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3D PRINTED CORES DEDICATED TO SINGLE CRYSTAL CASTING

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ABSTRACT

Due to the need for more efficient engines and gas turbine in the aerospace industry, foundry cores must be more and more complex and are becoming difficult to produce by the conventional ceramic injection molding process (especially new generation cores). The additive manufacturing process allows to produce complex cores with high resolution to meet the need for investment casting. 3DCeram Sinto, a turnkey provider for 3D printing ceramics (machine, materials and process) and Avignon Ceramic, manufacturer of cores for investment casting since 1990, by injection molding and recently 3D printing, have joined forces within U3DC to provide the precision foundry world with proven solutions in the production of 3D printed ceramic cores and to offer a complete printing solution.

Thanks to this partnership with the use of specific ceramic powders dedicated to single crystal casting and to the tailored suspension development, we could obtain optimal properties, thermal expansion, porosity, flexural strength and microstructure analysis of the sintered material. This presentation will highlight the technical results for both technologies, 3D printing compared with injection molding.

Keywords: Foundry cores, stereolithography, ceramic 3D printing, single crystal casting

3D PRINTING FOR SURGICAL PLANNING: CASE REPORT

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ABSTRACT

Surgeons use to perform their surgery depending on their experiences as well as visual aids from medical imaging techniques such as magnetic resonance imaging (MRI) or computed tomography (CT). However, due to the anatomical complexity of the surgery, two dimensional or virtual images are not sufficient to achieve successful structural details. 3D printing technologies have brought a new era in medicine by providing surgical planning. In this study, case reports about 3D printing application for surgical planning for maxillofacial surgery are presented. By the usage of 3D printing techniques and related software, planning of surgical cutting and designing of drilling guides in skeletal surgery could be done. In this regard, data on computer from radiological imaging were converted to three-dimensional visualization of the anatomic structures and then virtual surgical planning of the operations were done by the surgeons. Finally, 3D models were manufactured by additive manufacturing in order to verify the design and usability of the implants before the surgery. As a result, it has been shown that additive manufacturing methods have great importance in production of custom-made implants and fixation plates for the treatment of skeletal deformities with complex anatomy.

Keywords: surgical planning, 3D printing, implant, additive manufacturing

3D PRINTING OF ALKALI-ACTIVATED MORTAR USING ROBOT

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ABSTRACT

Ram extruder combined with Universal Robot 10e was used to print a 35-layer structure with thicknesses of 0.7cm for each layer and a 10cm diameter. For printing material, an alkali-activated mortar (cementitious composite) was developed using ground granulated blast slag (slag) and red mud -bauxite residue- as binders, NaOH as an activator and continuous graded sand. Flexure and compressive strength tests were conducted to measure hardened properties.

Keywords: 3D Printing, Universal Robot, Alkali-activated Mortar

A CASE STUDY ON THE INJECTION MOLDING WITH A 3D PRINTED INJECTION MOLD

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ABSTRACT

Injection molding is the most common method for mass production of plastic parts. It's perfect for producing large numbers of identical parts with precise tolerances in a short amount of time. Previously, 3D printing was mainly utilized in the design and production process to build and test prototypes that would be injection molded later. 3D printers can now directly build molds thanks to advancements in printer accuracy, surface polish, and materials.

Keywords: Injection Molding, 3D Printed Molds,

A CASE STUDY ON THE TOPOLOGY OPTIMIZATION OF PEDESTAL OF A STABILIZED ANTENNA FOR ADDITIVE MANUFACTURING

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ABSTRACT

Antenna pedestal is an electromechanical structure that provides the movement and control of an antenna system with two or three axes of motion in a stabilized manner. In this study, mechanical foundation of the pedestal which previously consisted of 4 different aluminum parts connected with screws and washers is re-designed for additive manufacturing as one single body that topology optimization was applied. Topology optimization goal is performed in order to reduce the total weight while keeping or strengthening the pedestal stiffness and modal behavior which is very important for antenna stabilization.

Keywords: Topology optimization, antenna system, design for additive manufacturing, lightweighting, metal additive manufacturing

A NUMERICAL AND EXPERIMENTAL INVESTIGATION ON BUCKLING BEHAVIOR OF ADDITIVELY MANUFACTURED RIBBED CASINGS

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ABSTRACT

Laser Beam Powder Bed Fusion (LB-PBF) is an additive manufacturing technology that enables manufacturing of complex structures with the advantages such as design freedom and reduced machining needs. However, LB-PBF process is a thermomechanical process and the plastic deformations, and residual stresses that occur in the component may affect its geometrical stability. Buckling is, on the other hand, a type of failure mode for materials, also known as instability that leads thin materials to buckle under compressive loads. To have a more stable buckling behavior in gas turbine engine casings, ribbing structures are being used due to their high compression strength-to-weight ratio. With the advantages of LB-PBF process such as the ability to create complex ribs and reducing machining needs, it can be preferred to manufacture ribbed engine casings via LB-PBF method.

In this study, different ribbed engine casings with identical volumes are designed and plastic shape deformations, residual strains, and stresses caused by LB-PBF are inspected. Along with these studies, buckling and post-buckling simulations are performed on the designed and process simulation-derived casings including the residual strains and stresses, and compressive tests are physically carried out on manufactured parts in order to compare with simulation results.

Keywords: Laser beam powder bed fusion, process simulation, ribbing, buckling, post-buckling.

A STUDY OF DIFFERENT TOOL PATH STRATEGIES FOR LASER METAL DEPOSITION PROCESS

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ABSTRACT

Laser Metal Deposition (LMD) is an additive manufacturing process that is used to manufacture three-dimensional parts. To produce zero-defect parts, it is essential to minimize defects and maximize density. LMD involves the stacking of layers and has complex thermal history affecting the geometrical, metallurgical and mechanical properties. Tool path strategy directly impacts the thermal history affecting the density, microstructure, and stresses originating in the part during deposition. In literature, very few studies correlate the tool path strategies with density, hardness and final microstructure of the part. This study aims to understand in detail the effect of tool path strategies on the geometrical, metallurgical and mechanical properties. Five different 316L-Si stainless steel U shape geometries were deposited with varying tool paths using Erlaser hard + clad LMD system.

The deposits are still being analyzed for hardness, density, microstructure and presence of defects. The influence of different tool path geometries will be reported in detail in the full paper submission.

Keywords: Laser Metal Deposition, Tool path strategies, 316L-Si stainless steel, Microstructure, Density.

ADDITIVE MANUFACTURING OF CLINICAL PRACTICE TRAINING MODELS USED IN MEDICINE AND DENTISTRY

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ABSTRACT

The study mentioned in this article aims to investigate the role of three-dimensional anatomical models in clinical education. Considering the study plan, the training models that the users need for learning and experience applications in the education processes of medicine and dentistry were determined as the first task. After that, DICOM data digital anatomical data files, namely STL files, were obtained from appropriate CT/CBCT/MRI radiological images. Educational models were produced by using an SLA 3D printer. Radiological images were segmented from special images related to image processing methods and 3D printed with specific materials for application in clinical training within the scope of these findings. On the training model developed within the scope of this work, a patient-specific clinical training phantom model has been made. Repetition of clinical training on 3D-printed physical models specific to the scenario has removed the physical constraints for surgical training. As a result of this work, dependence on high-cost foreign phantom models has decreased. The advantages of the study are that it can reduce operator-dependent variables, shorten the operation time, reduce radiation exposure, and increase the success of the procedure, thanks to the patient-specific planning and application of the surgical procedure with three-dimensional models.

Keywords: Training Model, Medical Education, 3D Anatomical Modelling, 3D Printing, SLA

ADDITIVE MANUFACTURING TECHNOLOGY CONFORMITY ASSESSMENT MODEL (TCA.M.) FOR AUTOMOTIVE APPLICATIONS

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ABSTRACT

Over the last decade, Additive Manufacturing (A.M.) has encountered vast adoption from aviation, defense, white goods and automotive industries as an innovative and sustainable low-volume mass production technology. There are a number of commercial A.M. technologies and systems developed for the fabrication of various metal, polymer and composite materials, and choosing the right technology is the foremost stage of the sector-oriented investment plan of any company. Several technology selection tools, guideline books etc. were already published. However, an accessible industry-specific method or tool that evaluates the systems released by equipment manufacturers in terms of technical specifications has not been developed yet. Organizations have to base their equipment selection on benchmarks provided by manufacturers, and choosing the wrong equipment in terms of technical specifications is where an organization could potentially suffer the most. Mathematical tools are most useful for solving complex multiple-criteria problems, involving a lot of human perceptions and judgments, whose decisions have a long-term impact. In this paper, a problem was created using the technical specifications provided by a number of A.M. equipment manufacturers, and a Technology Conformity Assessment Model (TCA.M.) was developed and applied to select the most suitable equipment for automotive industry applications, reducing the human factor and improving investment processes.

Keywords: Automotive Industry, Decision Making, Technology Analysis

AN ALGORITHM FOR POWDER CLEANING OF ADDITIVELY MANUFACTURED PARTS WITH INTERIOR CHANNELS

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ABSTRACT

With the increasing adoption of Additive Manufacturing (AM) technologies, direct manufacturing of parts with complex interior geometries has become possible. However, for most of the Powder Bed (PB) approaches, powder removal is the bottleneck for manufacturability, it constitutes a design limit. Even on technologies like Selective Laser Melting (SLM), where the powder is not strictly adhered to the surface and gravity would be enough to clean the inner powder, complex channel structures made the cleaning by manual rotation virtually impossible. In this study, an algorithm is proposed to detect inner channels and exit points of a mesh file (of STL or OBJ format) and to form a graph of the inner channel structure. Furthermore, for each node on the graph, the shortest path to exit points is found, which allows the formation of a tree-type data structure. The algorithm is realized using Python programming language and the related libraries. Series of rotational motions (lists of angles and durations) that would allow total powder removal are obtained. Even though the skeleton generation and exit point detection take time, the algorithm is promising with some performance enhancements.

