Constellium	Pantcho Stoyanov Concordia University
Dan Sanders Boeing	Rahbar Nasserafi Spirit Aerosystems Inc	Don Li Howmet
Jason Scheuring Kaiser Aluminum	Nihad Ben Salah NBS-M&P Consulting	Richard Freeman PRI
Dana Rosenblatt Boeing	Sabine Spangel Novelis	Elise Rae Castorina Boeing
	Alison Park NASA	

CONTENTS

Scroll to the title and Click on it to link to the paper. After viewing the paper, use the browser's back button to return to the beginning of the Contents.

View Mobile App for the most up-to-date technical program details.

Session: Additive Manufacturing I

Evaluating Stress Corrosion Cracking in Additive-Friction-Stir-Deposition-Processed AA7075 Aluminum Alloy for Aerospace Applications

Dr. Nilesh Kumar and Mr. Ebenezer Acquah, The University of Alabama, Tuscaloosa, Alabama, USA

Solid State Additive Manufacturing and Repair of Metallic Components and Structures Using the MELD Process

Mr. Ed Colvin, MELD Manufacturing, Christiansburg, Virginia, USA

Additive Manufacturing Applications for Automotive, Defense, and Aerospace at MT Aerospace

Mr. Markus Axtner, Mr. Robert Bonne, Mr. Nicolas Bour, and Mr. Bastian Poser, MT Aerospace AG, Augsburg, Germany

Topology Optimization of an Additively Manufactured Heat Exchanger

Prof. Ali Bonakdar¹, Mr. Joseph Nonso Orakwe², and Prof. Ehsan Toyserkani²
(1) The University of North Carolina at Charlotte, Charlotte, North Carolina, USA
(2) University Of Waterloo, Waterloo, Ontario, Canada

About the Challenge of Deducing Valid Strength and Durability Data in Laser Powder Bed Fusion of High-Strength Aluminum Alloys

Mr. Frank Palm, Airbus Central Research and Technology, Taufkirchen, Germany

Solid State Additive Manufacturing for Multi-metal Heat Exchangers

Mr. Mark Norfolk, Fabrisonic, Lewis Center, Ohio, USA

Session: Modeling and Simulation of Manufacturing Processes I

Data-Driven Modeling for Microstructure-Property Relationships of Additive Manufactured Stainless Steel Parts

Akanksha Parmar and Prof. Yung Shin, Purdue University, West Lafayette, Indiana, USA

How Computational Fluid Dynamics Can Support Manufacturing in Space

Ms. Allyce Jackman and Mr. John Wendelbo, Flow Science Inc., Santa Fe, New Mexico, USA

Notice: ASM International retains a nonexclusive, perpetual, worldwide, royalty-free right, without restriction or limitation, to use, reproduce, publicly distribute and display the abstract.

CONTENTS

Stability Modeling in Aerospace Machining: A Physics-Guided Machine Learning Approach with Adaptive Sampling for Self-Aware Operations

*Dr. Noel P. Greis, Dr. Monica L. Nogueira, Prof. Harish Cherukuri, and Dr. Rafi Marandi
University of North Carolina at Charlotte, Charlotte, North Carolina, USA*

Simulation Accuracy of Hot Form Quench Process

Dr. Mohamed Mohamed and Mr. Tim McGuire, Impression Technologies Ltd., Coventry, United Kingdom

Session: Advances in Coatings and Surface Modification I

Ranking of Refractory-High-Entropy-Alloy-Based Coatings for Hot-Forging Dies

*Dr. Tanjore Jayaraman¹ and Dr. Ramachandra Canumalla²
(1) United States Air Force Academy, Colorado Springs, Colorado, USA
(2) Weldaloy Specialty Forgings, Warren, Michigan, USA*

Crack-Free Tungsten Coating on Oxide Dispersion Strengthened Plate via a Novel Laser-Based Additive Technique

Dr. Jeongwoo Lee and Prof. Yung Shin, Purdue University, West Lafayette, Indiana, USA

Session: Additive Manufacturing II

Additive Friction Stir Deposition of Al6061 for Vacuum Chamber Fabrication

Dr. Chase Cox, MELD Manufacturing Corporation, Christiansburg, Virginia, USA

Understanding of Grain Growth and Texture Formation of Inconel 718 Processed by Single-Track Laser Scanning

*Ms. Liuqing Yang¹, Dr. Youxing Chen¹, and Dr. Jordan Weaver²
(1) University of North Carolina at Charlotte, Charlotte, North Carolina
(2) National Institute of Standards and Technology, Gaithersburg, Maryland, USA*

Additive Manufacturing of Novel Nickel-Based Alloys for High-Performance Heat Exchangers

Dr. Matias Garcia-Avila, ATI, Monroe, North Carolina, USA

Session: Advances in Coatings and Surface Modification II

High-Temperature Alloys and Their Oxidation

*Dr. Alexander Donchev, Dr. Mario Rudolphi, and Dr. Mathias Galetz
DECHEMA-Forschungsinstitut, Frankfurt am Main, Germany*

When Choosing Lightweight Materials, Don't Forget Your Coatings!

Mr. Michael R. Bonner, Saint Clair Systems, Inc., Washington, Michigan, USA

CONTENTS

Laser-Assisted Cold Spray as an Alternative to High-Velocity Oxygen Fuel, Plasma, and Helium-Based Cold Spray

Mr. Fredrick Laguines, ES3, Warner Robins, Georgia, USA

Shortening the Path towards Successful Adoption of a Cr(VI)-Free Electroplating Process

Dr. Aga Franczak and Dr. Bart Van den Bossche, Elsyca, Wijgmaal, Belgium

Session: Material Solutions for Sustainability in Aerospace

Three Ways to Apply Science of Recycling Alloys to Produce Green Aerospace Alloys

Dr. Katharina Strobel, AMAG Rolling GmbH, Ranshofen, Austria

AMAG's Development into a Global Player in Sustainable Aviation

Mrs. Christine Manatt¹ and Dr. Ramona Tosone²

(1) AMAG Rolling, Winona Lake, Indiana, USA

(2) AMAG Rolling GmbH, Braunau am Inn, Austria

Aluminum Alloys Solutions for Wings of the Next Generation

Dr. Erembert Nizery¹, Dr. Jean-Christophe Ehrstrom¹, Dr. Marion Bellavoine¹,

Dr. Nicolas Bayona-Carrillo¹, and Dr. Frank Eberl²

(1) Constellium C-TEC, Voreppe, France

(2) Constellium Aerospace and Transportation, Issoire, France

Designing for Sustainability with Material Intelligence

Mr. Roger Barnett, Mr. Freddy Moriniere, and Mr. Austin Flanary, ANSYS Granta, Cambridge, United Kingdom

Selection of Magnets for Permanent Magnet Synchronous Machines in All-Electric Aircraft by Applying Decision Science Techniques

Dr. Tanjore Jayaraman, United States Air Force Academy, Colorado Springs, Colorado, USA

Session: Modeling and Simulation of Manufacturing Processes II

Efficient Prediction of Thermal History and Molten Pool Shape in a Large Domain for Metal Additive Manufacturing via Surrogate Modeling and Machine Learning

Mr. Corbin Grohol and Prof. Yung Shin, Purdue University, West Lafayette, Indiana, USA

A Discontinuous Dynamic Recrystallization Model for Predicting Grain Features during Friction Stir Processing

Ms. Prachi Sharma¹, Mr. Deepak Dhariwal², and Dr. Amit Arora¹

(1) Indian Institute of Technology Gandhinagar, Gandhinagar, India

(2) Virginia Tech, Blacksburg, Virginia, USA

CONTENTS

Numerical Analysis of the Flow and Orientation of Reinforcements in a Polymer Matrix during the Direct Ink Writing Process

Mr. Rajat Mishra and Dr. Amit Arora, Indian Institute of Technology Gandhinagar, Gandhinagar, India

Advances in Superplastic Forming Simulations

Mr. Landon K. Henson and Mr. Jacob Spurgers, Boeing, Tukwila, Washington, USA

Simulation as Enabler for Future Material and Process Improvements

*Dr. Achim Buerger, Sasi Chinnasamy, Sven Steinmann, Christian Tussing,
Dr. Sabine Spangel, and Philippe Meyer, Novelis Koblenz GmbH, Koblenz, Germany*

Session: Additive Manufacturing III

Enhancing the Mechanical Properties of 3D-Printed Plastic Components through Electroplating Process, Pre-optimized with a Computer-Aided Engineering Approach

*Dr. Aga Franczak¹, Mr. Sean Wise², Dr. Bart Van den Bossche¹, and Mr. Paulo Vieira¹
(1) Elsyca, Wijgmaal, Belgium
(2) RePliForm Inc., Baltimore, Maryland, USA*

Eliminating Graphite in Additive Friction Stir Deposition

*Dr. Yuri Hovanski, Mr. Lukas Dean, and Mr. Jacob Hansen
Brigham Young University, Provo, Utah, USA*

Development of Water Cavitation Abrasive Surface Finishing for Post-process Cleaning, Smoothing, and Peening of Additive Manufactured Titanium Parts to Meet the Aerospace Industry's Requirements

*Dr. Daniel G. Sanders¹, Dr. Dwayne Arola², Dr. Mamidala Ramulu², Mr. Rohin Petram²,
Mr. Cole Nouwens², Mr. Conall Wisdom², and Mr. Alex Montelione²
(1) Sugino Corporation, Itasca, Washington, USA
(2) University of Washington, Seattle, Washington, USA*

Rapid Additive Manufacturing Parameter Set and Materials Development using ICMD Materials Design Software

Mr. Kerem Taskin, QuesTek Innovations LLC, Evanston, Illinois, USA

Session: High-Temperature and Gas Turbine Materials I

Laser Peening Improved Fatigue Life and Strength of Single-Crystal CMSX-4 after Corrosive and High-Temperature Exposure

Dr. Lloyd Hackel, Metal Improvement Company, Curtiss-Wright Surface Technologies, Livermore, California, USA

High-Temperature Oxidation and Corrosion Behavior of Chromized Rene 80 by Pack Cementation and Slurry

*Mr. Michael Kerbstadt, Dr. Emma White, and Mathias C. Galetz
DECHEMA-Forschungsinstitut, Frankfurt am Main, Germany*

CONTENTS

Session: Light Alloy Technology I

Dry Sliding Wear Properties of SiC/Mg Composites by Spark Plasma Sintering

Dr. Yoshiki Komiya, Nihon University, Chiba, Japan

Optimizing Sheet Metal Forming for Aircraft Doorframe

*Dr. Bjorn Carlsson, Ingemar Nygren, Bjorn Helgesen, Jonas Liljeberg, and Sture Olsson
Quintus Technologies, Vasteras, Sweden*

Session: Tribology and Wear of Aerospace Materials

Influence of Temperature on the Tribological Behavior of Inconel 718, Haynes 25, and Silicon Carbide under Fretting Conditions for the Purpose of Long-Lasting Gas Turbine Engines

Ms. Marie-Laurence Cliche and Prof. Pantcho Stoyanov, Concordia University, Montreal, Quebec, Canada

Tribological Assessment of Exit Guide Vane Support Tabs in a Jet Engine

Dr. Mary Makowiec, Pratt & Whitney, East Hartford, Connecticut, USA

Session: Emerging Materials and Processes I

Clean Hot Isostatic Pressing Processing to Minimize Surface Oxidation

Mr. Andrew Cassese and Mr. Chad Beamer, Quintus Technologies LLC, Lewis Center, Ohio, USA

Using Temperature to Simulate Thixotropy in 100% Solid Coatings

Mr. Michael R. Bonner, Saint Clair Systems, Inc., Washington, Michigan, USA

Stainless Character of a Martensitic Grade with Structural Hardening and High Mechanical Strength: Improved Durability Applied to the Aerospace Market

Dr. Charles Declairieux and Dr. Laury-Hann Brassart, Aubert & Duval, Les Ancizes, France

Session: Titanium Alloy Technology · Materials Characterization and Failure Analysis I

Solid-State Additive Manufacturing of Titanium Alloys Using MELD Process

Dr. Mandana Meisami Azad, MELD Manufacturing, Christiansburg, Virginia, USA

Investigation into Manufacturing Complexities Intrinsic to Superplasticly Formed and Diffusion Bonded Components by Statistical Modeling, Simulation, and Experiments

*Mr. Bryan Ferguson, Mr. Eric Bol, Mrs. Neha Kulkarni, Dr. Daniel G. Sanders, and Prof. M. Ramulu
University of Washington, Seattle, Washington, USA*

CONTENTS

Session: High-Temperature and Gas Turbine Materials II

Co-Mo-Cr-Si Coating on Haynes 282 by a Novel Hybrid Method of Laser Direct Deposition and Selective Remelting

Mr. Kyung-Min Hong and Prof. Yung Shin, Purdue University, West Lafayette, Indiana, USA

High-Vacuum Heat Treatment for Aerospace Materials

Mr. Thomas Hart, SECO/VACUUM, Meadville, Pennsylvania, USA

Session: Light Alloy Technology II

Developments at Novelis to Address New Challenges in the Aircraft Industry

*Dr. Sabine Spangel, Philipp Rumpf, Andreas Bach, Christian Tussing, Sven Steinmann, Sasi Chinnasamy, Dr. Achim Buerger, and Philippe Meyer
Novelis Koblenz GmbH, Koblenz, Germany*

Airware Friction Stir Welding Tailor-Welded Blank for High-Performance and Cost-Efficient Stiffened Panel for Aerospace Applications

*Dr. Frank Eberl¹, Mr. David Chartier², Mr. Jacques-Erwan Ducatez², and Mr. Julien Laye³
(1) Constellium Aerospace and Transportation, Issoire, France
(2) Airbus Atlantic, Toulouse, France
(3) Constellium C-TEC, Voreppe, France*

Forming Plates Demonstrator Using Creep Age Forming Technology

Mr. Edgar Jose Da Silva and Dr. Paula Costa, Embraer, São José dos Campos, Brazil

Session: Emerging Materials and Processes II

Shear-Assisted Processing and Extrusion of Aluminum-Cerium and Aluminum 7075 Aluminum Alloys

Dr. Cindy Powell and Dr. Scott Whalen, Pacific Northwest National Laboratory, Richland, Washington, USA

Flexible and Lightweight Robotic Deployment System for Confined Spaces

*Mr. Georg Heidelberg¹ and Mr. Alun Reece²
(1) Loop Technology, Kansas City, Missouri, USA
(2) Loop Technology, Dorchester, United Kingdom*

Session: Titanium Alloy Technology • Materials Characterization and Failure Analysis II

Tailoring Strength and Toughness of a New ATI High-Strength Titanium Alloy

Mr. John V. Mantione, Dr. David Brice, and Dr. Matias Garcia-Avila, ATI, Monroe, North Carolina, USA

CONTENTS

ATI Titan 171: A New High-Temperature Titanium Alloy with Improved Strength and Creep Resistance

Dr. David Brice, Mr. John V. Mantione, and Dr. Matias Garcia-Avila, ATI, Monroe, North Carolina, USA

Session: Material Challenges for Hydrogen Storage and Propulsion • Composite Materials and Structures

Moving into Terra Incognita—White Areas on the Map of Material Performance

Mr. Christian Rueckert, Airbus Operations GmbH, Bremen, Germany

A Review of Material Considerations for Hydrogen Pressure Vessels

*Ms. Sofia Verdi and Prof. Anthony Bombik
University of North Carolina at Charlotte, Charlotte, North Carolina, USA*

High-Rate Composite Deposition for Aerostructures

*Mr. Georg Heidelmann¹ and Mr. Alun Reece²
(1) Loop Technology, Kansas City, Missouri, USA
(2) Loop Technology, Dorchester, United Kingdom*

