SFF SYMPOSIUM MANUSCRIPTS APPEARING IN THE MARCH 2019 ISSUE OF *JOM*

Thirteen materials-related manuscripts from the 2018 SFF Symposium were selected by the Organizing Committee for publication in the TMS journal *JOM* (March 2019). Papers may appear in only one publication, or they must be substantially revised and improved for submission to *JOM*. The titles and abstracts appear here so readers will know that the papers have appeared in print.

The following authors chose to publish their manuscript only in *JOM*, so their papers do not appear in this proceedings.

Comparison of Stainless Steel 316L Parts Made by FDM-based and SLM-based Additive Manufacturing Processes

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The selective laser melting (SLM) process has been of great interests for metal part fabrication. A number of studies have been conducted for an in-depth understanding of how the stainless steel 316L parts are fabricated using this powder-bed-fusion based additive manufacturing (AM) process. In comparison with SLM stainless steel 316L, this paper introduces an innovative AM process for making austenitic stainless steel 316L part using a metal-polymer composite filament (Ultrafuse 316LX). The stainless steel 316L metal specimens are printed by a material-extrusion (FDM) based 3D printer loaded with Ultrafuse filament, followed by an industry standard debinding and sintering process. Tests are performed to understand the material properties, such as hardness, tensile strength, and microstructural characteristics. Part shrinkage is also analyzed based on the features of FDM stainless steel 316L component. A preliminary guideline is discussed on how to select these two alternative AM processes for metal parts fabrication.

Defect Identification and Mitigation via Visual Inspection in Large-Scale Additive Manufacturing

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Defect identification and mitigation is an important avenue of research to improve the overall quality of objects created using additive manufacturing (AM) technologies. Identifying and mitigating defects takes on additional importance in large-scale, industrial AM. In large-scale AM, defects that result in failed prints are extremely costly in terms of time spent and material used. To address these issues, researchers at Oak Ridge National Laboratory's Manufacturing Demonstration Facility investigated the use of a laser profilometer and thermal camera to collect data concerning an object as it was constructed. This data provided feedback for an in-situ control system to adjust object construction. Adjustments were made in the form of automated height control. This paper presents results for both a polymer- and metal-based system. Object construction for both systems was improved significantly, and the resulting objects were more geometrically identical to the "ideal" 3D representation.

Full Field Strain Measurement of Material Extrusion AM Parts with both Solid and Sparse Infill Geometry

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Full field strain, during tensile deformation, is measured in parts produced by Material Extrusion Additive Manufacturing (MEAM) using Digital Image Correlation (DIC). Much has been done to study stress and strain at the part level, however local levels of stress and strain within MEAM parts remain largely unexplored. This study documents the effects of tensile loading on MEAM parts of both solid and sparse infill geometry. Local effects of tensile strain on different toolpath orientations are also studied. A novel build strategy for creating sparse infill geometry is also introduced and tested.

Investigation of External Illumination Strategies for Melt Pool Geometry Monitoring in SLM

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Coaxial monitoring in SLM can be applied using different configurations in terms of sensor choice and observed bandwidth. The use of external illumination to observe the melt pool geometry by suppressing the process emission is an option, where the melt pool geometry can be visualized independently from the changes in the emission behavior. However, the correct choice of the illuminator and the configuration in which it is implemented is an issue that requires further attention. This paper is aimed at obtaining a direct observation of the molten pool geometry using an external illumination source to suppress process emission. A coaxial imaging system was devised for this purpose and two different setups for light launching were designed and tested, namely a diode laser beam coaxial to the working laser and a lateral low-coherence laser illuminating the whole build platform. The advantages and criticalities of each experimental setup are extensively discussed. External illumination was found to be useful for interpreting directly the SLM melting conditions. Furthermore, the real scan position and velocity could be measured through an image processing algorithm on the captured frames.

Melt Pool Analysis and Meso-scale Simulation of Laser Powder Bed Fusion Process (L-PBF) with Ti-6Al-4V Powder Particles

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Laser powder bed fusion (L-PBF) process is accompanied by rapid melting and solidification that results in intense thermo-capillary convection within the melt pool. An open source particle simulation software is utilized to generate a single layer of spherical powder particles of variable diameters. Considering the importance of particle size and particle size distribution (PSD) in L-PBF process, three distinct categories of PSD are generated with identical settings. A 3D thermo-fluid model is developed in this study that incorporates the generated layer of powder particles of non-uniform sizes over a thick substrate. A moving volumetric heat source is applied to melt a single track in the powder layer through the user defined function (UDF) in FLUENT software. Temperature dependent material properties including variable surface tension is considered for the computation. The numerical model is used to simulate Ti-6Al-4V powder particles to observe the melt pool flow dynamics. Presence of particles of smaller diameter in the powder mix supports a consistent and continuous melt pool flow while any kind of void enhances fluid convection in the downward direction causing a temporal increase in melt pool depth.