Keywords: Powder Based Additive Manufacturing, Powder Cleaning, Powder Cleaning Algorithm, Automated, Post Process

AN INVESTIGATION ON THE EFFECTS OF PROCESS

PARAMETERS ON THE GEOMETRICAL CHARACTERISTICS OF LASER DEPOSITED SINGLE TRACKS USING PH 13-8 MO STAINLESS STEEL POWDER

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ABSTRACT

Laser Metal Deposition (LMD) is a well-known Additive Manufacturing method used to manufacture parts, coating applications to enhance surface properties of high value parts, add features on already existing parts, repair applications and to manufacture functionally graded parts. The single bead geometry and melt pool penetration depth below the substrate that is the portion of the substrate that melts and gets mixed with the deposited material significantly influence the final mechanical properties of the part. It is therefore necessary to select and control LMD process parameters in order to obtain single bead tracks with the optimum geometry. This study investigates the effect of process parameters on the geometry of single bead tracks using PH 13-8 MO stainless steel powder. This study shows that the process parameters can be effectively controlled to achieve the required outcome.

Keywords: Laser metal deposition, PH 13–8Mo stainless steel, Process parameter, Single bead track geometry

ANALYSIS OF THE FORCES AND VIBRATIONS ACTING ON THE CUTTING TOOL IN THE MICRO-DRILLING PROCESS OF TI6AL4V MATERIAL PRODUCED THROUGH EBM METHOD

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ABSTRACT

Thanks to its multiple usage areas, Ti6Al4V alloy is a highly preferred and researched material. Recently, with the development of additive manufacturing technologies, studies on this alloy have intensified. Additive manufacturing has recently become a very important alternative for designs which cannot be manufactured by traditional methods. Work pieces produced by additive manufacturing cannot be used directly in the areas of use. Because they may not have the desired features directly. Generally, various machining processes are applied after additive manufacturing. The most used of these processes are turning, milling and drilling. There are many reference studies on the processes on the parts produced with traditional methods. However, since the materials produced by additive manufacturing have different properties, they should be examined separately. In machining, cutting parameters, surface quality, tool life, labor costs, energy costs, geometric tolerances, etc. have a direct impact on many details. Micro hole drilling is used in special fields (aerospace, defence, automotive, medical). It is also a process that needs to be worked very carefully. Micro drills can break easily because they have very small diameters. In this study, cutting forces and vibration affecting tool life and quality were investigated. Ti6Al4V alloy produced with EBM was used in the study. Three different diameters (0.3mm, 0.4mm, 0.5mm) of micro drills were tested at different feed rates and different speeds in dry cutting conditions. A 3-axis high-precision CNC workstation was used in the studies.

Keywords: Ti6Al4V, EBM, Micro Drilling, Vibration, Additive Manufacturing, Cutting Forces

ANGLE DEPENDENT PRODUCTIVITY RESEARCH OF CONFORMAL CHANNEL GEOMETRY SECTION IN LPBF

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ABSTRACT

It is known that channel orientation at different angles is a necessity in CCC design strategies developed by focusing on regions exposed to intense heat in molds. In the design studies carried out in this area, it is seen that the channel geometries produced without support in LPBF (laser powder bed fusion) production systems complete the geometry by being oriented at 90°, 180°, 45° and intermediate angles throughout the entire channel geometry. Within the scope of this study, which will not affect the efficiency of the duct geometry in terms of overall flow in CCC applications, and ideal positioning where the sagging problem in the duct cross-section is minimal, and suggestions on duct design, duct section productions in cylindrical and pentagonal forms at different scales and angles, then laboratory work and SEM examination constitute the general content of the study.

Keywords: Conformal cooling channels (CCC), Laser powder bed fusion (LPBF), Design for additive manufacturing (DFAM), Maraging Steel (MS1).

ASSESSMENT OF THE MECHANICAL AND CORROSION PROPERTIES OF ALSI10MG PARTS PRODUCED THROUGH SELECTIVE LASER MELTING (SLM) AFTER VARIOUS POST PROCESSING CONDITIONS

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ABSTRACT

In this paper, investigation of mechanical and corrosion properties of was carried out on AlSi10Mg components produced with SLM technique, results different microstructures and mechanical properties, that are undergoing various post-processing conditions such as hot isostatic pressing (HIP), T6 heat treatment, shot peening, anodizing and alodining. For comparison, the same examination was also performed on samples of non machined AlSi10Mg alloy without any post-processing. HIP treatment consists of the application of heating to 520 °C and applying 1000 bar of pressure in inert gas atmosphere while maintaining the temperature and pressure for 120 minutes. A two-stage T6 heat treatment included solid solution at 535 ºC and artificial aging at 158 ºC for 10 h. Shot peen proceed according to AMS 2430, anodizing is done in accordance with MIL-A-8625, Type I and type II, and alodining is carried on AMS-C-5541 Class 1A. The process tensile specimens, designed according to ASTM standard, were printed and tensile tests were carried out. The results obtained showed that differences can be outlined among the samples at different post processing conditions. Corrosion test is performed on ASTM B117 on all specimens which is produced with SLM. The results of this study is to provide informations into the control of corrosion protection and mechanical evaulation of AlSi10Mg alloy by adressing suitable post processes.

Keywords: Additive manufacturing, Selective laser melting, AlSi10Mg, Mechanical properties, Corrosion resistance

BINDER JETTING OF PURE COPPER PARTS AND THEIR CHARACTERIZATION

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ABSTRACT

Complex designs enabled by metal additive manufacturing can strongly improve the pure copper parts performance. Only a few studies, however, assess the additively manufactured pure copper parts. Here, we focus on binder jetting additive manufacturing process to characterize the part densities, mechanical strength, thermal conductivity, and electrical conductivity. Two differently sized powder printed at two different layer thicknesses and sintered in different regimes to optimize the process. Results provide the pure copper material property that gives an insight into designing complex copper parts with binder jetting.

Keywords: copper additive manufacturing, binder jetting, copper sintering

CASE STUDY ON PRODUCTION OF MEDIUM TO LARGE SCALE PARTS BY WIRE + ARC ADDITIVE MANUFACTURING

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ABSTRACT

Wire + Arc Additive Manufacturing (WAAM) is a metal additive manufacturing (AM) technique that enables the production of medium to large-scale near-net-shape structural parts with a high deposition rate. During this process, the filler wire is melted using current arc and deposited on a substrate or already solidified part to build up the structures in a layer-by-layer manner. This manufacturing method has recently attracted the attention of different industrial sectors such as aerospace, aviation, and shipbuilding due to its outstanding advantages such as lower buy-to-fly ratio and consequently lower cost, ability to repair operations as well as being environmentally friendly. In the current case study, the production of an ellipsoid-like structure with height of one meter using ER70S-6 steel wire is examined by the WAAM method. Determining the ideal parameters to produce this structure and corresponding tool path strategy, production of the part with the created tool path strategy and the verification of the part geometry with 3D scanning after the part production are discussed.

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Keywords: WAAM, Tool Path Strategies, ER70S-6, 3D scanning

CHARACTERIZATION OF METAL POWDER REUSED MULTIPLE TIMES FOR LASER POWDER BED FUSION

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ABSTRACT

Laser Powder Bed Fusion (L-PBF) enables the manufacturing of highly complex parts with less material consumption for being used in various industrial applications. Metal powders are commonly used as feedstock material and the powder can be reused several times. Especially in aerospace applications, the reused powder characteristics are quite important in terms of traceability over the part quality since the aerospace industry requires high-quality and reliable end-use parts. In this study, Alloy 718 metal powder, which is generally utilized in high-temperature applications in gas turbine engines due to their good creep and corrosion resistance, were characterized over a 20 series of L-PBF build cycles. The powder characterization was performed in order to investigate the flow behavior of powder reused multiple times by using several methods such as powder rheology, particle size distribution (PSD), and quantitative morphology analysis along with apparent and tap density measurements. The results showed that no major and meaningful difference was seen among 20 times reused powder in terms of PSD and their morphology whereas there is a prominent difference seen by density measurements and with shear cell measurements by powder rheology. These methods revealed that reusing powder causes worse flowability trend.

Keywords: Laser powder bed fusion, powder reuse, powder characterization, powder rheology, particle size distribution and morphology.

COLD SPRAY EFFECT ON OXIDE DISPERSION STRENGTHENING OF INCONEL 718

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ABSTRACT

Oxide dispersion strengthened Inconel 718, ODS In718, produced by Low Pressure Cold Spray method. The Cold Spray was conducted with He / N pressure of 8 bar, max temperature of 130-330 ºC, %20 powder density, %25 air flow, 2 mm/s tracking speed, and 2mm hatch distance with 14 mm stand-off distance. Mechanical alloying was applied to the powders using a Fritsch Pulverisette P6 classic line planetary mono mill machine with hardened stainless steel veil in Argon atmosphere at a rate of 300 rpm. With and without the balls 1 hour tries are conducted up to 5 hours. Stainless steel 10 mm grinding balls are used with 1 to 1 ball to powder ratio. The smples heat treated for 1,2 and 3 hours at 1050 ˚C. The results obtained from EDX analysis satisfied the estimated composition. TEM analysis of cold spray samples showed a homogeneous distribution of nano sized Y-Ti (Hf, Zr, Al) oxides through the microstructure of obtained material. Heat treatment of the cold sprayed samples effectively decreased the porosity of the coating. The observations showed comparable results with that of selective laser melting technique.