Development of SiC/Carbon Ceramic Matrix Composites by Direct Ink Writing and Low-Temperature Pyrolysis

Mr. Trevor R. Williams, University of North Carolina at Charlotte, Charlotte, North Carolina, USA

Novel Resin Systems to Enable Rapid and Low-Cost Prototyping as well as High-Rate Aerospace Manufacturing to Increase the Rate of Innovation and Deployment of Capability

Mr. Maximilian Schultes and Mr. Atefeh Nabavi, RAMPF, Burlington, Ontario, Canada

Session: Space Materials and Applications • Joining and Welding

Additive Manufacturing Development of a 350 kN-Class Engine Thrust Chamber

*Dr. Keum-Oh Lee¹, Dr. Hyeonjun Kim¹, Mr. Jaesung Shin¹, Mr. Byoungjik Lim¹,
Dr. Junseong Lee¹, Dr. Jaesung Park¹, Dr. Yong-Oh Noh², and Ms. Sook Lee³
(1) Korea Aerospace Research Institute, Daejeon, Republic of Korea
(2) Vitzro Nextech, Ansan, Republic of Korea
(3) Korean Air, Daejeon, Republic of Korea*

Additively Manufactured Structured Fabrics for Deployable Antenna Structures

*Dr. Punnathat Bordeenithikasem¹, Tracy Lu², Dr. Connor McMahan², and Prof. Chiara Daraio²
(1) NASA Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA
(2) California Institute of Technology, Pasadena, California, USA*

The Development of Foam-Enabled Phase Change Material Heat Exchangers

Ms. Melanie A. Buziak, ERG Aerospace, Oakland, California, USA

CONTENTS

MELD and Cu-Cr-Zr for Space Applications

Dr. Chase Cox, MELD Manufacturing Corporation, Christiansburg, Virginia, USA

Space Launch System Program Potential Enhancements

*Mr. Michael Niedzinski¹, Mr. Chris Cianciola², Mr. Tyler Nester², Mr. Chad Bryant², Mr. Terry Prickett²,
Mr. Scotty Sparks², Mr. James Burnum², and Mr. Robert Bobo²*

(1) Constellium LLC, Ravenswood, West Virginia, USA

(2) NASA, Huntsville, Alabama, USA

Fatigue Performance and 3D Residual Stress Map of Refill Friction Stir Spot Welded 2219 Aluminum Joints

Mr. Matteo Bernardi and Prof. Benjamin Klusemann

Helmholtz-Zentrum Hereon, Institute of Materials Mechanics, Geesthacht, Germany

Advances in Refill Friction Stir Spot Welding

Dr. Yuri Hovanski¹, Ms. Ruth Belnap¹, Mr. Paul Blackhurst¹, Dr. Josef Cobb², and Dr. Heath Misak³

(1) Brigham Young University, Provo, Utah, USA

(2) NASA Marshall Space Flight Center, Huntsville, Alabama, USA

(3) Spirit AeroSystems, Inc., Wichita, Kansas, USA

Session: Titanium Alloy Technology • Materials Characterization and Failure Analysis III

Utilizing Near-Net Titanium Extrusions in Aerospace Plate and Forging Applications

Mr. Steven James and Mr. Phani Gudipati, Plymouth Engineered Shapes, Hopkinsville, Kentucky, USA

Advancements in Near-to-Net Extrusion Manufacturing Technology for Aerospace Applications

Mr. Phani Gudipati, Mr. Michael Campbell, and Mr. Steven James

Plymouth Engineered Shapes, Hopkinsville, Kentucky, USA

ATI Titan 27: $\alpha+\beta$ Alloy with Superior Strength and Ductility

Dr. Andrew J. Temple¹, Dr. John Foltz¹, Erik Rogoff¹, Dr. Bhuvu Nirudhodd²,

Dr. Luis Ruiz-Aparicio², and Dr. Ming Li²

(1) ATI Specialty Materials, Monroe, North Carolina, USA

(2) ATI Specialty Rolled Products, Natrona Heights, Pennsylvania, USA

Hot Hardness Test Method for Characterization of High-Temperature Alloys

Dr. C. Paul Qiao, L.E. Jones Company, Menominee, Michigan, USA

Mechanical Characterization of Li-Ion Batteries in Abusive Loading Conditions

Mr. John Sherman and Prof. Anthony Bombik

University of North Carolina at Charlotte, Charlotte, North Carolina, USA

CONTENTS

Session: Residual Stress

Novel Accelerated Thermomechanical Laser Powder Bed Fusion Modeling Using an Effective Heat Source

Prof. Ali Bonakdar¹, Dr. Shahriar Imani Shahabadi², and Prof. Ehsan Toyserkani²

(1) The University of North Carolina at Charlotte, Charlotte, North Carolina, USA

(2) University of Waterloo, Waterloo, Ontario, Canada

Effect of Scan Strategy on Dissimilar Bimetal Cladding through Laser Directed Energy Deposition: A Numerical Study

Mr. Nishkarsh Srivastava and Dr. Amit Arora, Indian Institute of Technology Gandhinagar, Gandhinagar, India

Modeling Residual Stress Evolution during Electro Slag Remelt Process

Dr. Pavanachand Chigurupati and Dr. Corey J. O'Connell

Special Metals Corporation, Huntington, West Virginia, USA

Reduction and Determination of Residual Stresses in 7xxx Aluminum Thick Plates

Dr. Roland Morak, Mr. Thomas Ebner, Dr. Katharina Strobel, and Dr. Ramona Tosone

AMAG Rolling GmbH, Braunau am Inn, Austria

Evaluation of Residual Stress Distribution in Additively Manufactured Inconel 625 Using Finite Element Analysis and Experimental Investigations

Prof. Marjan Molavi-Zarandi and Prof. Ali Bonakdar,

University of North Carolina at Charlotte, Charlotte, North Carolina, USA

ATI Titan 23: A New Low-Distortion β Titanium Alloy for Additive Manufacturing

Dr. David Brice¹, Dr. Matias Garcia-Avila¹, Dr. Andrew Temple¹, Ms. Jia-Huei Tien², and Dr. David F. Bahr²

(1) ATI, Monroe, North Carolina, USA

(2) Purdue University, West Lafayette, Indiana, USA

Session: Additive Manufacturing I

Evaluating Stress Corrosion Cracking in Additive-Friction-Stir-Deposition-Processed AA7075 Aluminum Alloy for Aerospace Applications

Dr. Nilesh Kumar and Mr. Ebenezer Acquah, The University of Alabama, Tuscaloosa, Alabama, USA

Additive friction stir deposition (AFSD) has emerged as an attractive solid-state additive manufacturing process due to its ability to improve the mechanical properties of metallic materials while maintaining a very small carbon footprint. This research focuses on the stress corrosion cracking (SCC) susceptibility of AA7075 aluminum alloy processed via AFSD. Microstructural analysis of both the feedstock and post-AFSD AA7075 was conducted to understand the impact of the deposition process. The investigation into SCC involved slow-strain-rate tensile testing in a 3.5 wt.% NaCl solution at ambient temperature, employing varying strain rates. Comparative analysis with the feedstock rod elucidated the influence of AFSD on SCC resistance, providing critical insights into the efficacy of AFSD processing in mitigating SCC risks in aerospace applications.

Solid State Additive Manufacturing and Repair of Metallic Components and Structures Using the MELD Process

Mr. Ed Colvin, MELD Manufacturing, Christiansburg, Virginia, USA

MELD Manufacturing has developed a unique friction stir additive manufacturing process, a solid-state technique that can print large metallic parts faster than other additive manufacturing methods. An open-atmosphere process, it requires no special chambers or vacuum and uses scalable equipment, with no practical limit to component size. With no melting required, the process can print a wide variety of alloy systems including multi-alloy builds. The MELD® process has exciting potential for a wide range of industries including aerospace, high-performance auto/racing, industrial, and defense. The many advantages include an ability not only to make new parts but also to add features and repair parts that have wear or other damage. Parts are printed fully dense and do not require further processing such as hot isostatic pressing or sintering to improve the quality of the material. Because parts printed using the MELD process are near net shape upon completion, there is much less material waste, resulting in cost reduction. MELD parts are not only bigger, but they can be printed at least ten times faster than other processes. Another advantage is the ability to join dissimilar materials such as aluminum to steel.

We will discuss detailed microstructures and properties for a number of alloys, as we have developed alloy- and part-specific techniques for a wide variety of geometries and performance requirements. Much of the talk's focus will be on directionality in properties, comparing x, y, and z directions and associated orientations for fracture toughness and corrosion properties. MELD is unique in that the process can directly print high-strength aluminum alloys such as 6061, 7075, and 7050 with mechanical, damage tolerance, and corrosion properties similar to conventional wrought products such as forgings while reducing time and cost and producing complex geometries not possible with die forging.

Additive Manufacturing Applications for Automotive, Defense, and Aerospace at MT Aerospace

Mr. Markus Axtner, Mr. Robert Bonne, Mr. Nicolas Bour, and Mr. Bastian Poser, MT Aerospace AG, Augsburg, Germany

Additive manufacturing with powder bed fusion has been applied for several years in various markets and materials. On the basis of long experience, Ti-6Al-4V, AlMg-Si10, and AISI 316 have been introduced step by step to industrial applications. Small-series products with complex shapes and high tolerance requirements are produced on different additive manufacturing machines depending on size and material restrictions. In parallel, the directed energy deposition process is currently under development, showing advantages in geometry thickness and size as well as higher stability in mechanical properties and lower porosity density. A challenge for industrialization is fast prediction of shrinkage to accelerate the preproduction phase and accompanying processes such as heat treatment and machining, which are widely available in house. This presentation will give an overview of the state of the art of development, optimization, and industrialization.

Topology Optimization of an Additively Manufactured Heat Exchanger

Prof. Ali Bonakdar¹, Mr. Joseph Nonso Orakwe², and Prof. Ehsan Toyserkani²,
¹The University of North Carolina at Charlotte, Charlotte, North Carolina, USA;
²University Of Waterloo, Waterloo, Ontario, Canada

Single-liquid forced convection heat exchangers or cold plates have been investigated to keep automotive power electronics modules at optimal operating temperatures. Thermal-fluidic topology optimization is also becoming popular in realizing efficient microchannel heat sinks. Inspired by an interesting Puntzero design case study [1], this work presents a novel methodology that combines topology optimization and latticing techniques to obtain additive manufacturable high-performance heat sinks. A redesign process to replicate, adapt, and optimize the existing design was first undertaken, geared at imbuing flow improvements while retaining heat dissipation performance. Thereafter, manufacturability assessments for additive manufacturing took place to uncover necessary considerations for various design variants. Finally, design studies and performance characterization via computational fluid dynamics simulations were undertaken to gain insightful indices. Study findings indicate that the employment of two-dimensional topology optimization and lattice design strategies leads to better use of the design space. Conducted numerical investigations reveal better flow and thermal performance indices compared to baseline serpentine and replicated Puntzero cold plates (less pressure drop, lower mean base temperature), evaluated at a baseline characteristic pumping power [2]. Manufacturability indices are also encouraging, while the need for holistic workflows to bridge all aspects of the design process is identified and targeted for future development.

[1] nTop (2023), Liquid-cooled cold plate for automotive power electronics

[2] Moreno, G., NREL (2020), *Power Electronics Thermal Management*

About the Challenge of Deducing Valid Strength and Durability Data in Laser Powder Bed Fusion of High-Strength Aluminum Alloys

Mr. Frank Palm, Airbus Central Research and Technology, Taufkirchen, Germany

For several decades, the established way to design and manufacture strength-driven aircraft structures such as brackets, beams, and shafts has been based on a differential approach where the deployed high-strength aluminum material is provided by a material supplier. Such semi-products as sheet or plate are quality assured, and their strength properties are proven as well trackable. A material certificate enables safe computer-based designs and reliable stress analysis to estimate or predict static and fatigue behavior. A close correlation between design stress assumptions and material properties such as ultimate tensile strength and yield strength is possible, and strong confidence about validity on the finally manufactured (machined) 3D part is given. All of this is based on trust that material test samples and machined parts will have more or less the same bulk material surface conditions, leading to reproduceable 3D stress evolution and distribution. Unfortunately, this is not the case for laser powder bed fusion (LPBF)-generated parts or test bodies. Owing to inherent surface roughness and a variety of bulk material imperfections, a stress-driven description and analysis of the test samples is notoriously invalid, as the localized stress evolution after the part is loaded appears extremely undefined. Clear differentiation between machined test bodies and "as-built" rough test elements is necessary. Part durability and load bearing capabilities are affected extraordinarily by the LPBF build conditions, the build platform that was used, and where it was located in the build chamber. A new more formalized approach is necessary to extract the desired or required performance data so that stress and quality engineers are satisfied and able to release and approve 3D-printed parts. Especially for high-strength aluminum-alloy applications where LPBF has to compete against fully (easy) machined parts (from "safe" plate materials), such a remedy is inevitable. This presentation will show some ideas for coping with this challenge.

Solid State Additive Manufacturing for Multi-metal Heat Exchangers

Mr. Mark Norfolk, Fabrisonic, Lewis Center, Ohio, USA

Over the last few years, 3D printing has promised designers freedom of geometry. Solid-state (no melting) 3D printing processes are now allowing freedom of material. New processes leverage ultrasonic energy to produce metallurgical bonds between layers of metal foils near room temperature. This low-temperature attribute of the process enables printing multiple metals in one part, creating complex internal channels, and embedding electronics into solid metal. These attributes have been leveraged to create millions of electrification components in the automotive space—both electrical busbars and complex heat exchangers. This presentation will provide an overview of the welding technique and provide several specific case studies, namely multi-metal radiators for satellites that enabled 30% lower weight and 30% improved thermal performance by eliminating thermal interfaces, cold plates that integrate aluminum, copper, and embedded electronics in one single print job, and multi-metal busbars and flexible connections for thermal applications.

Session: Modeling and Simulation of Manufacturing Processes I

Data-Driven Modeling for Microstructure-Property Relationships of Additive Manufactured Stainless Steel Parts

Akanksha Parmar and Prof. Yung Shin, Purdue University, West Lafayette, Indiana, USA

The high upfront cost of determining the resultant mechanical properties of metal parts built by additive manufacturing significantly hinders widespread adoption in the industry. The objective of this study is to establish data-driven models that can correlate the microstructural details to mechanical properties. Once established, such data-driven models can provide a quicker way of predicting mechanical properties based on given microstructure information and can reduce the cost of achieving desired mechanical properties by drastically reducing the number of experiments required. The major advantage of such an approach is that a data-driven model can be built based on the widely available but scattered data in the literature along with an additional small number of necessary experimental data and it can be used to predict mechanical properties for various manufacturing processes used and heat treatment conditions. This presentation shows successful case studies for building data-driven models of microstructure-property relationships for selected stainless metallic parts made by additive manufacturing processes, such as stainless 17-4 and 316L, with good prediction capabilities for yield strength, ductility, and ultimate tensile strength. Detailed image analysis methods and establishment of the data-driven models using machine learning are also described.