Effect of Initial Surface Features on Laser Polishing of a Co-Cr-Mo Alloy Made by Powder-Bed Fusion

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One of the challenges facing widespread use of parts created by the powder-bed fusion process is the high surface roughness that necessitates some type of post-build finishing process. Laser polishing (i.e., remelting), which uses surface-tension-driven flow to reduce roughness on irradiated metallic surfaces, is one potential finishing process. This work examines the effect that surface features on the as-built part have on the performance of continuous-wave laser remelting of Co-Cr-Mo alloy (Celsit 21-P, Stellite 21 equivalent) samples produced by powder-bed fusion manufacturing. This is accomplished by the comparison of three-dimensional surface measurements before and after laser remelting using focus-variation microscopy. Engineering models used to simulate the surface profile as a result of laser remelting are presented. The results from this work provide insight on the fundamental physics occurring during laser remelting on parts made by powder-bed fusion and will aid parameter selection for surface consolidation and smoothing.

Experimental Study of the Sub-systems in a Microscale Additive Manufacturing Process

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High throughput miniaturization and scalability of complex 3D architectures in microproducts is often limited by the resolution of the existing additive manufacturing (AM) processes. We are developing a microscale selective laser sintering (μ-SLS) machine for fabricating true-3D metallic microarchitectures with submicron feature size resolutions. This paper presents experimental testing and validation of the major sub-systems in the machine. A comprehensive study of the precision and accuracy of the optical subsystem, the global positioning stage, local XY nanopositioning stage, powder bed dispense system, and the control mechanisms largely determines the part quality and throughput of the sintering process. Preliminary sintering results with optimized process parameters have also been discussed in this paper. The ultimate objective of these analyses is to develop mathematical models for an optimized microscale sintering process.

Effect of Process Parameters on Mechanical Properties of Wire and Arc Additive Manufactured AlCu6Mn

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Wire and arc additive manufacturing (WAAM) is an additive manufacturing technique that can directly fabricate large 3D parts. In this study, a variable polarity cold metal transfer (CMT) pulse arc was employed to melt the mental wire onto a substrate. Tensile tests and microscopy were conducted for investigating the effects of heat input on the mechanical properties and microstructure of AlCu6Mn after WAAM deposition. The highest tensile strength of 295 MPa and tensile elongation of 18% were obtained with appropriate heat input. Also, the bottom region of the sample has the best mechanical properties, followed by the middle and top region under the same parameters. This is mainly due to the increasing of over-burn defects and grain size in the top region with the accumulation of heat in the repeated thermal cycle.

The following authors chose to publish their manuscripts in this proceedings and to publish a substantially improved paper in *JOM*.

Effect of Powder Degradation on the Fatigue Behavior of Additively Manufactured As-Built Ti-6Al-4V

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Additive manufacturing (AM) technology has enabled many industries to generate functional parts with an increased level of complexity via a layer-by-layer melting. In laser-powder bed fusion (L-PBF), the most commonly used AM process for metals, powder is often recycled due to its high cost. However, there is no comprehensive study on how recycling powder affects its rheological properties, and the mechanical and fatigue behavior of the final manufactured part. In this study, a comparison of new and used Ti-6Al-4V powder characteristics was made. The comparison includes morphology, size distribution, as well as monotonic tensile and fatigue behavior of fabricated specimens. Conclusions and suggestions on powder recycling are made. Results indicate that the powder particle size distribution (PSD) becomes narrower and the morphology of the particles change with recycling. However, no comparable effect was observed on the monotonic tensile and fatigue behavior of the AM as-built Ti-6Al-4V specimens.