Keywords: Nano-oxide, ODS, Superalloy, Cold-Spray, Coating

COMBINATION OF PERIDYNAMICS AND GENETIC ALGORITHM BASED TOPOLOGY OPTIMIZATION METHODS FOR AM-FRIENDLY DESIGNS

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ABSTRACT

Topology optimization (TO) is a practical tool to generate light-weighted engineering structures for various manufacturing industries. However, manufacturing constraints and surface smoothing are still considerable challenges for TO algorithms. Existing TO frameworks utilize mechanical analysis approaches that discretize the whole domain with elements or particles. Therefore, obtained geometries from TO have been criticized for their complex shapes. In this study, we propose a coupled framework to generate AM-friendly designs which result in less support structure and higher surface quality. For this purpose, the generative topology optimization method (GTO), which uses genetic algorithm to search for the best alternative set of geometry within all the possible topology results, is coupled with the peridynamics topology optimization (PD-TO) method to evolve the PD-TO results into AM-friendly shapes. The PD- TO method discretizes the problem domain using equally spaced particles during the TO process. Hence, PD-TO generates a point cloud file with relevant artificial material density values in the final state. Then, GTO method utilizes the point cloud and material densities as an input file to achieve better final geometry. Consequently, AM-friendly designs achieved from GTO are compared with the initial results obtained from PD-TO to demonstrate the efficiency and capability of the proposed method.

Keywords: AM-friendly design, generative topology optimization, peridynamic, additive manufacturing, topology optimization

COMPARISON OF DYNAMIC MECHANICAL PROPERTIES OF ALSI10MG LATTICE STRUCTURES PRODUCED BY SELECTIVE LASER MELTING

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ABSTRACT

Three different AlSi10Mg lattice structures, face-centered cubic (FCC), diamond and auxetic, were produced by selective laser melting (SLM). Dynamic compression tests were applied to as-build samples at two different strain rates (750 s^{-1} and 1100 s^{-1}) by Split-Hopkinson Pressure Bar (SPHB). While the maximum compressive strength was found as 43 MPa in FCC structure, diamond structure had the lowest compressive strength with 24 MPa. Initial results of additive manufactured AlSi10Mg lattice structures showed that the maximum load carrying capacity of the FCC structure is higher than that of diamond and auxetic lattices.

Keywords: Selective laser melting, AlSi10Mg, Lattice structures, Split-Hopkinson Pressure Bar, Mechanical properties

COMPARISON OF SINGLE AND TWIN SCREW EXTRUDERS FOR THE PRODUCTION OF GLASS AND CARBON REINFORCED HIGH DENSTIY POLYETHYLENE (HDPE) FILAMENTS

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ABSTRACT

HDPE is a newly used thermoplastic for additive manufacturing but there is some problem to overcome. They need to be strengthened with various micro size additives. The distribution of the fibers in the matrix is of vital importance. The production process is affected by many parameters such as temperature, extrusion speed, cooling rate, matrix, and fiber particle size. In this study, a comparison was made by using single and twin-screw extruders to produce 10% glass and carbon and reinforced HDPE filaments. Mechanical properties were evaluated based on tensile tests. Reinforcing fiber to the HDPE matrix increases the tensile strength. If the matrix and fiber particle size are reduced to 250µ before the extrusion, it is possible to achieve high tensile results close to twin screw extrusion with single screw extrusion, but homogeneous distribution of fibers in the matrix is not satisfactory.

Keywords: Single screw extruder, twin screw extruder, filament production, additive manufacturing

CONTACT-FREE SUPPORT STRUCTURES EFFECT ON DIMENSIONAL DEVIATION OF LPBF PRINTED COMPONENTS WITH OVERHANG FEATURES

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ABSTRACT

Laser powder bed fusion (LPBF) process has gained great attention in recent years since it enables the production of very complex parts with acceptable dimensional accuracy, cost and mechanical properties. Since LPBF process is a thermal process and very high thermal stresses occur during production, dimensional deviations occur especially in very thin and overhang regions. The aim of this study is to show the feasibility of using contactless supports at thin and overhang regions for reducing dimensional deviation of the final part. For this purpose, 1.5 mm thick overhang parts with 30^0 inclination angles with respect to build plate were manufactured with LPBF process from In718 material. Contactless supports with different amount of gaps between the overhang surface and the support (0.23, 0.31 and 0.38 mm) were used during production. The produced parts were 3D scanned with a blue light device. Results show that contactless supports are good alternative to solid supports in the production of overhang parts with LPBF method and contactless support gaps directly affect the dimensional deviation of the final part.

Keywords: dimensional deviation, contactless support, LPBF

COORDINATION OF SPATIAL & TEMPORAL LASER BEAM PROFILE TOWARDS ULTRA-FINE FEATURE FABRICATION IN LPBF

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ABSTRACT

Laser powder bed fusion (LPBF) is a layer-wise metal additive technology that provides high shape and dimensional flexibility compared to conventional technologies. Thanks to the distinctive manufacturing characteristics, the process can be theoretically described as free-form fabrication technique. Therefore, it is generally used in applications that are required high performance and structural complexity. Lattice structures, twin skinned high-performance parts, complex heat exchangers, custom biomedical parts can be given as generic examples for the application range. Nonetheless, despite the provided shape and dimension flexibility, the fabrication of parts with ultra-fine geometrical features such as wall thickness or strut size under 200 µm still pose a problem for the technology. Particularly, the geometrical fidelity of ultra-fine features is decreasing when their dimensions become comparable to the laser beam diameter (typically 50-100 µm) and the powder grain size (typically 50-100 µm). Therefore, the mismatch between the digital model and final geometry is counted as one of the main obstacles.

The studies presented in the literature have generally addressed ultra-fine features in terms of process parameters and different scanning strategies, and most of them remarked the importance of using optimum process parameters with correct scanning strategy for reducing the dimensional mismatch between the actual and final part (Abele et al., 2015). However, the technological limitations of the LPBF machines in terms of temporal-spatial synchronization and control of the laser beam, which can be described briefly as scanning performance, were mostly neglected. Although there were specific studies which investigated the problem in parameter, geometry and technology domains together, scanning performance of different LPBF machines were not regarded during the research (Wang et al., 2017), (Kranz et al., 2015). Nevertheless, even though the process parameters and/or design rules are well-defined for specific structures in the ultra-fine segment, repeatability and validation of these works are still a controversial issue because of variability in the technological capacity of the LPBF machines (Lopez Taborda et al., 2021), (Thompson et al., 2016). Often industrial grade LPBF systems do not operate at their full potential for producing fine features, since they are initially developed for producing larger dimensions. The scanner systems and the fiber laser sources used in these machines are capable of a greater control of laser spatial and temporal emission profile essential for the ultra-fine dimensions. However, these features have been hardly explored due to the rigid machine architectures not allowing the end-user to access parameters related the scanner dynamics and laser temporal emission profile independently. Principally, for developing the process towards ultra-fine features and preventing any misdirection, process parameter and scanning induced errors should be detected and separated at the initial stage. The correct detection of processing capability and system precision are required to be identified at a 2D scan layer level prior to moving towards complex 3D geometries.

In this study, temporal-spatial coordination of the laser beam during the different scanning conditions were studied towards the future manufacturing of ultra-fine struts by LPBF. An industrial grade LPBF system with open architecture was used for the purpose (3DNT LLA 150, Solbiate Olona, Italy). The laser emission could be controlled at a vector level allowing to operate the laser in continuous wave (CW), pulsed wave (PW) or single point exposure (SPE) flexibly with dedicated control software (Direct Machining Control, Vilnius, Lithuania). The machine operated with a single mode fiber laser (AFX1000, nLIGHT, Vancouver, WA, USA) coupled to a scanner head (MS-III, Raylase, Wessling, Germany).

The shape and dimensional errors emerged due to incorrect trajectory and temporal control of the laser beam were investigated with the aid of laser marking tests. Laser power, scan speed and hatch distance were studied in range close to what is employed in LPBF with a conventional hatch strategy. Al 5457 substrate, and simple 2D circular geometry with different nominal radii (R_{nom}) were used to realize the

study. The scanned geometries on the substrate were characterized with optical microscopy. Shape and dimensional fidelity were evaluated in terms of actual radius and circularity of the area. In Figure 1, tabulated data of characterized samples are representatively shown, and the errors are physically described via characterized samples. According to the different scanning speeds, the scanning performance of the LPBF system was evaluated in terms of fine ($200 \leq D \leq 1000\ \mu m$) and ultra-fine fabrication segments ($\leq 200\ \mu m$), and the scan-related errors were shown for different dimension scales (Figure 1-B). Technological feasibility map of the employed LPBF system was deducted. The laser marking tests aided the definition of process parameter ranges for the different feature sizes involved. Especially the link between the scan speed and the minimum vector length for a stable laser emission profile was established. The results show that complete scan trajectories based on hatching can be carried out with sufficient geometrical accuracy if the correct scan parameters are selected.

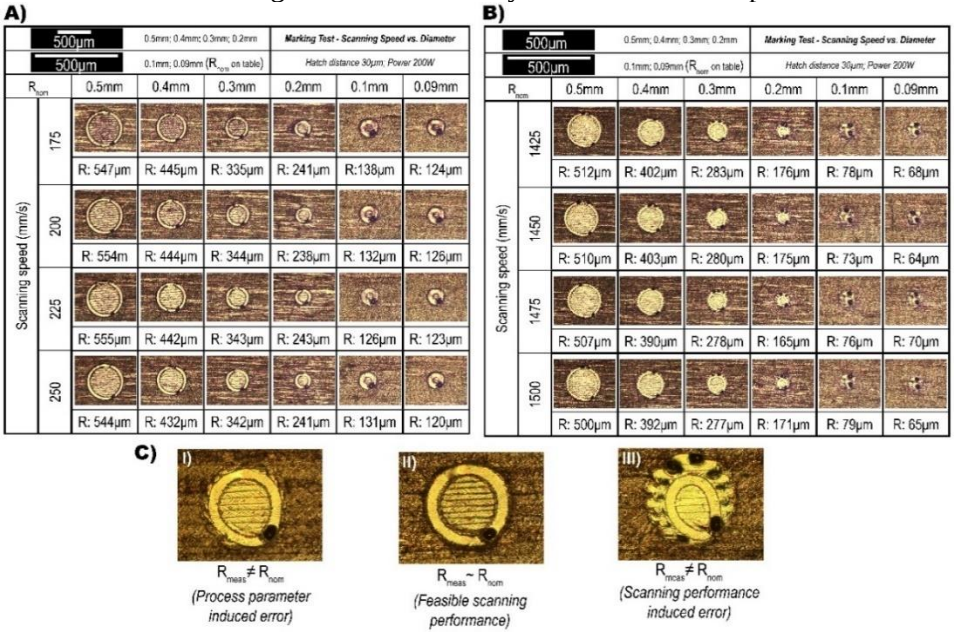

Figure 1. Representative sample characterization tables: A) Low scanning speeds and expected scanning performance (only dimensional error that is caused by the nonoptimal laser power). B) Relatively high scanning speeds and poor scanning performance for ultra-fine segment (shape and dimension error). C) Process and scan induced error description.