How Computational Fluid Dynamics Can Support Manufacturing in Space

Ms. Alyce Jackman and Mr. John Wendelbo, Flow Science Inc., Santa Fe, New Mexico, USA

Additive manufacturing has been proposed as a solution to the needs of explorers to have readily available means for manufacturing parts in space. Many of the challenges facing additive manufacturing researchers here on earth are exacerbated or dramatically changed in space due to the difference in environmental conditions, gravitational forces in particular. Fluids are especially affected by these changes, where the lack of gravity can improve some of the manufacturing constraints such as printing on overhangs, while also creating challenges such as controlling the molten pool characteristics and thermal gradients. In the process of printing metals and polymers to make parts, control of fluid flow, heat transfer, and solidification are of utmost importance. This presentation will discuss some of the solutions available to the research community for modeling processes under different gravitational conditions, and how computational fluid dynamics coupled with analytical and empirical models can address printing challenges. Additionally, specific case studies looking at polymer extrusion and laser-based manufacturing and welding in low to no gravity will be presented.

Stability Modeling in Aerospace Machining: A Physics-Guided Machine Learning Approach with Adaptive Sampling for Self-Aware Operations

Dr. Noel P. Greis, Dr. Monica L. Nogueira, Prof. Harish Cherukuri, and Dr. Rafi Marandi, University of North Carolina at Charlotte, Charlotte, North Carolina, USA

Stability control of the machining process for aerospace parts with complex geometries and tight tolerances can be difficult to maintain in operational environments due to uncertainty about optimal parameter selection. On the shop floor, machining parameters are typically selected based on manufacturer recommendations or, in most cases, operator experience. The fusion of physics-based and data-driven approaches in physics-guided machine learning (PGML) represents a transformative breakthrough for optimal parameter selection that helps to ensure simultaneous achievement of part accuracy, high surface finish, and productivity. Physics-guided machine learning leverages measurement data generated during the machining process while incorporating decades of theoretical process modeling efforts and domain knowledge. Acquiring the large amounts of data needed for purely data-driven models can be costly. On the other hand, many physical processes are not completely understood by domain experts, so physics-based models must make simplifying assumptions that compromise optimal parameter selection. Further, machining parameters that yield stable dynamics depend not only on the time-varying dynamics of the specific machine tool and workpiece but also on specific conditions in the ambient operational environment. As a result, selection of optimal parameters to avoid instabilities (c.f., chatter) and maximize productivity requires continuous monitoring and updating of the SLD to ensure that the process remains within a stable regime. In this presentation, the PGML approach combined with an adaptive, data-driven sampling methodology for collecting measurement data is shown to offer an efficient method for determining the true underlying stability model for optimal parameter selection. Knowledge of the true stability model enables operators—and ultimately the machines themselves—to make in-process optimal parameter adjustments during production. As machines become more intelligent, self-knowledge of the true stability model is the foundation for self-aware operations and, as required, machine self-control to perform parametric adjustments that maintain process stability.

Simulation Accuracy of Hot Form Quench Process

Dr. Mohamed Mohamed and Mr. Tim McGuire, Impression Technologies Ltd., Coventry, United Kingdom

It could be said that Hot Form Quench (HFQ®) is a complex forming process, in which the strain rate and temperature change dynamically. Therefore, the accurate modeling of material behavior during HFQ is crucial. We have developed a novel damage model to predict the failure limit during HFQ forming. The modern damage model must be fully calibrated and validated for accurate HFQ simulation. This calibration process requires a high-quality data set, including uniaxial tensile data and forming limit curve data in different temperature and strain rate regimes. Impression Technologies Ltd.'s material testing and modeling facility includes digital image correlation and running an optimization code to calibrate the modern continuum damage mechanical model efficiently. The model validation must be relevant to the process parameters relevant to the HFQ production line. These parameters are (i) the forming process window (forming speed, temperature, forming force and blank holder force, quenching time, and quenching force), (ii) tool design, (iii) temperature control, and (iv) lubrication. Harmonic integration and optimization of all process parameters require good calibration and validation of the model.

Session: Advances in Coatings and Surface Modification I

Ranking of Refractory-High-Entropy-Alloy-Based Coatings for Hot-Forging Dies

Dr. Tanjore Jayaraman¹ and Dr. Ramachandra Canumalla²,

¹United States Air Force Academy, Colorado Springs, Colorado, USA;

²Weldaloy Specialty Forgings, Warren, Michigan, USA

High-entropy alloys have been prominent materials of interest over the past two decades. Lately, attention has turned toward refractory high-entropy alloys (RHEAs) suitable as coatings for conventional hot-forging die materials, such as Uddeholm Dievar and H13, which have a superior combination of properties including ambient- and elevated-temperature mechanical properties, including wear, thermal, and strength properties, and degradation resistance. Refractory high-entropy alloys are potential competitors to the current conventional coatings for forging dies. We analyzed the RHEAs available in the current literature using decision science and data-driven techniques, including multiple-attribute decision making (MADM) for sorting and ranking the RHEAs, principal component analyses for consolidating the ranks, and hierarchical clustering for identifying similarities among the top-ranked alloys. The ranks assigned by several MADM techniques, including ARAS (additive ratio assessment), MAUT (multi-attribute utility theory), MOORA (multi-objective optimization on the basis of ratio analysis), ROVM (range of value method), TOPSIS (technique of order preference by similarity to ideal solution), and WEDBA (weighted Euclidean distance-based approach), were consistent; in fact, the Spearman's correlation coefficient was greater than 0.80. The investigation identified RHEAs' potential as coatings for hot-forging dies, identified top RHEAs having properties significantly superior to the current benchmark, and suggested directives for further development. Specifically, the top-ranked RHEAs, $Al_{20.4}-Mo_{10.5}-Nb_{22.4}-Ta_{10.1}-Ti_{17.8}-Zr_{18.8}$ and $Ti_{20}-Zr_{20}-Hf_{20}-Nb_{20}-Cr_{20}$, have far superior properties, such as low wear rates (associated with their body-centered cubic structure), thermal conductivity lower than 75 W/mK, and yield strengths at ambient and elevated temperatures (up to 800 °C) greater than 1300 MPa, compared to the conventional hot-forging die materials. Thus, these RHEAs are very attractive as coating materials for dies for forging high-temperature alloys in a cost-effective way with improved die life. The analysis also reveals the alloy design strategy for further development of even higher quality RHEA-based coatings.

Crack-Free Tungsten Coating on Oxide Dispersion Strengthened Plate via a Novel Laser-Based Additive Technique

Dr. Jeongwoo Lee and Prof. Yung Shin, Purdue University, West Lafayette, Indiana, USA

A new laser-based additive manufacturing technique, offset laser cladding, was introduced to achieve dense tungsten coating on an oxide dispersion strengthened (ODS) substrate as a plasma-facing material. Different from ordinary directed energy deposition, which leads to incomplete melting of tungsten and excessive melting of the ODS substrate, the offset laser cladding technique can achieve complete melting of tungsten, while substrate melting is suppressed. Simulation methods were used to calculate laser parameters for experiments: laser power, scanning speed, powder size, offset distance, and powder nozzle setup. Tungsten coating using offset laser cladding in an open chamber condition showed that dense coating was achieved with a pore size of 1 to 2 μm . The result is comparable to that of vacuum plasma spray tungsten coating, which requires a high-level vacuum chamber. A thin interface layer (2–5 μm) was formed between the tungsten coating and ODS substrate that can alleviate thermal damage due to a large thermal expansion coefficient difference. While a small amount of surface melting was involved, the microhardness test revealed that the ODS substrate was insignificantly affected by laser heating during offset laser cladding.

Session: Additive Manufacturing II

Additive Friction Stir Deposition of Al6061 for Vacuum Chamber Fabrication

Dr. Chase Cox, MELD Manufacturing Corporation, Christiansburg, Virginia, USA

Additive friction stir deposition (AFSD) is a solid-state additive manufacturing process that can be used to produce near-net-shape Al6061 components. Al6061 is a lightweight and strong aluminum alloy that is commonly used in aerospace applications. It is also well suited for vacuum chamber fabrication due to its high corrosion resistance and low outgassing. Additive friction stir deposition has several advantages over forging for the production of vacuum chambers. It can produce components with complex geometries and features that are difficult to achieve using forging. It can also produce components with a wider range of sizes and thicknesses than forging. Additionally, AFSD is a relatively fast and efficient process, which can reduce the time and cost of vacuum chamber fabrication. This presentation will discuss the use of AFSD to produce Al6061 vacuum chambers for silicon chip manufacturing. The presentation will begin with an overview of the AFSD process and its advantages for vacuum chamber fabrication. The presentation will then discuss the design and manufacturing of AFSD-produced vacuum chambers. The presentation will conclude with a discussion of the benefits of using AFSD to produce vacuum chambers for silicon chip manufacturing. The audience will learn about the AFSD process and its advantages for vacuum chamber fabrication, the design and manufacturing of AFSD-produced vacuum chambers, and the benefits of using AFSD to produce vacuum chambers for silicon chip manufacturing. This presentation will be of interest to engineers, designers, and other professionals who are interested in using AFSD to produce vacuum chambers for silicon chip manufacturing.

Understanding of Grain Growth and Texture Formation of Inconel 718 Processed by Single-Track Laser Scanning

Ms. Liuqing Yang¹, Dr. Youxing Chen¹, and Dr. Jordan Weaver², ¹University of North Carolina at Charlotte, Charlotte, North Carolina; ²National Institute of Standards and Technology, Gaithersburg, Maryland, USA

The advantageous weldability of Inconel 718 proves highly beneficial for metal additive manufacturing. The grain structure and texture of Inconel fabricated by selective laser melting (SLM) are interesting due to their impact on corresponding mechanical properties. The grain growth generally follows the <001> direction, but the understanding of texture formation along printing and scanning directions, affected by the thermal history of melting and cooling, is still inadequate, which limits the texture design. As laser powder bed fusion has many variables from laser-powder interaction and the overlap of different molten layers, this talk examines the SLM single track process to reduce the variables and facilitate the understanding of the development of grain and texture in Inconel 718. Three different laser scanning rates were selected to transition from conduction mode to keyhole mode, and the thermal histories from the melting and cooling processes were collected by an in situ thermal camera with a frame rate of up to 1800 frames/s. A relationship among scanning rate, thermal history, melt pool geometry, and texture formation will be discussed.

Additive Manufacturing of Novel Nickel-Based Alloys for High-Performance Heat Exchangers

Dr. Matias Garcia-Avila, ATI, Monroe, North Carolina, USA

The development of advanced materials combined with additive manufacturing offers unique advantages in the fabrication of complex components such as heat exchangers. The advancement of nickel-based superalloys designed for additive manufacturing with improved long-term stability at temperature enhances performance and enables highly efficient extreme-environment heat exchangers for power generation and high-speed aircraft. ATI has developed new superalloys that improve high-temperature performance, creep properties, and long-term stability compared to commonly used alloys that are additively manufacturable, enabling extended service life of components in extreme environments. This presentation will discuss powder production, the additive manufacturing development process, and the resulting mechanical, thermophysical, and environmental properties of these alloys.

Session: Advances in Coatings and Surface Modification II

High-Temperature Alloys and Their Oxidation

Dr. Alexander Donchev, Dr. Mario Rudolphi, and Dr. Mathias Galetz, DECHEMA-Forschungsinstitut, Frankfurt am Main, Germany

Structural materials for high-temperature applications depend on the formation of a protective scale limiting the attack of the surrounding environment and sufficient mechanical properties (e.g., creep resistance). Usually, iron- or nickel-based alloys contain a certain amount of chromium so that a chromia scale is formed. Chromia can protect the components in dry atmospheres and at temperatures below approximately 1000 °C. If such protective elements are not present in a sufficient amount, they have to be enriched in the surface zone. One possibility to do so is enrichment via a chemical vapor deposition (CVD) process called powder pack cementation. Protective elements such as chromium, silicon, titanium, or aluminum form a stable, protective oxide layer at elevated temperatures in oxidizing environments. Because TiO₂ becomes deteriorated at elevated temperatures, it cannot be used. Silicon and chromium oxides suffer from evaporation in water-vapor-containing environments; therefore, alumina is a better choice. The CVD parameters strongly influence the coating quality, which is a crucial factor for the later use of treated components. Results of different CVD treatments on several nickel-based alloys by varying the ratio of the activator and diffusing element (aluminum) will be shown and discussed in view of the prolonged use of the treated components for more efficient flights (i.e., less inspection intervals or lower fuel consumption by using lighter materials).

When Choosing Lightweight Materials, Don't Forget Your Coatings!

Mr. Michael R. Bonner, Saint Clair Systems, Inc., Washington, Michigan, USA

Advanced materials are forefront in virtually every design project today. With electrification across every industry—most notably in the transportation sector—lightweighting is essential. Nowhere is this more apparent than in the automotive and aerospace industries, where every ounce is important. Unfortunately, coatings are generally ignored. But in Formula 1, where every gram counts, coatings are carefully selected to provide superior performance at weights less than one-tenth that of a conventional passenger car. Ultraviolet (UV), electron beam (EB), and UV-LED technology, also known as energy curable technology, was developed in the late 1920s by Edwin Newton of the B.F. Goodrich Company to “vulcanize” natural rubber, so it is borne of the automotive industry. Ultraviolet curing began to evolve in the 1960s, with significant commercialization in the 1970s driven by the 1973 Arab oil embargo. Since that time, improvements in chemistry and processing technology have made it one of the most sustainable technologies used in manufacturing from automotive to aerospace.

In this presentation, we will examine how UV/EB technology provides greater durability with thinner films, which means lower weight, translating to lower energy demands for a vehicle, boat, airplane, and so on. In addition, we will show how UV/EB curable technology enables innovative manufacturing processes that consume less energy yet meet or exceed air quality standards without requiring add-on pollution controls. We will provide case studies which demonstrate higher throughput efficiency, reduced waste, and reduced CO₂ emissions, resulting in the recognition of this technology by regulatory agencies as a clean process alternative. This means more parts can be produced with less energy and lower environmental impact, which translates to savings during the manufacturing process and energy savings over the life of the vehicle.

Laser-Assisted Cold Spray as an Alternative to High-Velocity Oxygen Fuel, Plasma, and Helium-Based Cold Spray

Mr. Fredrick Laguines, ES3, Warner Robins, Georgia, USA

High-velocity oxygen fuel (HVOF), atmospheric plasma, and cold spray coatings have been traditionally used to provide wear- and corrosion-resistant coatings. High-velocity oxygen fuel and plasma are inefficient processes with low deposition rates, which results in excessive waste and high operational costs. Cold spray requires substantially less heat than HVOF or plasma; however, cold spray powders bond via kinetic energy, and therefore, expensive gases such as helium with a high speed of sound generally produce higher gas and particle velocities, which are required to achieve effective bond strengths. Recently, the cost of helium has become so excessive that performing cold spray repairs with helium is cost ineffective.

ES3 is working with Laser Fusion Technologies to integrate a 4 kW laser into a high-pressure cold spray system. The combined system forms a laser-assisted cold spray (LACS) system that prepares the substrates immediately prior to impact of cold spray particles. The LACS process results in increased bond strengths and potential for structural repairs, and eliminates the need for using helium as the gas medium for transporting cold spray particles. ES3 is proving out this technology by optimizing the process and performing typical aircraft-related metallurgical and mechanical testing to validate airworthiness considerations. ES3 will implement this technology in a U.S. Air Force facility as part of the current effort.