Effect of Energy Density on the Consolidation Mechanism and Microstructural Evolution of Laser Cladded Functionally-graded Composite Ti-Al System

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The engagement of additive manufacturing (AM) technology in developing intermetallic coatings involves additional heat treatment with a view to obtaining desirable microstructure and mechanical properties. This eventually increases the lead time and the manufacturing cost. To address these challenges, this study explores the fabrication of gradient and laminar structures of titanium aluminide (Ti-Al) composite coatings deposited on Ti-6Al-4V substrate via a single step laser cladding (LC). The alterations in microstructural properties, chemical composition and phase analysis of the coatings reinforced with TiC were investigated as a function of laser energy density. Evaluation of the deposited samples reveals that FGM composite clads were fabricated from Ti-Al blended with TiC when LED was set at 17.50 J/mm2. At the selected LED, a thermo-positive reaction between the constituents' materials was induced and it resulted in the formation of intermetallic compounds (e.g. Ti2AlC, and matrix phases) with a microhardness more than that of the substrate (Ti-6Al-4V alloy). This study provides new insights on the selection of process parameters for the coating manufacturers while employing low cost- and time-effective LC process for fabricating functional graded Ti-Al coatings.

Experimental Characterization of a Direct Metal Deposited Cobalt-based Alloy on Tool Steel for Component Repair

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Die casting dies made of tool steel is subject to impact, abrasion and cyclic thermo-mechanical loading that delivers damage such as wear, corrosion, and cracking. To repair such defects, materials enveloping the damage need to be machined and refilled. In this study, V-shape defects with varied sidewall inclination angles were prepared on H13 tool steel substrates and refilled with cobalt-based alloy using direct metal deposition (DMD) for superior hardness and wear resistance. The microstructure of rebuild samples was characterized using an optical microscope (OM) and scanning electron microscope (SEM). Elemental distribution from the substrate to deposits was analyzed using energy dispersive spectrometry (EDS). Mechanical properties of repaired samples were evaluated by tensile test and microhardness measurement. Fracture mechanism in tensile testing was analyzed by observing the fracture surface. The experiment reveals that V-shape defects with sidewall beyond certain angles can be successfully remanufactured. The deposits were fully dense and free of defects. The microstructure and tensile test confirm the solid bonding along the interface. The tensile test shows the mean ultimate tensile strength (UTS) of repaired samples is approximated 620 MPa, where samples fractured at the deposits region. Hardness measurement reveals the hardness of deposits is around 810 HV which is much higher than that of the substrate.

Curing Behavior of Thermosets for the Use in a Combined Selective Laser Sintering Process of Polymers

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Selective laser sintering (SLS) of polymers is an additive manufacturing process, which enables the production of functional technical components. Unfortunately, the SLS process is restricted regarding the materials that can be processed and thus resulting component properties are limited.

The investigations in this study illustrates a totally new additive manufacturing process which combines reactive liquids like thermoset resins and thermoplastics to generates multi material SLS parts. To introduce thermoset resins into the regular SLS process, the time-temperature-dependent curing behavior of the thermoset and the infiltration behavior has to be understood in order to assess the process behavior. The curing behavior was analyzed by rotational viscosimeter. Furthermore, the fundamental infiltration behavior was analyzed with micro dosing infiltration experiments. Finally, a thermoset resin in combination with a dosing system was choosen for integration in a laser sintering system.

Fabrication of Aligned Nanofibers along Z-axis – A Novel 3D Electrospinning Technique

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This study presents a 3D fabrication technique of nanofibrous scaffold for tissue engineering. A divergence static electric field was introduced in an electrospinning system to induce a self-assembly of aligned nanofibers into a tunable 3D architecture with thickness ranging from 2-12 mm. The effects of collector configuration on polycaprolactone (PCL) nanofiber attributes were investigated. Human fibroblast cells were cultured on the nanofiber scaffold in vitro for 7 days. It was found that the width and inclination angle of the collector influenced the nanofiber density distribution. The cells proliferated on the scaffold and organized as a fibrous matrix which mimicked the microstructure of native musculoskeletal tissues.

SFF SYMPOSIUM MANUSCRIPTS APPEARING IN A FUTURE ISSUE OF *Virtual and Physical Prototyping*

Four materials-related manuscripts from the 2018 SFF Symposium were selected by the Organizing Committee for publication in Issue I of 2019 of the *Virtual and Physical Prototyping* journal. Papers may appear in only one publication, or they must be substantially revised and improved for submission to *Virtual and Physical Prototyping*. The titles and abstracts appear here so readers will know that the papers have appeared in print.

The following authors chose to publish their manuscript only in *Virtual and Physical Prototyping*, so their papers do not appear in this proceedings.