CREEP BEHAVIOR OF 3D PRINTED CB/PEI COMPOSITES

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ABSTRACT

Reinforcing polymeric materials used in many 3D printed parts may bring several advantages such as multifunctionality by Fused Filament Fabrication (FFF). In this study, carbon black (CB) reinforced polyetherimide (PEI) filaments at 5, 10, and 20 wt.% CB contents were fabricated in a twin-screw extruder with a ratio of L/ D = 22 at 360℃ and 210 rpm. CB/PEI composites were printed using a custom-made 3D printer with 390℃ of nozzle temperature, -45°/+45° raster angle, and 100% infill. Thermogravimetric analysis showed that the thermal stability of neat PEI did not significantly change with the presence of CB. However, dynamic rheology analysis introduced CB-PEI interaction by a 5E5% increase for 20 wt.% CB/PEI in the storage modulus and a decrease in the frequency dependency of neat PEI. Besides, thermomechanical and mechanical properties improved with CB content and the highest flexural modulus was obtained from 20 wt.% CB/PEI as 1.8 GPa at 170℃. On the other hand, a short-term creep test was conducted to evaluate the in-service performance of the composites, and the results showed that the increase in CB concentration decreased the creep compliance by 40% for 5 wt.% CB/PEI compared to neat PEI at 30℃. With such a low-cost filler as CB, the addition can bring the tunability of PEI for several advanced applications.

Keywords: CB/PEI composites, high performance, creep behavior, TTSP

DEFECT DETECTION WITH IMAGE PROCESSING AND DEEP LEARNING IN POLYMER POWDER BED ADDITIVE MANUFACTURING SYSTEMS

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ABSTRACT

Selective Laser Sintering (SLS) is a type of additive manufacturing process which uses a laser to fuse polymer particles on the powder bed. The process critically relies on controlling the heat and uncontrolled thermal gradients can cause the parts to curl during the process, which may fail the ongoing build with a cost. This layer-wise manufacturing process needs to monitor the continuing build to ensure the process is free from problems. In this paper, deep learning-based defect detection system has been developed to detect any defect (curling, part shifting, short feed). The developed detection system aims to detect the existence of the anomaly during powder bed fusion process and send instant error notifications to the operator. Detection of the anomaly is a binary classification problem and it is solved with the scratch model. The novelty of the developed defect detection algorithm is, it can work independently from the size of the build area, the shape of the part and the location of the part. This study shows the detection system's effectiveness developed by the deep learning method without continuous human supervision in polymer powder bed additive manufacturing processes.

DESIGN AND ADDITIVE MANUFACTURING OF PEEK IMPLANTS FOR PATIENT-SPECIFIC CRANIOPLASTY SURGERY

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ABSTRACT

Additively manufactured patient-specific implants are developed for the cases where the standard implant solutions are inadequate. Steps to obtain an accurate patient-specific implant require knowledge of medical and engineering sciences, hence, physician-engineer cooperation. This study aimed to generate a tailor-made implant design for bilateral cranial defect and fabrication of the implant by using a fused filament fabrication(FFF) additive manufacturing technique. Computed tomography belonging to the patient was converted to 3D models via medical image processing. 3D anatomical models of the patient were printed by using SLA technology to plan the surgery. Implant design has been made through medically certified software by adopting design for additive manufacturing rules. Additive manufacturing technology-material combination has been determined depending on the mechanical behavior of the material after implementation, biological requirements of the region, and producibility of the material by selected AM technology. According to those, the implant has been produced in polyetheretherketone(PEEK) material using FFF technology. As a recently emerging technique in the biomedical field, printing ready-to-use, medical-grade PEEK material requires optimization of process parameters. The studies are made and a comparison analysis between digital and physical implant models has been done. After implementation, clinical experience has been reported and radiological results were evaluated.

Keywords: Medical Additive Manufacturing, Patient-Specific, PEEK, Implant, Cranioplasty

DESING OF A COMPLIANT CLAMPING MECHANISM FOR FDM BED IN ADDITIVE MANUFACTURING

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ABSTRACT

Nowadays spread of 3D printers is accelerated all over the world because of the recent developments in Additive Manufacturing (AM). Through AM complex geometries can be produced easier than the traditional manufacturing methods. Obviously, cost and time savings are one of the most important factors in manufacturing components with additive processes. However, large-size products have difficulties of transfer of research results in physical items in AM for various industries. Fused deposition modeling (FDM) is the most widely used type of 3D printing for most consumers. To have a successful print, proper 3D print bed platform adhesion is critical. For a supporting base of the design, multiple layers of filament are extruded in a pattern-like mesh that is called Raft. If the materials of the model are prone to wrapping, tip over, and fail later in the print rafts are very useful. Addition to the Raft, bed adhesives are also used to form a stickier layer for prints. Temperature-controlled chambers are also useful for avoiding wrapping. However, while printing larger parts that are spread through the print bed, these anti-wrap methods would not be sufficient due to the inequivalent cooling processes. For these types of 3D prints, a compliant bistable clamping mechanism will be designed and it will be actuated automatically with the aid of the algorithm embedded in the code. Once the printing operation is started, the designed clamps are activated at a certain point for stabilizing the product.

Keywords: Additive manufacturing, 3D printing, clamping mechanism, compliant mechanism

DEVELOPMENT AND STATIC LOAD TESTİNG OF ADDITIVELY MANUFACTURED STAINLESS STEEL NOSE LANDING GEAR AIRCRAFT PART FOR CIVIL AVIATION APPLICATIONS

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ABSTRACT

Coskunoz and Industry partners have been working towards manufacturing process development to reduce costs and lead times for parts used in civil aviation applications in Turkey with the goal to reduce the overall production cost. One technique evaluated is laser metal deposition (LMD). The aim was to design, develop and test a full scale additively manufactured stainless steel part for the nose landing gear of an aircraft. Conventionally the part was made by machining a forged stainless steel billet. To advance the manufacturing process further, Coskunoz investigated the feasibility to manufacture such a large critical component via additive manufacturing (LMD). Multiple materials were tried to find a suitable replacement for the conventional material. LMD process parameters were optimized, and the part was successfully manufactured and tested. This paper describes the design, development, manufacturing and testing of a critical component of a nose landing gear of a civil aviation aircraft and the lessons learnt throughout the design and development process.

Keywords: Metal Additive Manufacturing, Laser Metal Deposition, Process Development, Precipitate Hardening Stainless Steels

DEVELOPMENT OF A DIGITAL IMAGE PROCESSING ALGORITHM FOR ANOMALY DETECTION IN LARGE SCALE ADDITIVE MANUFACTURING

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ABSTRACT

Large Scale Additive Manufacturing (LSAM) defines a system that can be used for printing components on the order of several meters at high extrusion rates (up to 50 kg/hr). The feedstock material is in the form of thermoplastic or fiber-reinforced thermoplastic pellets which are almost 20 times cheaper than the filament-based feedstock. The system has the potential to significantly affect the automobile, aerospace, and energy industries. However, by increasing the scale of additive manufacturing, more numerous and diverse problems arise. Particularly, the variety of errors, long-term production costs, and energy inefficiency in 3D printing processes exceeding one cubic meter constitute a major hindrance to development in this field. The formation of defects such as warping, distortion, porosity, surface roughness, etc. needs to be monitored in real-time under the supervision of the operator for preventing permanent deformations. Recently, the developments in the field of image processing make it more convenient to monitor these problems in situ and to intervene in the process during printing. In this study, the common anomalies in the LSAM of ABS parts that can be recognized by image processing algorithms were reviewed.

Keywords: Large scale additive manufacturing (LSAM), Image processing, Anomaly detection,

DEVELOPMENT OF ALUMINUM ALLOY POWDERS FOR ADDITIVE MANUFACTURING

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ABSTRACT

This study aims to the production of AlSi10Mg powders with gas atomization and examines the effects of atomization parameters on powder characteristics and usability for the Laser Powder Bed Fusion (PBF-LB) process. 3 different powders were produced and characterized and then parts were produced with 18 different production parameters in the EOS M290 machine. The parts' surface roughness, porosity, hardness, optical microscope, and scanning electron microscope analyses were investigated. The particle size of powder used in the production is 20-63 µm, the oxygen/hydrogen level is appropriate, and its chemical composition is similar to the standard AlSi10Mg alloy. The results demonstrated that surface roughness (Ra) differed around 4-5% compared with parts produced with manufacturer A powder. Ra values on different surfaces were investigated with different parameters. Standard levels were achieved in porosity analyzes (99.86%). It has been observed that the thermal stresses caused by the heat generated by the parameters in the system cause significant differences in the hardness value (122±12 Vickers). In OM and SEM studies, parameter-related errors (energy deficiency, formation of gas pores, fusion errors, etc.) and differences in structures were determined.

(Manufacturer A powder is used in AM systems at the TRL9 level.)

Keywords: AlSi10Mg alloy, metal powder, gas atomization, powder characterization, parameter optimization

DEVELOPMENT OF MULTIFUNCTIONAL 3D PRINTED SCAFFOLD FOR BIOMEDICAL APPLICATIONS

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ABSTRACT

Additive manufacturing (AM) has become significant in biomedical applications due to necessity of customized fabrication of the patients. Fused deposition modeling (FDM) is one of the low cost additive manufacturing (AM) techniques that can provide fast and accurate solutions in biodegradable hard tissue applications. However, commercial filaments do not provide patient-specific requirements. In this study, it was aimed to develop a multifunctional filament for scaffold fabrication by FDM process that could carry the drug and provide sustainable drug release. Metformin (MET) was selected for drug loading onto halloysite nanotube (HNT). In the matrix of polylactic acid (PLA), HNT was responsible for both carrying the metformin and improving the mechanical properties of the scaffold. Scaffolds with infill design of grid porous structure was fabricated. Tensile test properties and controllable drug release of the printed scaffolds were investigated. According to the results, scaffolds have shown about 125% of increment in tensile strength. Drug release was quite sustainable till five days and 50% of the loaded drug were gradually released over time. It has been seen that the developed drug loaded scaffold has potential to be used in biomedical application of hard tissues.