Shortening the Path towards Successful Adoption of a Cr(VI)-Free Electroplating Process

Dr. Aga Franczak and Dr. Bart Van den Bossche, Elysa, Wiggmaal, Belgium

For decades, Cr(VI) has been favored as a coating in various industries, including automotive and aerospace, due to its ease of production and corrosion-resistant characteristics. However, Cr(VI) is a well-established carcinogen that has the potential to induce cancer in humans, and its fabrication results in the emission of carcinogens into the atmosphere, which has adverse impacts on both the environment and public health. Due to the toxic and cancer-causing nature of Cr(VI), the European Union initially opted for a full prohibition on Cr(VI) plating, beginning in 2024. Nonetheless, the European Court of Justice invalidated the CTAC (Chromium Trioxide REACH Authorization Consortium) authorization ruling on April 21, 2023, requiring the European Chemicals Agency to reevaluate this authorization before April 20, 2024. Throughout this interim period, the use of Cr(VI) can persist under existing conditions, and the ruling issued in April 2024 will dictate the fate of this authorization. In the United States, decorative plating businesses will be required to cease Cr(VI) use by 2027, while hard chrome plating facilities will be required to do so by 2039. This additional time provides an opportunity to manage the ongoing transition from the current Cr(VI) plating process to a more promising alternative, which at this time seems to be the Cr(III) plating process. However, substitution of Cr(VI) will require different technologies to be applied; new plating lines or new manufacturing lines will be required, which is associated with large investment costs and, thus, a slow transition process. Consequently, reducing the risk of investing in incorrect technology or infrastructure would prove exceedingly advantageous in this scenario. For this purpose, it is strongly recommended to verify the efficacy of the new plating process configuration and its performance through computer-aided analysis (CAA). This numerical simulation method involves creating a digital replica of the envisioned plating process, based on technical data considering type of the plating bath used, plating tank configuration, adequate process parameters, and geometry of the part to be plated. The CAA method enables conducting process performance analysis in regard to current density and metal layer thickness distributions before the actual plating process is installed. This presentation showcases the application of the CAA approach in designing, developing, and optimizing the new plating process. It aims to improve decision making for the effective and sustainable replacement of the Cr(VI) plating process.

Session: Material Solutions for Sustainability in Aerospace

Three Ways to Apply Science of Recycling Alloys to Produce Green Aerospace Alloys

Dr. Katharina Strobel, AMAG Rolling GmbH, Ranshofen, Austria

As the global industry strives to become carbon neutral, the production of aerospace-grade aluminum faces challenges. The lack of availability of primary aluminum from CO₂-neutral sources and the lack of availability of alloying elements are creating economic and political pressures. The science of recycling alloys is one approach to countering these challenges. This concept includes strategies such as broadening compositional windows, adapting alloy compositions to common pre- and/or post-consumer scrap compositions, and venturing into uni-alloy concepts. At AMAG, these efforts are supported by one of Europe's largest aluminum recycling facilities. Decade-long experience and continuous development have led to unique scrap sorting abilities. This contribution discusses the science of recycling alloys concept and how we have implemented it to supply the aerospace industry with products with a low CO₂ footprint.

AMAG's Development into a Global Player in Sustainable Aviation

Mrs. Christine Manatt¹ and Dr. Ramona Tosone², ¹AMAG Rolling, Winona Lake, Indiana, USA; ²AMAG Rolling GmbH, Braunau am Inn, Austria

As a premium aluminum manufacturer, with a strong focus on specialized products, AMAG has been supporting the aerospace industry for nearly two decades. With the opening of the new Center for Material Innovation and Smart Factory, AMAG is uniquely positioned to support the global transition to a more sustainable future in aerospace. By making sustainability and decarbonization a key focus at the time of product development, we can supply premium aerospace-quality aluminum with industry-leading recycled contents and low overall CO₂ footprints. AMAG's newest generation of sustainable aluminum products is capable of meeting the high quality and performance requirements of the aerospace industry while supporting AMAG's push to be a carbon-neutral company by 2040.

Aluminum Alloys Solutions for Wings of the Next Generation

Dr. Erembert Nizery¹, Dr. Jean-Christophe Ehrstrom¹, Dr. Marion Bellavoine¹, Dr. Nicolas Bayona-Carrillo¹, and Dr. Frank Eberl², ¹Constellium C-TEC, Voreppe, France; ²Constellium Aerospace and Transportation, Issoire, France

In a context where aircraft production remains high, the challenge posed by increased environmental concerns requires efforts in all relevant domains to improve sustainability of the whole aircraft life cycle. On the structural side, wings of the high-build-rate A320 and B737 are mostly made out of conventional aluminum alloys. For the next generation of wing structures, a new set of aluminum-copper-lithium Airware[®] alloys with reduced density versus conventional alloys has been developed. The combination with advanced joining techniques and their improved manufacturability offers weight savings on the wing box of the order of 10 to 15% at competitive costs.

On the material side, the lower wing skins are particularly important for the overall wing performance, since they account for the larger weight share. AW236, the new lower-wing aluminum-copper-lithium Airware solution (TRL 6 maturity), is a key enabler of the next-generation metallic wing, with -5% in density and +35% in spectrum fatigue lifetime compared to advanced conventional 2xxx solutions. Advanced metallic materials solutions for stringers and upper wing skins are also under development.

The improved performance of Airware alloys can also be exploited within new wing design concepts such as high-aspect-ratio wings. Aluminum alloys are well suited to concepts involving out-of-plane loads, such as truss-braced wings. In addition, aeroelastic tailoring of wing covers has been demonstrated to be achievable using smart designs, playing on rib orientation and sub-stiffening in particular. All alloy options including Airware are fully recyclable, which along with their lightweighting potential makes these materials a strong asset for a more environmentally friendly aircraft industry.

Designing for Sustainability with Material Intelligence

Mr. Roger Barnett, Mr. Freddy Moriniere, and Mr. Austin Flanary, ANSYS Granta, Cambridge, United Kingdom

Materials are central to any company's journey to net zero. Products are being developed by teams that need to consider materials that meet performance, cost and environmental considerations as well as shifting customer attitudes. But many of these engineers are unaware of the sustainability impact of their material selection. These considerations need to be made at the beginning, not the end, of the design process to avoid costly redesign and delays to product launch. Using a material management framework, reference data, and analysis tools, it is feasible to make proactive data-driven decisions on materials at the earliest stages of design. This includes rapid, detailed analysis of products, identifying alternative materials, and publishing preferred materials lists that include sustainability indicators. By having a single authoritative source of materials truth across a business and value chain, engineers (who may not have the authority or knowledge to introduce new materials) can select from a list of preferred materials. They have real-time visibility of the impact of their material choices for a product at all stages of the product life cycle, and all within their native CAD/product life cycle management/simulation environment.

Selection of Magnets for Permanent Magnet Synchronous Machines in All-Electric Aircraft by Applying Decision Science Techniques

Dr. Tanjore Jayaraman, United States Air Force Academy, Colorado Springs, Colorado, USA

Permanent magnets are ubiquitous in aerospace applications, specifically in modern environment-friendly and high-efficiency electric machines for energy conversion power generation, as in more-electric and all-electric aircraft. Since the last century, the industrial production of permanent magnets matured from steels through magnet alloys, ferrites, alnicos, and platinum-cobalt alloys to rare-earth-based permanent magnets. The permanent magnets for design and materials engineers for wide applications continually expand, including magnetic high-entropy alloys (HEAs). The selection of an apt permanent magnet catering to the application's demands, as in permanent magnet synchronous machines in all-electric aircraft, is critical. The attribute specifics include long-term performance in harsh conditions, long service life, miniature sizes, reduced weight, and superior retention force. We analyzed the permanent magnets in the current literature by applying decision science techniques. Several interaction-based, utility-based, and distance-based multiple-attribute decision-making methods (MADMs) sorted and ranked the magnets based on the performance requirement of the intended application. Principal component analyses consolidated the ranks of the magnets, while hierarchical clustering identified similarities (or differences) among the magnets. The ranks assigned by several MADMs, including WASPAS (weighted aggregated sum product assessment), DEMATEL (decision-making trial and evaluation laboratory), WEDBA (weighted Euclidean distance-based approach), were concurrent—the Spearman's correlation coefficient was greater 0.75. The decision-science-driven technique identified variants of cobalt samarium and neodymium magnets as the top choice, followed by alnicos, ferrites, platinum-cobalt alloys, and magnetic HEAs. The investigation provided perspectives on critical properties for consideration, permanent magnet selection, substitute magnets, and potential existing materials to focus on further research and development.

Session: Modeling and Simulation of Manufacturing Processes II

Efficient Prediction of Thermal History and Molten Pool Shape in a Large Domain for Metal Additive Manufacturing via Surrogate Modeling and Machine Learning

Mr. Corbin Grohol and **Prof. Yung Shin**, Purdue University, West Lafayette, Indiana, USA

This study is concerned with predicting accurate temperature fields in a large domain using a surrogate modeling technique and machine learning for metal laser powder bed fusion processes. Though high-fidelity modeling has been demonstrated to provide accurate representations of the attendant molten pool geometry and temperature field, simulation of large-scale components is not feasible, even with massively parallelized computing, due to prohibitively high computing costs. Using a low-fidelity model, while computationally efficient, cannot predict temperature history and molten pool shapes accurately. To overcome this challenge, a surrogate modeling approach is developed using a lower-fidelity model to extract temperature variation in a large domain with pertinent features for use in a Gaussian process regression, and an active learning algorithm is implemented to determine when and where the high-fidelity model, which has been developed in the authors' group over the years, needs to be simulated to improve modeling results. Using such an approach, the high-fidelity model computational load can be decreased significantly, increasing calculation throughput. With this approach, accurate molten pool shapes of a large domain are predicted with affordable computational time. The validation results are provided to show that this hybrid method is effective and provides reasonable accuracy.

A Discontinuous Dynamic Recrystallization Model for Predicting Grain Features during Friction Stir Processing

Ms. Prachi Sharma¹, Mr. Deepak Dhariwal², and Dr. Amit Arora¹,

¹Indian Institute of Technology Gandhinagar, Gandhinagar, India; ²Virginia Tech, Blacksburg, Virginia, USA

Friction stir welding (FSW) and processing leads to severe plastic deformation in materials. The large amount of strain combined with the high temperature of processing results in dynamic recrystallization and grain growth. The final properties of the processed materials are dependent on the recrystallized grain structure. Here, we present an analytical framework based on discontinuous dynamic recrystallization principles considering plastic deformation, nucleation, and growth. The present model is coupled with the heat transfer and material flow model for FSW, wherein the temperature and strain rates are computed. The computed strain rate and temperatures are utilized as input parameters in the present model. Kernel density estimation is used to compute the grain size distribution during the process. The computed grain size distribution is compared with the experimentally measured grain size in a sample subjected to the same processing conditions.

Numerical Analysis of the Flow and Orientation of Reinforcements in a Polymer Matrix during the Direct Ink Writing Process

Mr. Rajat Mishra and Dr. Amit Arora, Indian Institute of Technology Gandhinagar, Gandhinagar, India

Composites have many advantages over other materials, such as high specific strength and stiffness, design flexibility, and durability. The orientation of the reinforcement with respect to the matrix is an important factor in determining composite properties. This work presents a computational fluid dynamics-discrete element method (CFD-DEM)-based numerical model to predict the orientation of the particles during printing of a graphite-reinforced polymer composite from a nozzle. The polymer flow is simulated by solving the mass, momentum, and energy equations in three dimensions. The effect of polymer flow on the reinforcement graphite particles is calculated using one-way coupling of the fluid flow with particle mechanics. The particle position, distribution, and orientation are computed using DEM concepts. The computed particle orientation during printing is compared with the orientation of the graphite particles during the extrusion-based direct ink writing process. The orientation of the particles is optimized for the nozzle dimensions, melted polymer flow rate, and reinforcement concentration. The results show that the coupled CFD-DEM method is effective in showing the reinforcement particle behavior during printing of composite materials.

Advances in Superplastic Forming Simulations

Mr. Landon K. Henson and Mr. Jacob Spurgers, Boeing, Tukwila, Washington, USA

Advances in superplastic forming simulation with advanced finite element analysis have enabled timely qualitative and quantitative assessments of part and tool design with a decreased reliance on manufacturing trial and error. Implementing a model-based engineering (MBE) and full digital thread approach to superplastic forming manufacturing processes allows for optimization of the design, including maximization of part quality and repeatability at a significant cost and time savings.

Finite element models (FEMs) are developed using the commercial software LS-DYNA. Simulations of the titanium superplastic forming diffusion bonding (Ti-SPFDB) forming process are performed. This advanced analysis provides key insights into the complex interactions between the die (tooling surfaces) and pack (four-sheet titanium part). The first phase of analysis includes assessment of die closure, leading to pivotal understanding of the mechanisms for wrinkle formation. After die closure, the FEM is utilized to analyze the pack behavior under pressurization. Complex forming of the core sheet cells will begin to occur according to the pack and die design. Results provide key insight into how a particular die and pack design are likely to form in industrial settings. These predictions lead to early insights of potential risks in sheet wrinkling and regions of excessive thinning before the die and pack are manufactured. Understanding these risks a priori aids in panel design, allowing multiple design iterations and forming sensitivity on subscale trials studies before an actual part is formed.

This is a significant improvement over an approach that relies on trial and error, providing the opportunity to realize significant cost savings within the overall design and manufacturing process of Ti-SPFDB parts. Through improved simulation capabilities with LS-DYNA, these costs can be alleviated through an iterative MBE approach, in which simulation results advise necessary changes to tooling design and pack configuration, all of which occurs prior to real-world forming.

Simulation as Enabler for Future Material and Process Improvements

Dr. Achim Buerger, Sasi Chinnasamy, Sven Steinmann, Christian Tussing, Dr. Sabine Spangel, and Philippe Meyer, Novelis Koblenz GmbH, Koblenz, Germany

The aircraft industry is facing a multitude of challenges to deliver growing production rates, high-performance materials, and cost-effective manufacturing and to meet increasing sustainability requirements. Aluminum suppliers are well positioned to fulfill these demands while permanently being pushed to develop improved solutions. The presentation will highlight how Novelis applies advanced virtual tools to take up successfully these challenges. The activities extend from alloy design, process optimization for new sheet and plate products, and innovative component manufacturing methodologies such as roll forming to the performance of the developed solutions in an aircraft application. Improved machining practices with reduced distortion shall be achieved based on digital twins describing the residual stress state of thick rolled, solution-treated, and quenched plates for structural parts.

Session: Additive Manufacturing III

Enhancing the Mechanical Properties of 3D-Printed Plastic Components through Electroplating Process, Pre-optimized with a Computer-Aided Engineering Approach

Dr. Aga Franczak¹, Mr. Sean Wise², Dr. Bart Van den Bossche¹, and Mr. Paulo Vieira¹,
¹Elsyca, Wijgmaal, Belgium; ²RePliForm Inc., Baltimore, Maryland, USA

Electroplating is an electrochemical SF process creating a thin metal coating on a part surface. Like numerous other post-processing methods employed for 3D-printed components, electroplating serves the purpose of enhancing the physical characteristics of the part. This can encompass augmenting wear resistance, providing corrosion protection, or improving aesthetics. Interestingly, the additive manufacturing industry does not possess a comprehensive understanding of this process, and is not aware that photopolymer, fused/sintered powder, or filament 3D-printed parts can be plated. Furthermore, understanding the influence of electroplating on the mechanical characteristics of 3D-printed components necessitates gaining insights into various mechanical aspects as well. Electroplating applied to 3D-printed plastic materials, as an example, has the potential to produce a strengthened composite and introduce metallic capabilities to initially nonconductive materials. To craft a composite of metal and resin, using techniques such as stereolithography and electroplating, it is essential to assess whether a plated plastic can bridge the gap between printed metal and plastic components. This involves comprehending the principles of mixtures to estimate tensile properties derived from individual constituents or adapting the design to accommodate the added coating when it is already in place. It is important to note that as the geometry of the part becomes more intricate, the deposition of metal on its surface becomes increasingly uneven. This complexity presents challenges in controlling the electroplating process and achieving a uniformly distributed metal layer coating across all surfaces to be plated, which may require the development of specific mitigation strategies. Hence, it is highly advisable to utilize an upfront analysis and optimization of the electroplating process within the context of computer-aided engineering (CAE) to ensure efficient and effective process performance. Unlocking the mystery of electroplating of 3D-printed plastic parts and the role of CAE is what this presentation aims to achieve.