Effects of Direct Metal Deposition Combined with Intermediate and Final Milling on Part Distortion

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Combining Direct Metal Deposition and milling in one machine promises the additive fabrication of complex parts with high surface quality and dimensional accuracy. However, residual stress induced by the additive process can impair the final part shape after finishing. Undercuts and inaccessible areas are particularly prone to distortion, since they require intermediate milling steps during buildup. Herein, both strategies to reduce residual stress by process optimization and to compensate distortion by adapted toolpaths are discussed. The effects of intermediate and final milling on dimensional accuracy are analyzed for the fabrication of a critical cantilever from stainless steel. 3D scans reveal that additive buildup on a semi-finished part leads to local warpage of milled surfaces. However, global distortion is not significantly affected by intermediate milling steps. An approach is finally proposed that could improve the transition between additive and subtractive process steps.

Using Big Area Additive Manufacturing to Directly Manufacture a Boat Hull Mold

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Big Area Additive Manufacturing (BAAM) is a large-scale, 3D printing technology developed by Oak Ridge National Laboratory's Manufacturing Demonstration Facility and Cincinnati Inc. The ability to quickly and cost-effectively manufacture unique molds and tools is currently one of the most significant applications of BAAM. This work details the application of BAAM to fabricate a 34' catamaran boat hull mold. The goal of this project was to explore the feasibility of using BAAM to directly manufacture the mold without the need for thick coatings. The mold was printed in 12 individual sections over a five-day period. After printing, the critical surfaces of the mold were CNC-machined, and the sections were assembled. The success of this project illustrates the time and cost savings of BAAM in the fabrication of large molds.

Evaluating the Relationship between Deposition and Layer Quality in Large-scale Additive Manufacturing of Concrete

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Scaling up additive manufacturing (AM) for automated building construction requires expertise from different fields of knowledge, including architecture, material science, engineering, and manufacturing to develop processes that work for practical applications. While concrete is a viable candidate for printing due to its common use in building, it raises important challenges in deposition due to the material deformation that occurs as concrete transitions from fresh to hardened states. This study aims to experimentally quantify the deformation of printed concrete layers under the influence of different processing variables, including layer thickness, printing orientation, and direction. A mixer-pump extrudes the material and an industrial 6-axis robotic arm, which provides various ranges of movement in different axes, layers the material. The results of this study can be used to develop a tool for predicting and accounting for the deformation of concrete layers during the AM process.

The following authors chose to publish their manuscripts in this proceedings and to publish a substantially improved paper in *Virtual and Physical Prototyping*.

Technology Integration into Existing Companies

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The implementation of additive manufacturing as an industrial manufacturing process poses extraordinary challenges to companies due to their far-reaching differences to conventional processes. In addition to the major differences in the production process, the pre and post process steps in particular also require a rethinking for companies and their employees. To overcome these challenges and specifically to assist SMEs in the integration of technologies five industrial companies are researching together within research project "OptiAMix", funded by the German Federal Ministry of Education and Research (BMBF) and coordinated by the Paderborn University. This paper focuses on the development of an optimal and standardized process chain and its implementation in a general integration methodology. This enables the standardized integration of additive manufacturing in order to create a uniform understanding of the procedures and tasks within the company for the industrial application of additive manufacturing at an early stage as well as the full exploitation of its high potentials. Therefore, the methodology also includes other technology-specific components such as strategic component selection, decision support for "make or buy" and the implementation of automated component marking.

SFF SYMPOSIUM MANUSCRIPT APPEARING IN A FUTURE ISSUE OF *International Journal of Bioprinting*

One materials-related manuscript from the 2018 SFF Symposium was selected by the Organizing Committee for publication in a future issue of International Journal of Bioprinting. This author chose to publish their manuscript only in International Journal of Bioprinting, so their paper does not appear in this proceedings. The title and abstract appear here so readers will know that the papers have appeared in print.

Near-Field Electrospinning of a Polymer Bioactive Glass Composite

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Bioactive glasses have recently gained attention in tissue engineering and 3D bioprinting because of their ability to enhance angiogenesis. Some challenges for developing glass-based composite scaffolds for different tissues are to control the glass dissolution and achieve the macroporous structure. In this study, we investigate the fabrication of scaffolds with a polymer/bioactive glass composite using near-filed electrospinning (NFES). An overall controlled three-dimensional scaffold with pores containing random fibers is created and aimed to provide superior cell proliferation. Highly angiogenic borate bioactive glass (13-93B3) in 20 wt.% is added to polycaprolactone to fabricate scaffolds using the NFES technique. Scaffolds measuring 5x5x0.2 mm3 in overall dimensions are fabricated and seeded with human mesenchymal stem cells to investigate the cell viability. The cell viability on scaffolds fabricated with polymer and polymer glass composite materials using both NFES technique and extrusion-based 3D printing is compared and discussed.