Keywords: Fused deposition modeling, filament, scaffold, HNT, drug loading

DIMENSIONAL ACCURACY INVESTIGATION OF TIO_2 REINFORCED POLYMER NANOCOMPOSITE PARTS PRINTED BY DLP

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ABSTRACT

In this study, it is aimed to obtain 3D-printed polymer nanocomposite parts with the utmost dimensional accuracy and show how the accuracy is affected by varying fractions of reinforcement. Polyurethane acrylate (PUA) is chosen as the matrix material due to its extensive usage and titanium dioxide (TiO2) nanotube is chosen as the reinforcement material due to its photocatalytic properties, which can provide antibacterial properties for future nanocomposite studies. Nanoresins were prepared by ultrasonic mixing of nanotubes in the resin homogeneously. Sample parts were printed using digital light processing (DLP) and dimensional accuracy is discussed using the data of the optical measurements.

Keywords: Titanium dioxide nanotubes, PUA, nanocomposite, DLP, dimensional accuracy

DIMENSIONAL VARIATIONS IN EBM PRODUCED STRUT-BASED AND TPMS LATTICES

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ABSTRACT

The aim of this experimental study is to investigate the dimensional variations in Ti6Al4V specimens produced by electron beam melting technology from original CAD geometry. Strut-based and triply periodic minimum surface (TPMS) type of lattice structures were produced and investigated by scanning electron microscope (SEM). Face centered cubic (FCC), body centered cubic (BCC), gyroid, primitive and diamond type of lattices with fixed volume fractions were the main focus in this study. The experimental results revealed that the maximum and minimum dimensional variations were observed on gyroid and diamond specimens, respectively. The SEM images exhibited that excessive and more non-fully melted particles were observed on downfacing surfaces of the struts or walls than up facing surfaces.

Keywords: Electron beam melting, dimensional variation, lattice structure

DIRECTED ENERGY DEPOSITION OF REFRACTORY CR10MO25TA25TI15V25 HIGH ENTROPY ALLOY

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ABSTRACT

Worldwide growth of energy need requires the increase in the efficiency of energy systems. This results in the increase of operating temperatures and stresses exerted on the used materials especially in nuclear reactors. Therefore, Refractory High Entropy Alloys (RHEAs) due to their high thermal stability and radiation resistance are one of the interest areas of recent studies. In this study CrMoTaTiV RHEA produced by vacuum arc melting and directed energy deposition techniques have been investigated. Process parameter optimization and difference in the resulting products are analyzed and compared with VAM produced samples using XRD, SEM, EBSD and TEM analyses and compression tests.

Keywords: RHEAs, DED, EBSD, TEM

EFFECT OF HEAT TREATMENTS ON THE MICROSTRUCTURE AND MECHANICAL PROPERTIES OF INCONEL 718 ALLOY FABRICATED BY LASER POWDER BED FUSION METHOD

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ABSTRACT

Inconel 718 super alloy fabricated by laser powder bed fusion (LPBF) was subjected to different heat treatments. Microstructures of as-built and heat-treated samples were examined under aging, 980ºC+aging (HT980), and the 1100ºC+aging (HT1100) conditions. The microstructure of the as-built sample in the building direction and scanning direction consists of columnar dendrite and subgrain structures. These structures contain the Laves phase. In aging, most of the melting pools and scanning traces were dispersed and some of the Laves phases were precipitated. After the HT980 and HT1100, all the melting pools and scanning traces disappeared. In both these cases, the majority of the Laves phases collapsed. However, a more homogeneous structure was obtained in H1100. The highest hardness value was HT980 with 39%. However, in HT1100, a more ductile material was obtained despite the 25% increase in hardness.

Keywords: Inconel 718, Additive manufacturing, Heat-treatment, Phase analysis

EFFECTS OF DESIGN PARAMETERS ON SURFACE ROUGHNESS OF ADDITIVELY MANUFACTURED THIN WALL STRUCTURES

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ABSTRACT

Additive manufacturing (AM) has enabled the production of complex geometries that are not possible to be manufactured through traditional subtractive methods. Among the AM technologies, direct metal laser melting (DMLM) has gained considerable attention in many engineering industries due to its capability to fabricate components with high resolution. The benefits of DMLM technology have also been utilized in the production of thin-wall structures in the aviation industry. Many internal thin wall surfaces are retained as-build due to inapplicability of surface enhancement methods. Therefore, surface roughness of additively manufactured thin wall structures is thoroughly sensitive to quality of AM process. This may adversely affect the mechanical properties of the end-product. Therefore, in this study, thin-wall specimens made of CoCr are fabricated through DMLM and effects of wall thickness, build angle, laser incidence angle, and spatial distribution of these specimens on the surface roughness are investigated. For that purpose, printed surface topologies are analyzed using an optical profilometer and relationship between the control parameters and standard surface roughness metrics is presented.

Keywords: Surface Roughness, Thin Wall, DMLM, Additive Manufacturing, Design for AM

EFFECTS OF DIFFERENT PRODUCTION PARAMETERS ON MECHANICAL PROPERTIES IN FDM-PRINTED PRODUCTS

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ABSTRACT

FDM, which is a common additive manufacturing technology in producing plastic parts, allows for the comparison of many different production parameters. This article presents the variation of density, hardness, tensile and impact strength depending on the production parameters of the number of contours, infill pattern and orientation angle. 8 different production parameter combinations were created using 2 different contour numbers as 1 and 2, 2 different infill patterns as sparse high density and hexagram, and two different orientation angles as 0o/45o degrees, and sample production was made with FDM technology and ABS material. In the experiments performed on the samples produced with the specified production combinations, no major change in density and hardness was detected, and it was determined that the production parameter combination that gave the best results in both tensile and impact strength was hexagram infill pattern, 45o orientation angle and 2 contour production parameters.

Keywords: FDM, tensile strength, impact strength, ABS.

EFFECTS OF LATTICE STRUCTURES ON ADDITIVELY MANUFACTURED METAL PARTS

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ABSTRACT

With the recent advancements in the computational tools for additive manufacturing (AM) technologies, topology optimization method is becoming a must before fabricating an end-product with these digital manufacturing approaches. In addition to the structural optimization process, certain dynamic properties are further required for the designed parts especially in some application areas such as automotive and aerospace industries. For this purpose, interior of the parts can be utilized to acquire better dynamic properties. In this study, we will use lattice structures as interior filling patterns to increase the natural frequencies of the parts manufactured with a metal AM method. We will work on cantilever or simply supported beams to prove the advantages of our approach. These beams will be designed using various types of lattice structures and they will further be optimized using the SIMP topology optimization method. After the manufacturing of the samples, we will evaluate them using impact hammer tests. Furthermore, we will perform numerical analysis and compare them with the results of the experiments.

Keywords: Lattice Structures, SIMP Method, Topology Optimization, Metal Additive Manufacturing

ELECTROMAGNETIC CHARACTERIZATION OF 3D PRINTED METAMATERIAL ABSORBER WITH CONDUCTIVE PAINT

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ABSTRACT

In this study, electromagnetic characterization of 3D printed metamaterials manufactured by using conductive paint is carried out in terms of their absorption behavior. The samples have been prepared in sizes to fit waveguide setup in the frequency range of 12-18 GHz. 3D printing technique was used to prepare the substrate of the design while conductive paint and copper tape were used for the conductive parts of the structure including the metamaterial resonator and the ground plane. For electromagnetic characterization of the design, different thickness of substrate layers, various raster orientation ($0°, \pm 45°$ and $\pm 90°$), different infill densities have been simulated and experimentally tested in terms of their effects on absorption behavior. In addition, conductivity of the paint was improved by adjusting its formulation and the resulting absorption behaviors have been compared with copper tape using the same metamaterial dimensions. Using 3D printing technology along with conductive paint rather than solid conductors in manufacturing electromagnetic absorbers will provide the possibility of producing flexible and non-planar electromagnetic absorber structures in desired frequency ranges. The design can be easily adopted to different frequencies and this technique can be used to design wideband metamaterial absorbers using 3D layered structures.

Keywords: Additive manufacturing, 3D printing, conductive paint, Metamaterials, Absorber

ENERGY DENSITY DETERMINATION FOR L-PBFP OF TI-6AL-4V ALLOY FOR VARIOUS BEAM DIAMETERS AND HATCH DISTANCES

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ABSTRACT

It is important to determine the appropriate energy densities for an ideal (error-free) production in the laser powder bed fusion process. In this study, energy density levels were determined for the Ti-6Al-4V alloy via volumetric heat source model [1] simulations. Undesirable situations such as fusion problems, balling, excessive evaporation and keyhole regime were accepted as criteria for the evaluation. The developed process window covers analysis for different beam diameters of 50, 80, and 100 micrometers, hatch distances ranging from 30 to 100 micrometers. Laser power and scan speed range from 50 to 200 W and 250 to 1500 mm/s, respectively. It has been found that higher laser powers accompanied with higher laser scan speeds are prone to some production problems such as, keyhole, unstable pools and balling. Consequently, the analysis results are to be used as a guide before further experimental tests.

Keywords: Laser powder bed fusion process, Ti-6Al-4V, additive manufacturing

ESTABLISHING THE EFFECT OF PROCESS PARAMETERS ON THE MECHANICAL PROPERTIES OF 3DPRINTED PETG

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ABSTRACT

FFF is one of the polymer additive manufacturing production methods with an advantage of producing high volume parts in a short time with low cost compared to extrusion. Since the extrusion process results with better mechanical properties than 3D printed parts, a majority od research has been focused to optimize the mechanical properties of additively manufactured parts [1]. Through negative air gap and annealing, it is possible to achieve enhanced mechanical properties. Hence, this research aims to reveal the importance of air gap selection, sample standard types, infill patterns, post process temperature & time on mechanical properties through comparative studies.