Eliminating Graphite in Additive Friction Stir Deposition

Dr. Yuri Hovanski, Mr. Lukas Dean, and Mr. Jacob Hansen,
 Brigham Young University, Provo, Utah, USA

Additive friction stir deposition, also known as MELD, is a solid-state, near-net-shape metal additive manufacturing process. As a solid-state deposition process, it relies on deformation of metals below the melting point, which leads to significant benefits in microstructure and properties of the printed material. While the properties and deposition rates of additive friction stir deposition lead metal additive processes, initial work has been developed using graphite lubricants on the metal during the deposition process. These lubricants can at times find themselves within the overall deposition of the metal in such a way as to significantly reduce the as-deposited properties of the build. We show a comparison of properties of 7xxx series aluminum with or without graphite contamination, as a means of justifying the need for eliminating the use of graphite in additive friction stir deposition. Furthermore, we show a design for eliminating graphite and evaluate the proposed design on two separate manufacturers' platforms for additive friction stir deposition.

Development of Water Cavitation Abrasive Surface Finishing for Post-process Cleaning, Smoothing, and Peening of Additive Manufactured Titanium Parts to Meet the Aerospace Industry's Requirements

Dr. Daniel G. Sanders¹, Dr. Dwayne Arola², Dr. Mamidala Ramulu²,
 Mr. Rohin Petram², Mr. Cole Nouwens², Mr. Conall Wisdom², and
 Mr. Alex Montelione², ¹Sugino Corporation, Itasca, Washington, USA;
²University of Washington, Seattle, Washington, USA

The water cavitation abrasive surface finishing and peening process is undergoing preliminary testing to validate its use for cleaning, smoothing, and imparting compressive residual stresses onto additive manufactured titanium parts. The goal is to meet the aerospace detail part manufacturing requirements. This discussion will focus on the progress made in the past few months and examine its potential benefits as an alternative to the traditional methods.

Rapid Additive Manufacturing Parameter Set and Materials Development using ICMD Materials Design Software

Mr. Kerem Taskin, QuesTek Innovations LLC, Evanston, Illinois, USA

Many materials initially developed for conventional manufacturing paths such as casting or forging were adapted for additive manufacturing (AM) applications due to their relative weldability, increasing the likelihood of crack-free printability. However, due to the rapid solidification and remelting that occurs during the AM process, these alloys exhibit widely different microstructures and properties compared to their cast and wrought forms, and often lead to the formation of defects upon printing. As a result, in developing processing specifications for materials in AM, most companies go through an iterative design of experiments approach to establish processing parameters that result in reliable, repeatable, defect-free builds. In certain cases, this process can be time, cost, and labor intensive. At other times, the existing materials may not yield the desired properties and performance.

ICMD® is a software platform that utilizes a combination of physics-based models, thermodynamic and kinetic databases, and efficient model workflow and visualization features that allow for the optimization and design of both materials and processes. For additive manufacturing, ICMD can identify microstructures needed to satisfy properties which can be crucial to ensuring enhanced performance. Improved materials and thermal processing can be developed radically faster and at lower cost compared to an iterative design of experiments approach. Furthermore, in ICMD's AM toolkit, enhanced printability mapping features can help guide process parameter development, decreasing the number of experiments required to fine-tune specifications. This talk will provide an overview of the ICMD software and how the software-as-a-service product is used to accelerate the qualification of materials in metal AM. The talk will include examples of optimizing legacy alloys to improve printability; generating printability maps for optimal, defect-free builds; and optimizing post-build heat treatment processes to improve printed material properties.

Session: High-Temperature and Gas Turbine Materials I

Laser Peening Improved Fatigue Life and Strength of Single-Crystal CMSX-4 after Corrosive and High-Temperature Exposure

Dr. Lloyd Hackel, Metal Improvement Company,
Curtiss-Wright Surface Technologies, Livermore, California, USA

This study investigated the stress relaxation and fatigue life and strength of laser-peened single-crystal nickel superalloy (CMSX-4) specimens following sulfate corrosion and 300 hours of air oven exposure at 700 °C. Fatigue testing compared un-peened, shot-peened, and laser-peened specimens. The laser-peened specimens were treated by large-energy, large-spot peening and several specimens by a new cyclic laser peening plus thermal microstructure engineering process. Stress measurements by slitting/crack compliance showed that the plastic penetration depth of laser peening exceeded that of shot peening by a factor of 24. Tests of five non-laser-peened specimens all failed in the low-cycle fatigue regime at 27,000 cycles or less, whereas three identically tested laser peened specimens all achieved greater than 2-million-cycle runout without failure, indicating a fully consistent large benefit for life by laser peening. Additional tests showed fatigue strength improvement of 2 to 1 by laser peening.

High-Temperature Oxidation and Corrosion Behavior of Chromized Rene 80 by Pack Cementation and Slurry

Mr. Michael Kerbstadt, Dr. Emma White, and Mathias C. Galetz,
DECHEMA-Forschungsinstitut, Frankfurt am Main, Germany

Nickel-based superalloys are commonly used in gas turbines because of their outstanding high-temperature strength and creep properties. To also ensure sufficient oxidation and corrosion resistance, protective diffusion coatings are widely applied, such as chromium-based coatings, which are advantageous for hot corrosion and oxidation resistance between 650 and 950 °C. Chromium-based diffusion coatings are primarily formed using pack cementation, where the parts are fully embedded into a powder mixture, which is energy and labor intensive. Alternatively, slurry-based coatings would be significantly more economical. For aluminum, the slurry process is well established because a liquid phase is easily achievable at the substrate-particle interface, which is necessary for sufficient diffusion rates during heat treatment. Because of the high melting point of chromium, chromium-based diffusion coatings formed by the slurry technique have been unavailable to date.

Recently, chromium-silicon slurry coatings that form a liquid at the substrate-particle interface have been successfully developed. Higher chromium activity, due to the partial liquid state, enables ~10 times higher coating thicknesses compared to similar coatings applied by pack cementation. The high-temperature oxidation and corrosion performance of these novel chromium-silicon slurry coatings on the alloy Rene 80 was investigated and compared to that of pack cementation and uncoated samples. Isothermal and cyclic (1 h/cycle) exposures in lab air at 900 °C for 1000 h were carried out. The hot corrosion behavior was investigated by the deposition of 2.5 mg/cm² Na₂SO₄ salt. Afterwards, the samples were exposed at 700 and 900 °C for 300 h in a gas mixture of synthetic air containing 0.1% SO₂. The slurry-coated samples showed significantly reduced attack by oxidation and corrosion during the exposures due to the formation of a slowly growing Cr₂O₃ scale and a silicon-rich subscale.

Session: Light Alloy Technology I

Dry Sliding Wear Properties of SiC/Mg Composites by Spark Plasma Sintering

Dr. Yoshiki Komiya, Nihon University, Chiba, Japan

Magnesium and magnesium matrix composites have the advantages of light weight and high specific strength. In particular, magnesium is the lightest of the structural metals. However, the mechanical strength and wear resistance of magnesium are inferior to those of other metals. In this study, the mechanical properties and wear resistance of magnesium matrix composites were improved by adding TiB₂ or SiC to pure magnesium. The composites were sintered by the spark plasma sintering method, and their mechanical and wear properties were evaluated. The results showed that the mechanical strength and wear resistance of the composites were improved; 15mass%TiB₂/Mg and 25mass%SiC/Mg showed the highest tensile strength, and 15mass%TiB₂/Mg and 5mass%SiC/Mg showed the best wear resistance.

Optimizing Sheet Metal Forming for Aircraft Doorframe

Dr. Bjorn Carlsson, Ingemar Nygren, Bjorn Helgesen, Jonas Liljeberg, and Sture Olsson, Quintus Technologies, Vasteras, Sweden

In this presentation, we describe how the number of steps for producing a doorframe for a civil aircraft might be reduced from 16 to only 3 process steps. The aerospace industry has a tradition of using low-cost pressing techniques with only one die half, such as fluid cell pressing and rubber pad pressing, ideal when producing many different components in small series. The demonstrator door frame has a complex shape including a large central indentation, six non-circular holes, and an undercut. It has been manufactured in 2 mm (0.08 in.) aluminum 2024-0 and in 2024-W. After forming, the -W temper was aged at room temperature to obtain 2024-T42. In this project, we describe how the production of the doorframe for a large-scale commercial aircraft could be realized by the implementation of computer simulations (including analysis of springback and material thinning), modern tool design, and high-pressure forming technology. Again, by optimizing the earlier used fabrication process, the project demonstrated that the number of fabrication steps could be reduced from 16 to only 3 steps, thereby reducing or even eliminating the need for hand correction. The current tool has not been compensated for springback, yet the geometric accuracy and repeatability are very good.

Session: Tribology and Wear of Aerospace Materials

Influence of Temperature on the Tribological Behavior of Inconel 718, Haynes 25, and Silicon Carbide under Fretting Conditions for the Purpose of Long-Lasting Gas Turbine Engines

Ms. Marie-Laurence Cliche and Prof. Pantcho Stoyanov, Concordia University, Montreal, Quebec, Canada

In an effort to reduce greenhouse gas emissions in the aerospace industry, gas turbine engines will be required to significantly reduce their CO₂ emissions. To achieve this goal, the conditions in which materials are expected to operate will become harsher due to increases in temperature, pressure, and velocities. As a result, high-performance materials, with good mechanical and tribological properties, are needed to prevent the premature degradation and damage of critical engine components and improve the performance of the engines. Considering that there are many moving and contacting mechanical assemblies within the engines (e.g., bearings, seals, gears), having a good understanding of how different materials behave together is fundamental to ensure acceptable tribological performance. Therefore, the objective of this study is to fully capture the tribological behavior under demanding environments of commonly used nickel-based and cobalt-based superalloys. Three different materials have been selected: Inconel 718, a high-strength nickel-based superalloy; Haynes 25, a cobalt-based alloy; and silicon carbide, which is a highly corrosion-resistant ceramic. Similarly, Inconel 718 and silicon carbide were selected as counterfaces to provide both a superalloy and a ceramic material. The tribological tests were performed using a ball-on-disk tribometer where the samples were subjected to high temperatures (450 and 800 °C) and high vibration to more accurately simulate the operating environment the material would have to experience in the engine. The characterization of the worn surfaces was performed using confocal laser scanning microscopy, scanning electron microscopy, and energy dispersive x-ray spectroscopy. Overall, this study will establish the wear and friction performance of commonly used materials in the hot section of the gas turbine engines, and emphasis will be made on their interfacial behavior for tribological applications.

Tribological Assessment of Exit Guide Vane Support Tabs in a Jet Engine

Dr. Mary Makowiec, Pratt & Whitney, East Hartford, Connecticut, USA

Exit guide vanes are critical components at the rear of the low-pressure compressor in jet engines, responsible for directing airflow to maximize efficiency. This study focuses on evaluating and characterizing wear patterns on the support tabs of an engine-run exit guide vane with the aim of improving the longevity of future designs. In this presentation, findings from this investigation will be discussed, including the observed types of wear and the techniques employed for evaluation. Analysis methods include white light interferometry, scanning electron microscopy, elemental analysis, and x-ray photospectroscopy.

Session: Emerging Materials and Processes I

Clean Hot Isostatic Pressing Processing to Minimize Surface Oxidation

Mr. Andrew Cassese and Mr. Chad Beamer, Quintus Technologies LLC, Lewis Center, Ohio, USA

The hot isostatic pressing (HIP) process has often been coupled with oxidation of surfaces due to high oxygen partial pressure at the HIP pressure. Oxygen originates from several different individual sources, all of which must be controlled to avoid surface oxidation and various forms of contamination. This contamination may have detrimental effects on critical components that are exposed to fatigue. This has led to the need to wrap components with different types of metal foils getting the contaminants before these can react with the part surfaces. The need for getters of course consumes resources, creating a demand to develop a viable solution to this challenge.

Quintus Technologies has developed a new toolbox under the high-pressure heat treatment umbrella called Quintus Purus®, a combination of best practices for working with the HIP system, new equipment capabilities, and fit-for-purpose oxygen getter cassettes. This concept promises the opportunity to reduce oxygen species in the HIP process by over 95%. The result is a path for significantly less part surface oxidation and contamination. This will increase the efficiency and accuracy of further post-processing techniques such as chemical milling to allow for a more uniform surface finish. This presentation will highlight the current challenges with HIP equipment and the origin of the oxidation that causes part discoloration. It will focus on the best practices to mitigate moisture in the HIP furnace and highlight the industry benefits of HIP with Quintus Purus.

Using Temperature to Simulate Thixotropy in 100% Solid Coatings

Mr. Michael R. Bonner, Saint Clair Systems, Inc., Washington, Michigan, USA

Thixotropy is a very valuable property widely exploited in modern coating formulations to control the flow out in the film. This is usually achieved with rheology modifiers that create this shear thinning behavior. In conventional solventborne and waterborne coatings, this is virtually the only way to achieve this behavior, as temperature simultaneously affects both viscosity and solvent evaporation (including water). In 100% solid coatings, however, temperature can be used to simultaneously modify viscosity, reduce the need for monomer thinners, and control the flow out in the film. In this presentation, we will define thixotropic behavior and why it is important in coating applications to achieve the desired surface finish; introduce the "temperature hierarchy" in a coating operation; compare and contrast key similarities and differences between conventional and energy curable coatings; identify the unique properties and behaviors of 100% solid ultraviolet/electron beam coatings that allow temperature to generate thixotropic-like behavior in film formation; and contrast the leveling times available in conventional and energy curable coatings and the influence of the shortened cure cycle. In addition, we will cite examples where this is being done in current applications.

Stainless Character of a Martensitic Grade with Structural Hardening and High Mechanical Strength: Improved Durability Applied to the Aerospace Market

Dr. Charles Declairieux and Dr. Laury-Hann Brassart, Aubert & Duval, Les Ancizes, France

Martensitic stainless steels owe their high strength to aging heat treatments, during which the precipitation of hardening phases takes place. The temperature of these treatments is around 450 to 550 °C, and the nature of the precipitates varies according to the steel's chemical composition. This specific microstructure induces structural hardening and thus properties that meet the requirements of sometimes critical aeronautical structural parts. With a range of mechanical strength (R_m) between 1500 and 2000 MPa and a toughness (K_{IC}) from 50 to 140 MPa√m, these steels are suitable for severe conditions in service. In this context, Aubert & Duval has been developing the MLX®19 grade, a promising alternative to 300M, generally used for certain landing gear parts, with stainless properties. After development work on the vacuum induction melting double vacuum arc remelting process, followed by solution and aging heat treatment optimization, the targeted properties for use have been achieved. During aging, the duplex structural hardening obtained by the precipitation of NiAl and Ni₃Ti is combined with the appearance of reversion austenite, resulting in an R_m/K_{IC}

balance of around 1930 MPa and 52 MPa/m (compared with approximately 2000 MPa and 60 MPa/m for 300M). These optimized mechanical properties are coupled with the grade's inherent stainless properties, enabled by an appropriate chemical composition. As a result, stress corrosion resistance, a dimensional property for the targeted applications, is such that $K_{ISCC} > 40$ MPa/m at open-circuit potential, in the case of rising step load testing. The advantage of this grade over the currently used solutions for these applications lies in its stainless property. Indeed, the grade's resistance to corrosion, mainly due to its higher chromium content (i.e., 10% compared with 0.8% for 300M), offers different advantages: (i) increased service life, (ii) reduced need for coatings, and (iii) reduced maintenance.