Keywords: FFF, PETG, Air gap, Annealing, Specimen Standards

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EXPERIMENTAL ANALYSIS OF R-PHASE NITI TUBE ACTUATORS USING CONDUCTIVE/CONVECTIVE HEATING STAGE

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ABSTRACT

In the last few decades, Nitinol (NiTi) actuators have created a massive impact at the commercial level due to their application in various engineering and medical fields. NiTi wires sheets and tube actuators are a useful resource for harvesting any form of heat energy available. In any actuation application, the rate of actuation and actuation force are important parameters that determine the feasibility of the actuator. Current ongoing research aims to critically investigate and develop NiTi R-phased and martensitic phased actuators using commercially available material. Prior heat treatment and shape setting will be performed on the available NiTi material in the research lab facility at Dublin City University. A design test rig will be built capable of providing conductive and convective heating for cyclic heating and cooling of material consequently producing actuation. Input parameters such as heat flux, convective flux, and actuator shape setting will be optimized while the output parameters such as rate of actuation and actuation force will be reported and optimized. In the later stages of the investigations will be diverted towards the additive manufactured materials for a comparison of NiTi build by conventional methods and additive manufacturing. Criticality, of the NiTi actuators, is the rate of solid-solid phase transformation which is linked to the temperature distribution. Therefore, convective heat transfer correlations will be presented for an enormous range of input parameters.

Keywords: **NiTi, Heat Pipes, Actuators, Phase Transformation**

EXTRUDER DESIGN OF PRINTABLE COMPOSITES

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ABSTRACT

There are many extruder designs in today's standards for the extrusion of known extrudable metals and materials. Yet, when it comes to the design of the materials which were not extruded widely before, there are not many easy solutions for the design. In this paper, we designed a new extruder that works at given conditions for a given range of material properties. We found that the most impactful parameters for the design are: mill rpm, die diameter, outflow diameter, outflow speed, material viscosity, and the distance between the leaf and the inner surface of the extruder.

Keywords: Extruder design, Printable concrete, 3D printing

FOAMING PLA PARTS PRODUCED BY FUSED FILAMENT FABRICATION

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ABSTRACT

Fused filament fabrication (FFF) is a cost-effective additive manufacturing technique for the printing of polymeric parts. One of the most widely used FFF filament materials is Polylactic acid (PLA), which is a biodegradable and sustainable thermoplastic. In this work, we explored the performance of a novel foaming PLA filament, which enables the manufacturing of polymeric foams. The study focused on the effect of feed rate on the density and tensile strength. The results showed that as feed rate decreases, the porosity level increases, resulting in a decrease in tensile strength. The results demonstrate the great potential of foaming filaments in the additive manufacturing of complex parts with tunable mechanical properties.

Keywords: Additive manufacturing, fused filament fabrication, polylactic acid, polymer foams, mechanical properties.

HEAT PIPE EMBEDED COLD PLATE DESIGN WITH ADDITIVE MANUFACTURING TECHNOLOGIES

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ABSTRACT

Heat pipe embedded/integrated cold plates are mostly preferred to increase the thermal conductivity of the base material to have passive thermal management in reliable products. Thanks to Additive Manufacturing Technology, it became possible to find a high conductive product by simultaneously manufacturing the heat pipe in the cold plate. In this study, the heat pipe embedded cold plate design of an electronic chassis designed for a military product has been investigated in detail. With this study, it is seen that there are many outstanding advantages of using AM technology compared to the conventional heat pipe embedding techniques. Thermal analysis of a 6U size cold plate with a high thermal load is performed for aluminum & copper base material and groove type heat pipe embedded aluminum cold plate (HPECP). After that, the manufacturing constraints of both techniques are compared and important design capabilities with AM technology are discussed in detail. It is seen that by using AM technology, it is possible to have a lighter cold plate with improved thermal conductivity in one piece and even lower cost.

Keywords: Cold Plate, Heat Pipe Embedded Cold Plate, Additive Manufacturing, Groove Type Heat Pipe, Electronic Cooling

HIGH CYCLE FATIGUE PERFORMANCE OF AGE HARDENED AND HIPPED AM-ALSI10MG: INVESTIGATION ON POST PROCESS EFFECTS

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ABSTRACT

AM technology has begun to be widely used in the industry. There is an increasing demand on investigation of inevitable inherent defects developing from process parameters and raw material properties. The performing of post-processes to eliminate the production errors plays an important role in increasing the product quality. In this study, high cycle fatigue performance of AM-AlSi10Mg specimens produced by selective laser melting were evaluated. To investigate the effects on mechanical properties of build position, the specimens were prepared with different built directions (0°: horizontal - 45°: diagonal - 90°: vertical). Accordingly, natural ageing and artificial ageing with different temperature and hot isostatic pressure (HIP) were applied to the samples. Fatigue tests were performed under uniaxial load using 20 Hz frequency and a stress ratio of R=-1. Results of post processes were compared with as-built samples according to fracture surface analysis by characterizing porosity and crack propagation evaluation for all build directions. It is found that the ageing reduces the fatigue life. Contrarily, the fatigue life of the HIPped samples showed a great difference compared to the aged and as-built samples. Among the HIPped specimens, the vertical samples have higher fatigue life compared to other directions. It is observed that microstructural transformation of Silicon's size and morphology during the heat treatment is the main cause for fatigue property changes.

Keywords: AlSi10Mg, Post Processes, Ageing, HIP

HYBRID THERMOPLASTIC COMPOSITE MANUFACTURING BY ADDITIVE MANUFACTURING

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ABSTRACT

The most innovative production method of polymer matrix composites is additive manufacturing technologies. It has been a practice for years to optimize the various properties of polymer matrices by reinforcement fibers or particles of different sizes. It is possible to obtain positive results in the mechanical properties of fiber-reinforced polymers in this way. Especially fiber reinforcements made to thermoplastic polymers expand their usage areas and make the use of thermoplastics an important alternative. The recyclability of thermoplastics is critical to a sustainable future. The production of fiber-reinforced thermoplastics by additive manufacturing methods has become the focus of attention in recent years. Thermoplastic polymers reinforced with different fibers have been the subject of many studies. The limitations of existing thermoplastic composite manufacturing methods on geometry and their varying costs depending on the production volume limit the use in certain areas.

In this study, hybrid composite sample production was carried out by combining the positive aspects of two different fibers. Firstly, filament production was carried out with the extrusion process from the compounds in which carbon and glass fibers are used in equal proportions by weight. Polyamide 6 was used for the matrix. Sample production was carried out with the Fused Filament Fabrication method using filaments containing different fibers. Tensile strength and impact resistance values of the produced samples were compared, and thermal characterizations and morphological analyzes were performed.

While the samples produced with carbon fiber showed high tensile strength, glass fiber reinforcement had a lower effect on the tensile strength of the polyamide matrix. In impact resistance, carbon fiber reinforcement made the material brittle, while glass-reinforced samples showed a more ductile feature than carbon fiber reinforced ones.

Keywords: Thermoplastic, hybrid composites, additive manufacturing, carbon fiber, glass fiber, polyamide

INFLUENCE OF CERAMIC-BASED ADDITIVES ON THE DRY SLIDING WEAR BEHAVIOUR OF PA 12 PRODUCED BY SLS

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ABSTRACT

The Selective Laser Sintering is one of the main methods to fabricate polyamide matrix composites. Various reinforcements are used like metalic, polymeric and ceramic to produce polyamide based composites. Also, ceramic based additives have improved the tribological and thermal behaviour of the polyamide. In this study, Polyamide 12 (PA 12) matrix composites were produced with ceramic microsphere additives by Selective Laser Sintering methods using two different energy density values. Influence of ceramic based additives on the tribological behavior of PA 12 was investigated by wear tests. Dry sliding wear tests were carried out with 5N and 20N test loads, and 100 mm/s sliding velocity. The examinations revealed that the composite sample produced by 0.04 J/mm^3 energy density value provides the highest wear resistance compared to other samples.

Keywords: Polyamide composite, additive manufacturing, dry sliding wear, ceramic-based particulates.

INJECTION MOLDING OF MICROFLUIDIC DEVICES WITH 3D PRINTED INSERT TOOLS

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ABSTRACT

The use of microfluidic devices has grown in both potential and number of applications in recent years. Micro-injection molding (µIM) is an attractive method of manufacturing these devices due to its excellent process throughput and commodity-priced raw materials. Still, manufacturing microstructured tooling for prototyping remains a slow and costly endeavor. This work investigates the feasibility of utilizing additive manufacturing to produce polymer-based tooling for µIM. Inserts consisting of an array of 100µm-1mm-wide straight protrusions were made by stereolithography (SLA). The high flow rate of melted polymer material was molded in the inserts. The molded samples were characterized using surface profilometry and optical microscopy to investigate process resolution capabilities and replicability. It could be possible to replicate the features down to 100 µm in width at a melt temperature of 260ºC. The experiments revealed that the replication of micro-channels, including feature profiles, were highly sensitive to polymer-based tooling.

Keywords: stereolithography, micro injection molding, microfluidic, replication

INVESTIGATION FOR EFFECTS OF HEAT SUPPORT DESIGN FACTORS ON OVERHANGS IN DMLS PROCESS

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ABSTRACT

In this study, the manufacturability of overhangs with heat supports and the effect of design factors characterizing heat supports on part quality were investigated in the DMLS method. For this purpose, the distance between the overhangs and the heat support surface, the width and height of the heat supports, and the scanning order of the overhang and heat support sections are considered as independent factors. Sample productions were carried out using Inconel 625 alloy with different levels of these factors. Images were taken over the powder bed with the optical tomography system during the process. Dimension, roughness, hardness measurements and microstructure examinations were carried out on the produced samples. When the results were evaluated, it was observed that the dimensional deviation and surface roughness decreased with the decrease in the distance between the overhangs and the heat support surfaces. However, it has been observed that the scanning order of the overhang and heat support sections is quite effective on the quality of the part. When the relationship of the heat support width and height factors with the final product properties is evaluated, it is concluded that there is a lower level of relationship compared to the other two factors. When the cube sample produced as a reference in the experiment and the structure of the overhangs are compared, it is thought that the heat support parameters used in the experiment can contribute to subsequent studies.

Keywords: DMLS, Inconel625, heat supports

INVESTIGATION OF ELECTROCHEMICAL POLISHING ON THE SURFACE OF THE γ-TiAl PARTS PRODUCED BY ADDITIVE MANUFACTURING

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ABSTRACT

Additive manufacturing (AM) technologies play a significant role in the industrial field due to the possibility to build complex, near-net-shape, and porous parts. However, the high surface roughness of AM parts remains a critical drawback, limiting their use as an as-built part. Therefore, the electropolishing (ECP) treatment could be an alternative post-process method for simple, complex, or porous parts to enhance the surface. In this study, the fundamentals of the ECP process, experiments on additive manufactured part surfaces and the roughness reduction has been examined. A cubic γ-TiAl part produced by electron beam melting (EBM) was selected as the sample for the ECP process. The morphological results showed that ECP can improve surface finish. Surface roughness values are enhanced by 97.2 %, 96.9 % and 53.2%, in terms of Sa, Sq and Sz, respectively.

Keywords: Additive manufacturing, electrochemical polishing, electron-beam melting, surface texture.

INVESTIGATION OF FLUID FLOW CHANNEL GEOMETRIES FOR FUEL MANIFOLD BASED ON ADDITIVE MANUFACTURING PROCESS LIMITS

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ABSTRACT

Fuel manifold is gas turbine engine part that connects multiple inputs and outlets with liquid flow channels. The advantages of additive manufacturing (AM) technologies offer rapid production as well as customized designs with part consolidation for fuel manifolds. However, AM part surface roughness depends on the design and process parameters affecting the part performance with fluid flow. The poor surface quality and AM process limits decrease the part efficiency due to fluid pressure drop and reduced flow rate of fuel manifolds. This study focuses on the comparison of fluid pressure drop and flow rate of fuel manifold designed with varying additive fluid channel geometries based on AM process limits. Results show that quadrangle geometry provided the lowest pressure loss for the desired manifold geometry. In addition, the outlet velocity analysis showed that triangle cross section geometry has lowest deviation between outlets. Results will be evaluated based on surface roughness of samples.

Keywords: Additive Manufacturing, Microchannels, Design for Additive Manufacturing, Surface roughness

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INVESTIGATION OF LASER POWDER BED FUSION DEFECT INSPECTION BY IN-SITU MONITORING AND COMPUTED TOMOGRAPHY

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ABSTRACT

Complex processing nature of LPBF technology requires close monitoring of the component quality both in-situ and ex-situ. Defects unique to LPBF cause degradation in final component quality and process productivity. Novel characterization methods are being implemented in the AM industry for detection and characterization of defects. In-situ process monitoring (PM) enables inspection of the build quality during the production process. X-ray computed tomography (XCT) is a post-process non-destructive inspection technology allowing internal feature characterization, dimensional and material inspection of both inner and outer geometry.

This study aims to investigate the possibility of utilizing in-situ process monitoring for different types of LPBF defects detection. For this purpose, samples were designed and produced with different simulated defects intentionally embedded. These samples were monitored and inspected using a photodiode and a high-speed camera based in-situ PM system, a micro XCT system and conventional methods via destructively cutting samples. Defect morphology, location and geometrical properties were investigated for each varying inspection method. Integration of in-situ PM into the characterization of LPBF process and components were discussed and a correlation between different inspection methods was presented in the study.

Keywords: Additive manufacturing (AM), Process monitoring (PM), X-ray computed tomography (XCT), Laser powder bed fusion (LPBF), Defect inspection

INVESTIGATION OF SKINCORE STRATEGY TO INCREASE

PRODUCTIVITY FOR LARGE PARTS IN LASER POWDER BED FUSION SYSTEM

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ABSTRACT

Selective laser melting technology allows the production of complex parts that cannot be produced by conventional methods. With many different types of metal powder, parts in different sizes can be produced for different sector needs. Especially the production of large and high density parts can take long build times and risky. Residual stresses during production can be minimized by using different scanning strategies. However, this type of scanning strategy significantly reduces the production speed. At this point, the separation of the part into two bodies as shell and core with different scanning strategies gives the opportunity to minimize the residual stresses without compromising the production speed. In this study, it is aimed to determine the mechanical and microstructure properties of the parts produced by this method.

Keywords: hull&core, residual stress, chess strategy, stripe strategy

INVESTIGATION OF THE EFFECT OF LATTICE PARAMETERS ON MECHANICAL PROPERTIES AND RELATIVE DENSITY IN OPTIMIZATION OF LATTICE STRUCTURES IN ADDITIVE MANUFACTURING

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ABSTRACT

Due to energy and material savings importance of the design of light mechanical parts is increasing rapidly. Lattice structures are good method for designing parts with lightweight and multifunctional properties. With development of Additive Manufacturing (AM) technology, idea of obtaining lightweight and high-strength parts with lattice structures, which are difficult to manufacture with traditional manufacturing methods, is of interest. To obtain high specific strength parts with lattice structures, it is necessary to determine effective parameters by optimizing lattice parameters.

In this study, parameter optimization was performed on effective parameters of lattice structures, cell type, unit strut length and diameter. Analyzes were carried out under static conditions on three-point bending test pieces obtained at variable densities. In the parameter optimization studies, three types of lattice cells were used Simple Cubic (SC), Body Centred Cubic (BCC), and Face Centred Cubic (FCC). In the analysis studies, by comparing relative densities according to yield strength for different lattice structures, were determined optimum lattice parameters for minimum weight and highest strength. The obtained results were compared with literature.

Keywords: Lattice Structures, Additive Manufacturing, Lattice Parameters, Topology Optimization

LASER WELDABILITY OF LASER POWDER BED FUSED ALSI7MG0.6

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ABSTRACT

Laser Powder Bed Fusion (LPBF) allows to manufacture components with lightweight and near net shape suited to aerospace and aviation applications employing Al-alloys. The process is highly suited to one-of-a-kind or small batch production of small to medium sized parts. As the maturity of the process and its end-users increase, the demand for larger components becomes more relevant. The increase of part size by increasing the size of the LPBF machine inevitably increases the cost and the complexity of the employed system. Moreover, the parts produced by multiple lasers in a large powder bed may have issues related to residual stresses and part deformation. On top of that, the cost of process failure during producing of large parts is much higher in comparison. In the light of these, the use of joining operations, in particular welding, appears as a suitable option for the production of large components via LPBF. Indeed, the process lends itself well to also producing dedicated joint edge preparations, thickness and section variation within the location of the welded joint. Amongst different processes, laser welding stands out as a viable option as it can provide narrower weld seam and heat affected zone, produce less deformation on the parts and be automated with cartesian or robotic manipulators.

In the literature, laser weldability of some LPBF produced alloys such as Stainless Steel, Titanium and Inconel have been studied, and relatively successful welds with low relative densities were obtained (Jokisch et al., 2019; Matilainen, Pekkarinen, & Salminen, 2016; Wits & Jauregui Becker, 2015). However, as being one of the most commonly used materials in aerospace, automotive and aviation industries, laser welding of LPBF produced aluminum alloys still requires a further understanding. Various researchers made efforts on the laser weldability of the LPBF produced aluminum alloys, and the biggest challenge emerged as significantly high percentage of porosity, hence poor mechanical properties (Mäkikangas, Rautio, Mustakangas, & Mäntyjärvi, 2019; Möller, Schnabel, Scurria, Jöckel, & Baumgartner, 2021; Zhang et al., 2019). While the previous results show the overall problem, a greater understanding of the pore formation causes is required. From this perspective, the use of oscillating beams and wire feeding as more recent solutions appear to be neglected as well.

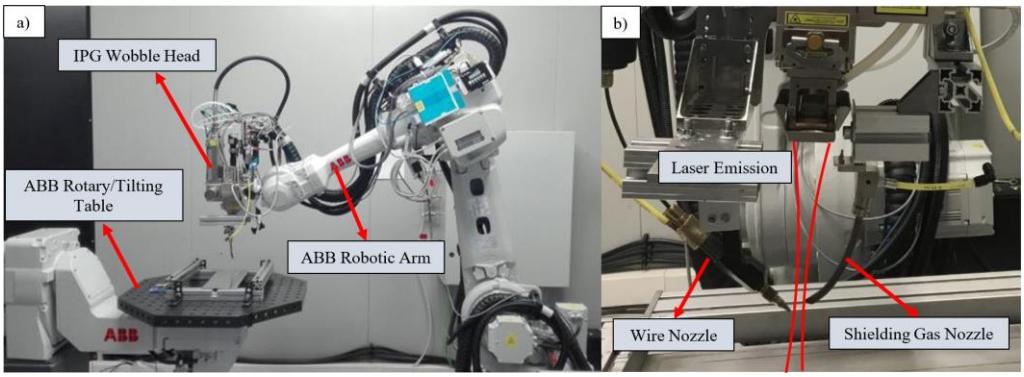

Figure 1. Welding system consists of a) robotic and beam oscillation units and b) wire feeding and shielding.

Accordingly, in this work laser weldability of LPBF produced AlSi7Mg0.6 is assessed with novel beam oscillation and wire feeding solutions. Flat plate specimens with 50 mm x 75 mm x 3 mm dimensions were produced with AlSi7Mg0.7 using an industrial LPBF system (Renishaw AM250) with sufficient part density (>99%). The welds were realized using an IPG YLS-6000 continuous wave infrared laser with a maximum power output of 6000 W. As seen in Figure 1.a), the laser system was equipped with a 6 degree of freedom ABB IRB 4600 robotic arm with ABB IRPB A-250 rotary-tilting table. In order to expand the research, IPG D50 Wobbling Head was used to virtually increase the beam size by oscillating it in a circling manner with certain frequency and amplitude values utilizing a galvanometric

mirror system. On the other hand, As seen in Figure 1.b), the effect of the filler wire was investigated using an Al 5356 filler wire with a diameter of 1.2 mm. The filler wire was fed using Abicor Binzel MFS-V3 and all welds were shielded using an Argon flow.