Session: Titanium Alloy Technology Materials Characterization and Failure Analysis I

Solid-State Additive Manufacturing of Titanium Alloys Using MELD Process

Dr. Mandana Meisami Azad, MELD Manufacturing, Christiansburg, Virginia, USA

Industrial interest in utilizing additive manufacturing (AM) processes for fabrication of large-scale and near-net-shape parts has largely increased in the past few decades. This is due to the potential for significant savings in raw material, lead time, and finish machining, as well as the ability to produce complex geometries that are not feasible with traditional manufacturing methods. Most melt-based AM processes require use of powders in vacuum chambers, and post-processing, such as hot isostatic pressing or sintering, is an additional step for most melt-based AM due to presence of some defects created during the rapid solidification process. MELD is a fully solid-state AM process that can use off-shelf materials to print a near-net-shape large components that are fully dense with less distortion and residual stress compared to most other AM technologies. This presentation will overview the development of the MELD process for titanium alloys, including Ti 6-4 and Ti 10-2-3. It has been demonstrated that the key processing factor in additive friction stir deposition for a good-performing material is temperature control deposition. This presentation will discuss the characteristics of as-printed materials fabricated using the MELD process. This will include microstructure, chemical and density analysis, and mechanical properties such as tensile and high-cycle fatigue performance. The effect of heat treatment on tensile properties will also be discussed. The results suggest that MELD Ti 6-4 and Ti 10-2-3 exceed the minimum requirements for die forging.

Investigation into Manufacturing Complexities Intrinsic to Superplasticity Formed and Diffusion Bonded Components by Statistical Modeling, Simulation, and Experiments

Mr. Bryan Ferguson, Mr. Eric Bol, Mrs. Neha Kulkarni, Dr. Daniel G. Sanders, and Prof. M. Ramulu, University of Washington, Seattle, Washington, USA

Superplastic forming is a sheet metal forming process that produces parts that are free of residual stresses, are dimensionally accurate, and have strains otherwise unobtainable. Diffusion bonding is a solid-state welding operation which combines two relatively flat, clean surfaces at high temperature to create a near flawless weld over a large surface area. Combination of superplastic forming with diffusion bonding (SPF/DB) creates a phenomenon where, under similar processing conditions, the material involved will produce a weld with itself, enabling a variety of reinforcing internal structures. Most superplastic parts are blow-formed to a die surface with small variations in thicknesses. This work investigated a process unique to SPF/DB using four sheets of titanium. The two outer sheets are formed to the die surface, while the two unsupported inner sheets form a complex sandwich structure that is all diffusion bonded. Because superplasticity is stress history dependent and somewhat chaotic, the geometry of the inner sheets is free to shift and translate such that small variations in the initial geometry create large changes in the final geometry. Modeling of diffusion bonding has been challenging due to variations in voids formed at the mating surfaces. A variety of techniques to measure the variances in forming were quantified using cell wall measurements, gas pathway measurements, and computer-vision-based geometry analysis. Finite element simulations of the inner sheet forming process compared the experimental results with idealized geometry. A stochastic diffusion bonding model was implemented to estimate the probability of voids formed; it used a statistical

version of Pilling's model, combined with theoretical voids formed from interacting surfaces based on surface roughness initial conditions. The results of the model and simulations were compared with experimental results for three different titanium alloys under different process conditions. These findings provide insights into the complexities of manufacturing four sheet SPF/DB structures.

Session: High-Temperature and Gas Turbine Materials II

Co-Mo-Cr-Si Coating on Haynes 282 by a Novel Hybrid Method of Laser Direct Deposition and Selective Remelting

Mr. Kyung-Min Hong and **Prof. Yung Shin**, Purdue University, West Lafayette, Indiana, USA

This presentation covers a novel hybrid method of the crack-free fusion of Co-Mo-Cr-Si, which is a cobalt-based alloy with molybdenum additions with the composition analogous to Triballoy® T400, on Haynes 282 for parts where extreme wear is problematic with high temperatures and corrosive media, such as industrial turbine applications, commercial jet engines, and rocket engines. To alleviate cracking of the coating during laser surface deposition/coating, previous attempts relied on preheating of the substrate to reduce cracks to alleviate a thermal mismatch between the substrate and molten powder. The primary aim of this work is accomplished by fusing a crack-free Co-Mo-Cr-Si layer using a novel hybrid process of combining laser cladding and laser remelting processes. The optimal process conditions for forming crack-free Co-Mo-Cr-Si coating on Haynes 282 were determined for both the laser powder bed fusion and remelting processes, and the microhardness and chemical compositions of the coating layers produced using optimal process parameters with and without remelting the substrate were compared. The chemical compositions of different phases present in the coating layer were analyzed by energy dispersive x-ray spectroscopy. Unlike the preheating method used in the past, the remelting process yielded minimal to no dilution at the surface, resulting in the preservation of the original Co-Mo-Cr-Si coating properties. This research shows that the remelting process is a promising method for scaling up to industrial applications.

High-Vacuum Heat Treatment for Aerospace Materials

Mr. Thomas Hart, SECO/VACUUM, Meadville, Pennsylvania, USA

High-vacuum heat treatment for aerospace materials is a critical process in enhancing the performance, durability, and reliability of advanced materials used in aerospace applications. There are many factors that can influence the performance of these materials; however, the removal of contaminants (high vacuum) to the heating environment and the minimization of oxidation are crucial to achieving superior material properties. The diverse range of aerospace materials that benefit from high-vacuum heat treatment includes superalloys such as Ti-6Al-4V, Inconel 718, Hastelloy X, Inconel 625, Waspaloy, Rene 41, Monel 400, Incoloy 825, Hastelloy C-276, and Haynes 230, where precise control over temperature, pressure, and gas composition within the vacuum environment creates the desired microstructure and performance qualities. High-vacuum heat treatment allows for processes such as high-temperature brazing, vacuum aluminum brazing, annealing, single-crystal annealing, stress relieving, age hardening, sintering, 3D printing post-processing, coating, diffusion bonding, hydriding, and dehydriding. This presentation underscores the paramount importance of high-vacuum heat treatment in advancing aerospace materials technology while providing fundamental principles and applications for engineers, researchers, and practitioners in the aerospace industry.

Session: Light Alloy Technology II

Developments at Novelis to Address New Challenges in the Aircraft Industry

Dr. Sabine Spangel, Philipp Rumpf, Andreas Bach, Christian Tussing, Sven Steinmann, Sasi Chinnasamy, Dr. Achim Buerger, and Philippe Meyer, Novelis Koblenz GmbH, Koblenz, Germany

In past years, the competition from fiber-reinforced composites has driven the development of aluminum alloys towards new plate and sheet products with enhanced damage tolerance and strength. Products allowing for high build rates have also come into the spotlight. Most of these developments were linked to specific new aircraft programs with clear property targets. Currently, the aluminum industry is facing new requirements from aircraft manufacturers such as sustainability targets and the need for reduced emission propulsion concepts along with new aircraft designs. To address these objectives, advanced alloys that allow for enhanced recycling, new reliable manufacturing methods, and improved properties and also consider new demanding requirements are needed. This paper describes new developments at Novelis for aerospace plate and sheet products to demonstrate how these challenges are being addressed.

Airware Friction Stir Welding Tailor-Welded Blank for High-Performance and Cost-Efficient Stiffened Panel for Aerospace Applications

Dr. Frank Eberl¹, Mr. David Chartier², Mr. Jacques-Erwan Ducatez², and Mr. Julien Laye³, ¹Constellium Aerospace and Transportation, Issoire, France; ²Airbus Atlantic, Toulouse, France; ³Constellium C-TEC, Voreppe, France

Friction stir welding has been studied extensively by major players of the aeronautics industry. This robust welding process can improve airframe performance by building up thick-gauge structures with thinner-gauge materials. Weight savings is possible due to the “T-joint” welded configuration and the good mechanical behavior of the welded joint. Cost savings can be achieved by reducing the machining time and the development of dedicated materials. Constellium and Airbus Atlantic have been collaborating for more than five years to propose a global and robust manufacturing sequence to join Airware® (AA2050) stiffened panels. Mechanical and corrosion aspects have been extensively assessed, including other material characteristics such as fatigue and damage tolerance. Industrial aspects such as tooling, nondestructive testing, and stress relief treatments have been studied. Results from various welded coupons and 1:1 scale prototypes were satisfactory and confirm the high potential of the technology for aero-structure manufacturing. However, to ensure cost performance of the process, it is mandatory to minimize the influence of post-milling distortions. Specific heat treatments and manufacturing process optimization could be considered as solutions to improve the robustness of this stiffened panel design. To assess the performance of process monitoring, a specific test program has been performed: many 1:1 scale and 1:2 scale coupons have been welded, heat treated, and machined in different industrial configurations; different Airware materials have been characterized; and specific heat treatments have been studied, including numerical simulation. The main results of these tests, the data analysis methods, and the potential of specific heat treatment for our welding configuration will be presented and discussed.

Forming Plates Demonstrator Using Creep Age Forming Technology

Mr. Edgar Jose Da Silva and Dr. Paula Costa, Embraer, São José dos Campos, Brazil

Creep age forming (CAF) is a forming process that combines creep/relaxation and precipitation hardening of the material. Precipitation hardening aluminum alloys are the typical materials used. The main application of CAF is in the aerospace industry to manufacture structural parts such as wing skins and other complex parts. The process has some advantages when compared to traditional manufacturing techniques. Creep age forming is independent of human skills, has high dimensional repeatability, and enables the forming of integrally stiffened parts. However, this process is not widely applied due to its high dependence on product design and the complexity of springback prediction and definition of the forming tool surface. This work presents a research and development project that aims to reduce the dependence on design and complexity of springback calculation through a new way of performing CAF. The Forming Plates project addresses the traditional CAF challenges, opening opportunities to increase the number of parts manufactured by this technology. The use of CAF reduces the recurrent costs of

parts and can improve the mechanical properties due to the use of plates with lower thicknesses. In addition, the waste of the machining process is reduced as well as the consumption of aluminum, which is in consonance with environmental, social, and governance requirements. This lecture will focus on challenges in the technology’s demonstrator manufacturing as well as on the results of the teardown campaign carried out on the demonstrator to evaluate the mechanical properties after CAF.

Session: Emerging Materials and Processes II

Shear-Assisted Processing and Extrusion of Aluminum-Cerium and Aluminum 7075 Aluminum Alloys

Dr. Cindy Powell and Dr. Scott Whalen, Pacific Northwest National Laboratory, Richland, Washington, USA

Shear-assisted processing and extrusion (ShAPE) is an emerging technology for the manufacture of extruded metal components with improved performance and lower embodied energy. The application of ShAPE to aluminum-cerium and aluminum 7075 alloys will be discussed as illustrative examples. Aluminum-cerium castings (Al-8Ce-4Mg) are known for their retention of tensile properties at elevated temperature, which is attractive for aerospace applications. However, the brittle intermetallic phases that enable high-temperature stability also make the alloy difficult to extrude. Al-8Ce-4Mg castings were easily extruded by ShAPE and achieved a highly refined microstructure with mechanical properties that include a doubling of yield strength and near tripling of toughness compared to conventionally extruded Al-8Ce-4Mg tested under identical conditions. Microstructural analysis shows increasing comminution of second-phase particles as process temperature decreases, which is attributed to higher load transfer from the aluminum matrix into the particles. The potential for ShAPE to improve, or even eliminate, process steps common to conventional extrusion will be illustrated for aluminum 7075. Here, aluminum 7075 castings were extruded at up to 12 m/min, far exceeding the 1 to 2 m/min limit for conventional extrusion while still meeting property specifications. Additionally, aluminum 7075 castings were extruded in the nonhomogenized condition, eliminating the requirement for a thermal homogenization treatment at 465 °C for 18 to 24 h. Microstructural analysis shows that extensive refinement and dispersion of second phases occurs during ShAPE extrusion.

Flexible and Lightweight Robotic Deployment System for Confined Spaces

Mr. Georg Heidekmann¹ and Mr. Alun Reece², ¹Loop Technology, Kansas City, Missouri, USA; ²Loop Technology, Dorchester, United Kingdom

A major challenge for aerospace manufacturers is access and assembly operations within confined spaces. Traditionally this process is done manually due to inadequate automated systems that are bulky, cumbersome, and must be proximate to their control hardware. Snake-arm robots can be disadvantaged by low stiffness and inaccuracy because they are cable driven. Bravura is a new type of robotic arm that solves this problem. It is a modular, scalable multi-axis, lightweight, articulated positioner that can bend and twist through openings, delivering a process head into restricted areas with high accuracy. Suitable tools for this highly flexible robotic arm include inspection devices, fastening systems, grippers, sealant dispensers, and other end effectors. It has a 1100 mm reach with a sizeable 5 kg payload and extends the possibilities for end-of-arm tooling by adding six degrees of freedom. Bravura can be installed on the end of another robot, Cartesian axes, an automated guided vehicle, or a combination of all. It uses custom configured frameless servo motors, paired with high-ratio harmonic gearboxes, resulting in high-power-density drive units. The low weight is due to its aluminum construction whilst continuous axis rotation means that it will never hit an axis limit when maneuvering. Custom path planning tools simplify insertion, removal, and recovery, and its powerful kinematic coupling functionality allows real-time synchronous motion planning with a host robot. Automating operations in confined spaces, such as a wing box, will allow for faster, safer, more repeatable production of aerospace structures. Additionally, removing the constraints imposed by the need for manual access will allow for more innovative wing design going forward.

Session: Titanium Alloy Technology • Materials Characterization and Failure Analysis II

Tailoring Strength and Toughness of a New ATI High-Strength Titanium Alloy

Mr. John V. Mantione, Dr. David Brice, and Dr. Matias Garcia-Avila, ATI, Monroe, North Carolina, USA

High-strength titanium alloys such as Ti-10V-2Fe-3Al (Ti-10-2-3) and Ti-5Al-5V-5Mo-3Cr (Ti-5553) are currently used in critical airframe applications such as landing gear, wing box structural members, and engine nacelles. In a solution-treated and aged condition, these alloys exhibit a high tensile strength (above 180 ksi) with moderate fracture toughness. Conversely, in the β annealed condition, these alloys exhibit significantly higher fracture toughness with lower tensile strength. Experiments conducted at ATI have identified a combination of alloy composition and processing parameters resulting in a new titanium alloy with an improved tensile strength and toughness capability. This presentation will focus on the effects of hot working parameters on the strength, ductility, and damage tolerance of a new metastable β titanium alloy: ATI Titan 23™.

ATI Titan 171: A New High-Temperature Titanium Alloy with Improved Strength and Creep Resistance

Dr. David Brice, Mr. John V. Mantione, and Dr. Matias Garcia-Avila, ATI, Monroe, North Carolina, USA

Titanium alloys are essential to the aerospace industry, comprising 15 to 25% by weight of modern jet engine components due to the high strength-to-weight ratio and innate resistance to corrosion. However, titanium alloys are limited by their maximum service temperature due to the reduction in mechanical properties and poor oxidation resistance at elevated temperatures. Common high-temperature titanium alloys, such as ATI 6-2-4-2™ (a near- α alloy) and ATI 17™ (an α - β alloy with high β content), offer a balance of creep resistance, fatigue life, and elevated-temperature strength. The newly developed ATI Titan 171 alloy is designed for superior elevated temperature strength and creep behavior over the incumbent alloys. This presentation will highlight the effect of heat treatment on microstructure and mechanical properties of cast and wrought ATI Titan 171 and showcase its printability through laser powder bed fusion.

Session: Material Challenges for Hydrogen Storage and Propulsion • Composite Materials and Structures

Moving into Terra Incognita—White Areas on the Map of Material Performance

Mr. Christian Rueckert, Airbus Operations GmbH, Bremen, Germany

Within the global effort to enable zero-carbon-emission flying, numerous approaches are being followed by aircraft manufacturers and the supply chain to provide according structures and systems. The dominant technology bricks such as tanks and piping have to function under harsh conditions, operating at 20 K over the complete lifespan of an aircraft. Today, there is no knowledge basis existing to provide answers to the question of whether or not the selected materials or combinations will perform. We cannot just follow the well-trodden paths of material characterization here for both metallic and composite substrates, but have to elaborate and validate relevant physical testing methods starting on the coupon level (L6). This presentation intends to give an overview of how Airbus is tackling this challenge, which basic tests are already carried out for metal and composite testing, and which “white spots” in the testing pyramid are still to be filled with accepted and verified test methods.

A Review of Material Considerations for Hydrogen Pressure Vessels

Ms. Sofia Verdi and Prof. Anthony Bombik,

University of North Carolina at Charlotte, Charlotte, North Carolina, USA

As government organizations, public interest groups, and consumers become more concerned about emissions and their effect on the climate, the aerospace and aeronautical industries have been pushed to minimize their emissions. As a result, there is a high demand for hydrogen fuel solutions—a fuel that has more energy per unit mass than jet fuel and whose exhaust gasses are steam. This presentation will act as a review of the research of materials within hydrogen fuel tanks. It will also address the challenges and conclusions of relevant research papers through the lens of aerospace applications. Utilizing hydrogen fuel has a unique set of challenges, the largest of which stems from the materials used in the fuel tank. The predominant challenge, maintaining hydrogen in its energy-dense liquid state, is difficult not only because the materials used must prevent leakage but also because proposed solutions are often costly, difficult to scale, or heavy. These leaks during the storage and transportation of liquid hydrogen have a significant impact on multiple aerospace projects, such as the multiday delay of the Artemis launch. Additionally, hydrogen fuel tank ruptures can be more of a concern in pressurized vessels as the hydrogen cannot easily dissipate and can ignite easily. Further, certain metals become more brittle when in contact with hydrogen, affecting other properties such as the ultimate tensile strength and life cycle of a structure. Through the review, the current landscape of liquid hydrogen storage in aerospace applications, its challenges, and its future will be elucidated.

High-Rate Composite Deposition for Aerostructures

Mr. Georg Heidelmann¹ and Mr. Alun Reece², ¹Loop Technology, Kansas City, Missouri, USA; ²Loop Technology, Dorchester, United Kingdom

A key challenge facing aerospace manufacturers is how to produce components at high quality and at a high rate to satisfy the production targets of the next generation of aircraft. This presentation highlights a number of innovative production technologies explicitly targeting high-rate deposition of composite materials on high-volume and large-scale aerostructures such as flight control surfaces, wing covers, and spars. The proposed approach utilizes gantry or robot deployable end effectors and peripheral equipment to nest, cut, sort, and kit composite plies before depositing them into double-curvature tooling, inspecting, and tacking in an effort to achieve rates in excess of 350 kg/h. The approach acknowledges that there is no one-size-fits-all method for the wide variety of geometries encountered in composite component manufacture and instead utilizes an array of end effectors and a common deployment platform to achieve optimal rates for a given target application. Two deposition approaches are considered: conformal pick and place, and roller. Pick and place has a benefit for complex ply shapes that need to be placed to a high tolerance, while roller deposition scores in terms of compactness. The strengths and weaknesses of the two technologies will be explored along with key performance capabilities and target application examples.

Development of SiC/Carbon Ceramic Matrix Composites by Direct Ink Writing and Low-Temperature Pyrolysis

Mr. Trevor R. Williams, University of North Carolina at Charlotte, Charlotte, North Carolina, USA

Ceramic matrix composites (CMCs) consisting of reinforced fibers and ceramics as matrix materials have been designed to possess significantly greater fracture toughness and thermal shock resistance, showing potential in turbine and combustion engines, hypersonic vehicles, and satellites. Additional manufacturing of CMCs allows the printing of complex geometry for component design. However, the fiber alignment is challenging in printed parts, and the sintering temperature of ceramics is high. The team hypothesized from other studies an initial ink formula for testing. Direct ink writing (DIW) will be used to print the parts for this study. The initial ink formula for the DIW paste consists of a preceramic polymer, poly(methyl-silsesquioxane) (Silres MK); solvent (isopropanol); inert filler (SiC powder, Starceram S Grade UF10); dispersant agent (BYK 180); reinforcement agent (commercialized, chopped, uncoated carbon fibers); cross-linking catalyst (Geniosil GF91); and rheology modifier (hydrophobic fumed silica, Aerosil R106). Rheological analysis will be done to analyze the specific effects of the components so that it is possible to better understand each of the components' individual contributions to the ink's rheology. The Tronxy 2, a DIW printer, will print parts that will be placed in a sintering furnace for cross-linking and pyrolysis.

is completed, the sample will be subjected to mechanical testing, and then microscopic analysis of the failed parts will be conducted. This work will employ SiC/carbon fiber CMCs to demonstrate that (i) the rheology property can guide for shear thinning, which is critical for DIW, and (ii) the low-temperature pyrolysis (<1000 °C) of SiC/carbon CMCs is efficient to form a dense structure, which will be discussed in detail.

Novel Resin Systems to Enable Rapid and Low-Cost Prototyping as well as High-Rate Aerospace Manufacturing to Increase the Rate of Innovation and Deployment of Capability

Mr. Maximilian Schultes and Mr. Atefeh Nabavi, RAMPF,
Burlington, Ontario, Canada

New structural and fire-smoke-toxicity-compliant resin systems that can be used directly on prototype tooling enable the fast manufacturing of early prototypes at an affordable cost. This makes revolutionary concepts feasible without risk to budget and schedule constraints. The combination of liquid resin systems, innovative prototype and low-rate tooling solutions, and fiber optimization tools such as tailored fiber placement unlock a new range of potential for enabling groundbreaking concepts and ideas while being fully rate scalable for aerospace high-rate manufacturing. With this combination, one can start testing novel concepts and parts within weeks from design definition at a low cost. This approach contributes to sustainability by virtue of unlocking the potential of revolutionary ideas and concepts while using tooling materials that are fully recyclable in a circular fashion and significantly reduces the energy requirements during transport, storage, and processing of the composite material.

Session: Space Materials and Applications Joining and Welding

Additive Manufacturing Development of a 350 kN-Class Engine Thrust Chamber

Dr. Keum-Oh Lee¹, Dr. Hyeonjun Kim¹, Mr. Jaesung Shin¹, Mr. Byoungjik Lim¹,
Dr. Junseong Lee¹, Dr. Jaesung Park¹, Dr. Yong-Oh Noh², and Ms. Sook Lee³,
¹Korea Aerospace Research Institute, Daejeon, Republic of Korea; ²Vitzro Nextech,
Ansan, Republic of Korea; ³Korean Air, Daejeon, Republic of Korea

Since the successful flight of Rocketlab's Rutherford engine, many NewSpace companies have been actively researching the development of large rocket engines using additive manufacturing. In this study, a 350 kN-class methane engine thrust chamber was designed and manufactured using additive manufacturing for the development of a reusable launch vehicle in South Korea. The powder bed fusion method was used for the combustor head, cylinder, and nozzle throat to produce a fine regenerative cooling channel structure and precise injectors, and the directed energy deposition method was used to produce the supersonic nozzle extension. In order to overcome the overhang structure commonly encountered in powder bed fusion, we developed a "Medusa"-type head design composed of multiple tubes, which enabled an integrated head and chamber design.

Additively Manufactured Structured Fabrics for Deployable Antenna Structures

Dr. Punnathat Bordeenithikasem¹, Tracy Lu², Dr. Connor McMahan², and
Prof. Chiara Daraio², ¹NASA Jet Propulsion Laboratory,
California Institute of Technology, Pasadena, California, USA;
²California Institute of Technology, Pasadena, California, USA

The 2017–2027 Decadal Survey for Earth Science and Applications from Space outlines the need for high-frequency antenna capabilities for use with CubeSat constellations to aid earth science objectives. Current technologies such as mesh reflectors and reflectarrays are insufficient for the higher-frequency applications, necessitating a novel antenna architecture with solid surfaces. Additionally, due to launch volume restrictions, deployable antenna structures are required to maximize the aperture size for a given stowage volume. Structured fabrics are continuums of interacting elementary particles or unit cells (e.g., chain mail is made of interlocking links). Such fabrics are conformable in the relaxed state but become rigidized when the particles interlock or jam in response to an external stimulus. In this talk, we will discuss the development of a deployable reflector antenna based on structured fabric technology. The particle geometry and spatial distribution were computationally designed and optimized for specific fold lines, which allows for a solid surface paraboloid upon actuation. The structured fabrics were fabricated using additive manufacturing due to the complexity and customization of each particle.

The Development of Foam-Enabled Phase Change Material Heat Exchangers

Ms. Melanie A. Buziak, ERG Aerospace, Oakland, California, USA

High-power electronics are limited by conventional thermal management technologies, particularly in space-based applications. Phase change material (PCM)-based heat exchangers dampen peak heat loads using latent heat, allowing sizing of the thermal management system based on the average heat load rather than the peak heat load. Phase change materials, often paraffin wax, inherently suffer from low thermal conductivity (~0.2 W/m-K); the resulting thermal resistance is too high for effective dampening. The performance of the PCM can be enhanced by the addition of an extended surface. This work will discuss both conventional and additively manufactured open-celled metal foam as extended surfaces to reduce thermal resistance and enhance performance of PCM heat exchangers. Conventional metal foam has been manufactured for more than 50 years and exhibits an order of magnitude better thermal performance than the most common extended surface, machined fins, as well as affording various manufacturability advantages. The more recent development of additively manufactured foam allows for more complex foam morphology and therefore enhanced performance, ideally keeping pace with the rapidly developing thermal management needs of the aerospace industry.

MELD and Cu-Cr-Zr for Space Applications

Dr. Chase Cox, MELD Manufacturing Corporation, Christiansburg, Virginia, USA

Additive friction stir deposition (AFSD) is a solid-state additive manufacturing process that is commercialized under the name MELD. It is a promising technology for the deposition of Cu-Cr-Zr, a copper alloy with excellent mechanical properties and high purity. Cu-Cr-Zr is commonly used in space applications due to its high strength, ductility, and corrosion resistance. This presentation will discuss the use of AFSD to produce Cu-Cr-Zr components for space applications. The presentation will begin with an overview of the AFSD process and its advantages for the deposition of Cu-Cr-Zr. The presentation will then discuss the mechanical performance and microstructure of AFSD-produced Cu-Cr-Zr components. The presentation will conclude with a discussion of the potential applications of AFSD-produced Cu-Cr-Zr components in the aerospace industry. The audience will learn about the AFSD process and its advantages for the deposition of Cu-Cr-Zr, the mechanical performance and microstructure of AFSD-produced Cu-Cr-Zr components, and the potential applications of AFSD-produced Cu-Cr-Zr components in the aerospace industry. This presentation will be of interest to researchers, engineers, and other professionals who are interested in the use of AFSD to produce high-performance metal components for space applications.

Space Launch System Program Potential Enhancements

Mr. Michael Niedzinski¹, Mr. Chris Cianciola², Mr. Tyler Nester², Mr. Chad Bryant², Mr. Terry Prickett², Mr. Scotty Sparks², Mr. James Burnum², and Mr. Robert Bobo²,
¹Constellium LLC, Ravenswood, West Virginia, USA; ²NASA, Huntsville, Alabama, USA

The Space Launch System (SLS) is a joint effort of NASA and industry targeting exploration of the Moon, Mars, and beyond, under the Artemis program. The SLS is a two-stage LOX/LH₂-fueled rocket powered with four RS-25 and RL-10 engines and augmented by two 5-segment solid rocket boosters. The initial payload consists of Orion crew and service modules for transfer of astronauts to the surface of the Moon. November 17, 2022 marked the start of the Artemis 1 mission, successfully demonstrating the launch system. Orion successfully launched and performed circumnavigation of the moon with a safe return to Earth. The next generation of the SLS will require significant enhancements to maintain safety and increase affordability, sustainability, producibility, and payload performance. Potential further optimization of the propulsive stages promises to deliver mass savings. Major tasks could potentially be optimization of the primary and secondary structural components via further design refinement and optimization as well as material substitution. Aluminum-lithium alloy 2050, which is already a part of the new SLS exploration upper stage, provides a potential opportunity for the core stage intertank and LOX and LH₂ tankage. This advanced aluminum product offers a 5% density reduction with 30% higher strength and improved stress-corrosion cracking resistance. In addition to potential structural material optimization, the SLS stages will be honing the technical performance and reliability of cryo-insulation systems that have been brought online since the shuttle retirement. Safety, technical, and payload capability performance requires rigorous cryo-insulation process control.

Fatigue Performance and 3D Residual Stress Map of Refill Friction Stir Spot Welded 2219 Aluminum Joints

Mr. Matteo Bernardi and Prof. Benjamin Klusemann, Helmholtz-Zentrum Hereon, Institute of Materials Mechanics, Geesthacht, Germany

For many years, the aviation industry has been closely monitoring friction-based welding due to its ability to reduce weight, circumventing the challenges associated with fusion-based welding. This technology also enables the joining of materials that are traditionally deemed challenging to weld using conventional methods. Refill friction stir spot welding (refill FSSW) has emerged as a solid-state joining process with substantial potential to replace single-point joining techniques such as riveting. This research centers on applying refill FSSW to the high-strength aluminum alloy AA 2219. It aims to explore various aspects of the welding process, including the fatigue behavior of the joint and the mechanisms of crack nucleation and propagation, with a particular emphasis on analyzing the residual stress within the weld. Analogous to friction stir welding, the intricate interplay of nonuniform plastic deformation, thermal gradients, heterogeneous material flow, and rapid microstructural changes during refill FSSW invariably induces internal residual stresses. Understanding the 3D residual stress field introduced by refill FSSW is essential for developing crack propagation models, a critical step for the industrial application of this technology.

Advances in Refill Friction Stir Spot Welding

Dr. Yuri Hovanski¹, Ms. Ruth Belnap¹, Mr. Paul Blackhurst¹, Dr. Josef Cobb², and Dr. Heath Misak³, ¹Brigham Young University, Provo, Utah, USA; ²NASA Marshall Space Flight Center, Huntsville, Alabama, USA; ³Spirit AeroSystems, Inc., Wichita, Kansas, USA

While rivets are the prominent choice for joining skin-stiffened aluminum structures, the current study focuses on the use of refill friction stir spot welding for assembly of skins and skin-stiffened structures. Aluminum-lithium skins were produced with and without sealant to evaluate production quality, distortion, and other key measures of quality for overlapping skin assemblies. Refill friction stir welding was also applied to joining high-strength aluminum extrusions to fuselage skins to produce skin-stiffened structures, with a focus on weld development for near edge joining at low-cycle times. Evaluation of weld properties including quasi-static lap shear and fatigue is presented in comparison with traditional riveted joints, as a means of comparison. An analysis of manufacturability of skin-stiffened structures produced via refill friction stir spot welding is presented, to provide detailed analysis related to process performance, machine dynamics, tool life, and overall material properties.

Session: Titanium Alloy Technology • Materials Characterization and Failure Analysis III

Utilizing Near-Net Titanium Extrusions in Aerospace Plate and Forging Applications

Mr. Steven James and Mr. Phani Gudipati, Plymouth Engineered Shapes, Hopkinsville, Kentucky, USA

Titanium alloys are widely used in aerospace design because of their exceptional design characteristics. Chief among those characteristics is strength-to-weight ratio, corrosion resistance, and compatibility with composites. On the downside, the use of titanium generally carries a higher cost. This is experienced both in its basic production (raw material and mill processing) and in fabrication/machining. With only four internationally qualified Ti-6Al-4V plate producers, and even fewer producers that have the capability of making low-residual-stress/high-flatness plate, demand can far exceed supply. This only further exacerbates cost and lead times. In addition, the war in Ukraine has disrupted the global supply chain, and it is becoming more difficult to source large titanium parts. One solution to meet demand is the exploration of alternative manufacturing solutions to production parts currently being produced from titanium plate. Plymouth Engineered Shapes has developed a sophisticated method of production to achieve the required plate properties with titanium extruded shapes for parts typically produced from rolled plate. This technique provides an alternative manufacturing source for these products as well as other benefits. Many parts that have been previously produced from joining multiple plates can now be produced via a single near-net extrusion. This improves the overall integrity of the part by simplifying the design while reducing manufacturing time. Also, utilizing a near-net extrusion improves the buy-to-fly ratio and allows for a significant reduction in machining of the final part.

This presentation will provide an in-depth analysis of properties taken from Plymouth-produced Ti-6Al-4V extrusions while examining the role extrusion ratio plays in fatigue. In addition, an evaluation and comparison of these properties to aerospace requirements of $\alpha+\beta$ and β -annealed plate/forgings will be given. The presentation will conclude with a summary of possible applications and considerations that are applicable to this manufacturing methodology.

Advancements in Near-to-Net Extrusion Manufacturing Technology for Aerospace Applications

Mr. Phani Gudipati, Mr. Michael Campbell, and Mr. Steven James, Plymouth Engineered Shapes, Hopkinsville, Kentucky, USA

Aircraft components with long constant cross-sectional areas can utilize extruded shapes in their design. For titanium extrusions, the most common examples are seat tracks produced from the workhorse grade, Ti-6Al-4V (Ti-64). However, outside of aerospace, the applications for titanium extrusions can be more varied, ranging from subsonic systems to unmanned submarines. To expand the role of titanium extrusions in aerospace, Plymouth Engineered Shapes (PES) has developed advanced manufacturing techniques for producing near-to-net extrusions. This has been achieved by capitalizing on some of the favorable characteristics of Ti-64, like its low flow stress above β transus. These shapes can be used in various aeroengine applications together with traditional products. Compared with a conventional part, the near-to-net shape that can be achieved through titanium extrusions allows for significant material yield savings through a closer approximation to the final part. In turn, less machining is required, and the buy-to-fly ratio is improved. This presentation will provide an overview of various Ti-64 profiles extruded at PES and demonstrate the improvement in buy-to-fly ratio with the use of near-to-net shapes. Furthermore, a summary of relevant mechanical properties, microstructural characterization, and the dimensional tolerances held over the length of the extrusion will be presented. Residual stresses, which play a critical role in the performance, machining, and structural stability of the extruded product, will also be discussed.

ATI Titan 27: $\alpha+\beta$ Alloy with Superior Strength and Ductility

Dr. Andrew J. Temple¹, Dr. John Foltz¹, Erik Rogoff¹, Dr. Bhuvu Nirudhoddi², Dr. Luis Ruiz-Aparicio², and Dr. Ming Li², ¹ATI Specialty Materials, Monroe, North Carolina, USA; ²ATI Specialty Rolled Products, Natrona Heights, Pennsylvania, USA

ATI Titan 27™ is an $\alpha+\beta$ alloy with superior strength, high-cycle fatigue, and workability compared to the legacy workhorse alloy Ti-6Al-4V. This alloy has a wider hot working range and can be produced in a variety of product forms: bar, billet, hot-rolled plate, and cold-rollable sheet. Similar microstructures to that of Ti-6Al-4V are observed via scanning electron microscopy when ATI Titan 27 is imaged in the backscatter electron imaging mode, with ATI Titan 27 having a slightly higher phase fraction (20%) of the body-centered cubic β phase. The strength of ATI Titan 27, as determined by room-temperature tensile tests, was measured to be 15% greater than that of Ti-6Al-4V. Electron backscatter diffraction was performed on as-deformed specimens to characterize the overall slip behavior. Additionally, less room-temperature load drop during stress relaxations tests indicates the potential of this alloy as a replacement for Ti-6Al-4V in applications sensitive to dwell fatigue. The novel strength and ductility of ATI Titan 27, with increased slip activation of non-close-packed planes, could enable future lightweighting and improved dwell fatigue resistance.

Hot Hardness Test Method for Characterization of High-Temperature Alloys

Dr. C. Paul Qiao, L.E. Jones Company, Menominee, Michigan, USA

Materials strength and bulk hardness are a function of temperature. For most engineering alloys, strength and hardness vary with temperature in a wide materials solid-state range. Materials strength and bulk hardness are closely correlated, although the correlation is often not precisely linear. Both materials strength and bulk hardness are critical materials properties of engineering alloys. While materials strength is a fundamental materials property obtained with standard compression/tensile test specimens for engineering component design, materials bulk hardness can be readily measured with an actual engineering component. Hence, bulk hardness has been commonly utilized as a materials testing method for product quality control. Hot hardness is the hardness attained at a specific temperature, which can be used to assess potential performance of materials and engineering components applied at elevated temperature. For instance, an alloy's potential wear and deformation behavior in IC and aerospace engine components can be estimated based upon its hot hardness property. The lack of a standard hot hardness testing procedure from open publications indicates that there is a need for developing an industry-standard hot hardness measurement procedure with which the materials properties among high-temperature alloys can be adequately defined and directly compared. A hot hardness test procedure using the Bruker TriboLab instrument has been developed at L.E. Jones Company (L.E.J) recently. The LEJ bulk hardness test method has been successfully applied with a significant number of high-temperature alloys. The detailed testing procedure developed along with results obtained is discussed in this research article. It is intended to continuously enlarge the alloy hot hardness database recently established with substantial inclusion of other commercially available high-temperature alloys.

Mechanical Characterization of Li-Ion Batteries in Abusive Loading Conditions

Mr. John Sherman and Prof. Anthony Bombik, University of North Carolina at Charlotte, Charlotte, North Carolina, USA

As the aerospace industry furthers development into long-term missions in often remote regions, a consistent supply of power has become a niche that batteries, most commonly lithium-ion batteries (LIBs), have dominated in recent years. Due to the high volatility and relatively unpredictable nature of LIB combustion, which can have catastrophic consequences for aerospace vehicles if left unchecked, recent development in the industry have been oriented around containment and mitigation of these events. Prediction of these failures has proven unreliable as degradation of battery performance and safety has shown to be complex with coupled thermal, electrochemical, mechanical, and environmental variables. To investigate the effect of mechanical abuse on these cells, LIBs were impacted with dynamic mechanical loading, and changes in their electrochemical performance in the short, medium, and long term were monitored. Through this, we characterized trends in experimental battery performance, which allowed us to predict the degree of damage and safety levels within cells. Further structural analysis and thermal abusive testing were performed on failed cells to allow for a better understanding of the leading mechanisms of cell failure and long-term consequences for sudden mechanical abuse. Using this knowledge, multiphysics modeling frameworks were developed to predict both sudden and long-term failure modes of LIBs subject to mechanical impact, and protocols were developed to determine degree of internal damage utilizing live electrical prognosis techniques. Additional models are proposed which consider mechanically abusive conditions and damaged internal structure in long-term safety determination of LIBs. Through this investigation, additional insight can be taken when developing battery packs considering protection from inciting incidents and operando safety analysis to considerations of long-term battery health given extreme conditions.

Session: Residual Stress

Novel Accelerated Thermomechanical Laser Powder Bed Fusion Modeling Using an Effective Heat Source

Prof. Ali Bonakdar¹, Dr. Shahriar Imani Shahabadi², and Prof. Ehsan Toyserkani²,
¹The University of North Carolina at Charlotte, Charlotte, North Carolina, USA;
²University of Waterloo, Waterloo, Ontario, Canada

The laser powder bed fusion (LPBF) process suffers from the induced residual stresses in printed parts due to the inherent high-temperature gradient during the process. A trial-and-error experimental approach would be inefficient for minimizing the residual stresses. Therefore, numerical modeling and simulation are beneficial tools for predicting residual stresses and deformation of LPBF-printed parts. However, the computational cost for conducting large-scale thermomechanical LPBF modeling is extremely high. In this presentation, a novel thermomechanical model is developed that incorporates the effective heat flux for accelerating LPBF process simulation. The residual stresses and deformation of the cube and cantilever geometries are predicted for a various range of process parameters. X-ray analyzer and optical scanner devices are used to validate the simulation results. The simulation results demonstrate that implementing the effective heat flux reduces computational time while providing acceptable accuracy.

Effect of Scan Strategy on Dissimilar Bimetal Cladding through Laser Directed Energy Deposition: A Numerical Study

Mr. Nishkarsh Srivastava and Dr. Amit Arora, Indian Institute of Technology Gandhinagar, Gandhinagar, India

Bimetallic components having diverse properties are essential for improved functionality in hot-condition applications such as airplanes, boilers, and nuclear reactors. Hybrid components such as copper-steel (SS316) with improved thermal conductivity and high strength are attracting attention for their improved thermal performance. However, cladding of copper on SS316 using laser-directed energy deposition (L-DED) is challenging due to differences in their thermophysical properties, resulting in residual stress and distortion. While various studies exist for scanning strategies on similar metal deposition, there is limited literature for dissimilar bimetallic cladding using L-DED. In this study, a one-way coupled thermomechanical analysis was performed using the finite element method. SS316 steel was taken as the substrate, and copper was the deposited part. The analysis was performed for six different scanning patterns: raster, zigzag, alternate line, out-in spiral, in-out spiral, and a novel S scan. The peak and average temperature were calculated for the six different scanning strategies and correlated with the residual stresses and warpage. The results provide insight into the effective scanning strategies for dissimilar bimetallic cladding with reduced residual stresses and warpage.

Modeling Residual Stress Evolution during Electro Slag Remelt Process

Dr. Pavanachand Chigurupati and Dr. Corey J. O'Connell, Special Metals Corporation, Huntington, West Virginia, USA

Among the key melt practices used to produce high-performance aerospace alloys, the electro slag remelt (ESR) process when executed with suboptimal melt conditions is known to leave behind internal cracks that retard the productivity of subsequent melt stages. Current work evaluates the complete history of evolving residual stresses during the ESR process by coupling solidification-induced thermal history to predict deformation response leading to residual stresses. Model space is used to represent the ESR process, accounting for complex thermal interactions of various structural elements and cooling circuits with the ESR furnace for a given melt rate and power recipe. The thermal history of the process for a complete ingot thus captured is fed to deformation models to predict residual stress evolution during the ESR process. The model procedures developed help us to evaluate residual stresses and their relation to factors controlling the ESR process. Measured data for hot ductility along with residual stress predictions from the model space were used to track material damage criteria to identify process conditions with higher risk of internal cracks. This work also covers how this model-based insight led us to near-optimal melt conditions along with the right balance of thermal processes that follow the ESR melt stage.

Reduction and Determination of Residual Stresses in 7xxx Aluminum Thick Plates

Dr. Roland Morak, Mr. Thomas Ebner, Dr. Katharina Strobel, and Dr. Ramona Tosone, AMAG Rolling GmbH, Braunau am Inn, Austria

Residual stresses play an important role in the producibility of complex structural parts, especially in the aerospace industry. Distortion due to residual stresses causes cost-intensive reworking and adaptation of the milling procedure or even rejects. These adaptations are time consuming due to lower milling speed, additional process loops, and increasing quality inspections. Thus, the semi-finished aluminum product industry aims to allocate plates free of residual stresses. To achieve this stress-free quality, the last year's research has revealed that the amount of residual stresses depends on the homogeneity of the microstructure and texture in all spatial directions. Only this achievement allows stress reduction via stretching, as indicated in the literature. Besides producing a homogenous microstructure, verifying the stress-free state is one of the major challenges. A nondestructive approach using ultrasonic runtime measurements can reveal the difference between the minimum and the maximum stress. This method's resolution is still not high enough to simulate the material's distortion caused by the milling procedure. For this reason, single-sided milling tests of complex, large parts are inevitable to emphasize the very high machining quality.

Evaluation of Residual Stress Distribution in Additively Manufactured Inconel 625 Using Finite Element Analysis and Experimental Investigations

Prof. Marjan Molavi-Zarandi and Prof. Ali Bonakdar, University of North Carolina at Charlotte, Charlotte, North Carolina, USA

Laser powder bed fusion (LPBF) holds significant promise in aerospace and various high-tech industries due to its adaptable manufacturing capabilities and the creative design possibilities it offers. Nevertheless, several factors, such as elevated residual stresses, unpredictable porosity, and dimensional accuracy, can impact the quality of components and hinder the widespread adoption of LPBF in industrial applications. Residual stresses are inherent to laser-based processes, and there is a current emphasis on research efforts to effectively manage these stresses. Developing an accurate numerical model to predict residual stresses in LPBF is vital for comprehending how processing parameters impact component quality.

This study investigates the impact of laser power and scanning speed on the magnitude and distribution of residual stresses in Inconel 625, employing a set of test coupons manufactured with the EOS 290 machine. The research adopts a comprehensive methodology, incorporating both finite element simulations and experimental analyses. Assessment of residual stresses extends beyond the coupon's surface, including evaluations throughout its depth in both longitudinal and transverse orientations. Six distinct process conditions were examined, involving three levels of laser power (100, 200, and 240 W) and three levels of scanning speed (750, 1000, and 1500 mm/s). In all six scenarios, both simulation and experimentation consistently revealed a gradual increase in tensile residual stress as depth below the surface increased in the area of interest. Notably, increasing the laser power from 100 to 240 W at a constant speed generally resulted in higher tensile residual stresses as depth increased beneath the surface. These trends were corroborated by both the simulation and experimental measurements. Furthermore, it was evident that the increase in laser power from 100 to 240 W had a more pronounced effect on residual stress values compared to variations in scanning speed.

ATI Titan 23: A New Low-Distortion β Titanium Alloy for Additive Manufacturing

Dr. David Brice¹, Dr. Matias Garcia-Avila¹, Dr. Andrew Temple¹, Ms. Jia-Huei Tien², and Dr. David F. Bahr², ¹ATI, Monroe, North Carolina, USA; ²Purdue University, West Lafayette, Indiana, USA

The high specific strength of titanium and its alloys makes these materials critical for aerospace applications. The advent of additive manufacturing (AM) enables the production of new designs that were previously unattainable. Most AM has adopted Ti-6Al-4V due to the large material property data sets, accessibility, and proven manufacturability. However, Ti-6Al-4V is limited in AM production due to the evolution of high residual stresses that result in part distortion and restricting the design window. The use of highly β -stabilized alloys that print and stay in a fully β condition result in lower residual stress and part distortion. ATI's novel Titan 23™ is a newly developed high-strength β titanium alloy that enables printing of large-format parts with negligible distortion relative to Ti-6Al-4V. Titan 23 demonstrates an improved combination of properties that enable wider applications of additively manufactured titanium parts. This work provides a direct comparison of ATI Titan 23 versus ATI 6-4 materials produced via laser powder bed fusion and the resulting microstructures, mechanical properties, and residual stresses developed during printing.