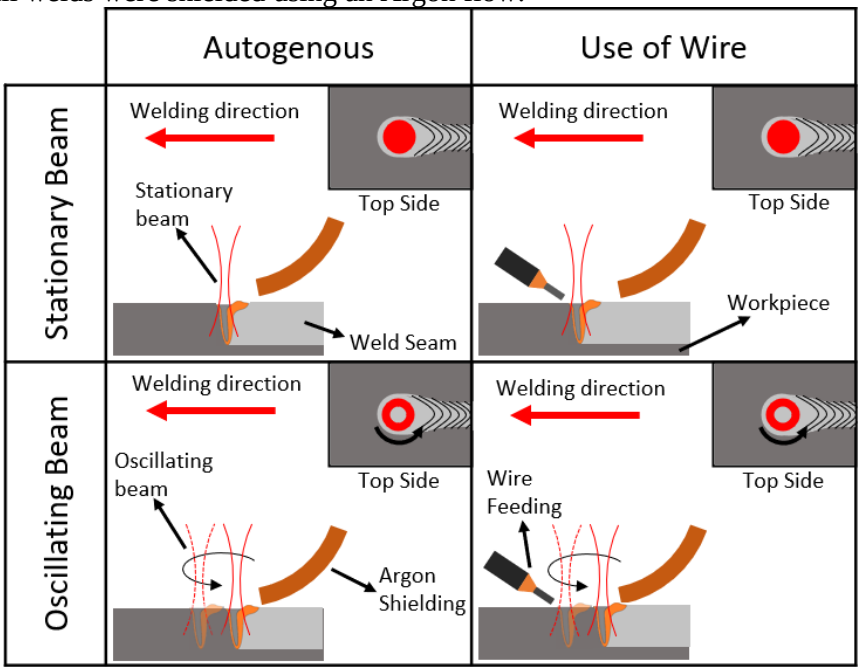

Figure 2. Representative bead on plate weld conditions.

Full pass weld conditions were sought in different weld configurations comparing beam oscillation and wire feeding solutions opposed to autogenous laser beam welding without oscillation. Figure 2. shows representative welds obtained through oscillating and stationary beams with and without the filler wire. The welding conditions were analysed further for the understanding the cause of the excessive porosity. Initial mechanical characterization was also carried out to assess the influence of the welding strategy.

MECHANICAL PROPERTIES OF CONTINUOUS CARBON FIBER-REINFORCED THERMOPLASTIC PARTS PRODUCED BY FUSED FILAMENT FABRICATION

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ABSTRACT

The use of continuous fiber (CF) upgrades conventional fused filament fabrication (FFF) and enables the production of carbon fiber-reinforced composites in a versatile fashion. The key feature of continuous fiber-reinforced FFF (CFR-FFF) is its capability to spatially control the fiber orientation – an additional design parameter that is not available in the conventional production of fiber-reinforced composites. Anisotropic mechanical properties of fiber-reinforced composites combined with this new capability provide new opportunities for the design of parts with spatially and directionally varying strength for demanding structural applications. In this work, we assessed the potential of CFR-FFF by exploring the fiber layout – mechanical property relationships in carbon fiber reinforced nylon specimens. The results show that both the modulus and tensile strength strongly depend on the fiber orientation. The findings demonstrate the great potential of CFR-FFF for the design and implementation of structural parts with enhanced load-bearing capacity. Future studies should combine these efforts with the advancements in topology optimization for achieving optimum performance.

Keywords: Additive Manufacturing, Fused Filament Fabrication, Carbon Fiber Reinforced Polymers, Mechanical Properties

MICROSTRUCTURE AND BONDING MECHANISM EVALUATION FOR BI-METALLIC SS 316-INCONEL718 PRODUCED BY DIRECTED ENERGY DEPOSTION PROCESS

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ABSTRACT

Bimetallic applications on functional parts produced via additive manufacturing methods have been worked by my researchers in order to obtain multi-directional benefits. One of the most compatible bimetallic application is the combination of SS316 and Inconel 718 pair which has a potential application in aerospace, energy and chemical industries. In this study, SS 316 deposited on the Inconel 718 substrate and Inconel 718 deposited on the SS 316 substrate by directed energy deposition additive manufacturing method were investigated. The bonding characteristics and performance, microstructure, micro hardness behavior at bonding region were examined in detail. Since the melting points and thermal conductivity of the binary materials are not very different, bonding was generally considered successful in terms of delamination. On the other hand, in the microstructure examinations, intermetallic structures that deteriorate the material characteristics were encountered and it was determined that these structures caused regional cracking and changes in the micro hardness values.

Keywords: Additive manufacturing, directed energy deposition, bimetals

MICROSTRUCTURE AND STRENGTH OF 3D PRINTED PART USING MICROPLASMA WIRE ARC ADDITIVE MANUFACTURING

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ABSTRACT

Additive Manufacturing (AM) is one of the significant thrusts in Industrial Revolution (IR 4.0). Nevertheless, one of the barriers for its wider adoption is lack of understanding on factors that affect the characteristics of the 3D printed/AM structure and high price of metal AM system. The research study tries to address this issue by studying the strength and microstructure from in house developed low-cost wire arc additive manufacturing (µPWAAM). Furthermore, application of micro plasma in WAAM is limited compared to other heat source. Hence, in this study, µPWAAM component with 50 mm height was additively manufactured and investigated. The microstructure shows there is existence of cellular structure near the substrate, columnar dendrites in the middle region and equiaxed dendrite at the top layer. The highest tensile strength of the part was recorded at 640.4 MPa. The study demonstrates that acceptable microstructure and strength of part can be produced by using low cost µPWAAM.

Keywords: Wire arc additive manufacturing, additive manufacturing, 3D printing,

MICROSTRUCTURES AND MECHANICAL PROPERTIES OF OXIDE DISPERSION STRENGHTENED INCONEL 718 ALLOYS PRODUCED BY SELECTIVE LASER MELTING

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ABSTRACT

In this study, three novel alloys of ODS-IN718 have been designed and produced. The alloy compositions have been determined by using CALPHAD based FactSage Software. Designed ODS-IN718 alloys of "In718 – Y_2O_3 (ODS1); In718 – Y_2O_3 – FeO (ODS2); In718 – Y_2O_3 – FeO – Hf (ODS3)" are produced by Selective Laser Melting (SLM) technique with various power and velocity parameters to optimize production parameters. In order to dissolve the non-equilibrium phases, which are detrimental to the mechanical properties, to anneal existing nano-oxides, to maximize the number densities of nano-oxides, and other strengthening phases of γ'/γ″, novel heat treatment process is applied based on the thermochemical calculations. The samples are solutionized/annealed at 1050 °C for 1 hour followed by aging at 650 °C for 5 h. It is observed that experimental results are consistent with the thermochemical modelling calculations in terms of existence of phases and their amounts. Moreover, after FeO and Hf additions, an increase in number density of nano-oxides and a decrease in nano-oxide sizes were observed. Increase in nano-oxide number density and decrease in size contributed strengthening of ODS-IN718 alloy.

Keywords: Additive manufacturing, ODS – Inconel 718, nano-oxide, Selective Laser Melting, FactSage

1.

MULTI-TRACK, MULTI-LAYER FINITE ELEMENT ANALYSIS OF THE TEMPERATURE FIELD DURING SELECTIVE LAYER MELTING OF 316L STAINLESS STEEL

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ABSTRACT

Selective laser melting (SLM) is a layer-by-layer additive manufacturing technique which involves the application of high-power laser beam for powder melting. The rapid melting and solidification during SLM control the material and physical properties of fabricated components. An accurate estimation of these phenomena is critical to predict the behavior of fabricated components. Given the multi-track multilayer structure of the real SLM process, thermal and physical elements display variations that play a crucial role in shaping the overall mechanical and microstructural behavior of SLM components. To address these concerns, the SLM process of a four-layer component with numerous tracks was modelled, as well as the element birth and death approach to handle layer construction during simulation. Using an existing FEM model, this paper discusses the evolution behavior of the melt-pool shape and thermal variables such as cooling rate, thermal gradient, and solidification rates of SLM 316L SS across many tracks and layers. In addition, the effect of different processing parameters in a multi-track multi-layer SLM was explored.

Keywords: selective laser melting, 316L, cooling rate, thermal gradient, residual stress, additive manufacturing, solidification rate.

NEW APPROACH FOR USAGE OF VIRGIN AND REUSED POWDERS TOGETHER IN LASER POWDER BED FUSION

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ABSTRACT

Laser powder bed fusion systems allow the use of many different metal alloy powders. The powders used as virgin at the beginning are sieved after production and continue to be used in a reused form. Virgin powder gives the desired results in production with its low humidity and correct particle size. During production, the laser beam does not only affect the meltpool area. With the effect of high temperatures, it causes consolidation in the surrounding particles and reduces the particle size quality. Although the powders are resized in sieving, virgin quality powder cannot be obtained. The same density and strength value should not be expected in the productions made by using these powders alone or together in several percentages.

Keywords: virgin powder, reused powder, sieving, microstructure

NOVAL DESIGN OF ANTI-BACKLASH MOTOR BRACKET MECHANISM AND BENCHMARK TEST

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ABSTRACT

Anti-backlash mechanisms are used to eliminate the backlash in the standard gear meshing, because of that, a revolute joint should be designed to obtain minimum clearance as possible. The main objective of the study is to re-design anti-backlash motor bracket mechanism by using design for additive manufacturing. The anti-backlash motor bracket mechanism has the "fixed bracket" which is connected to the "moving bracket" with a revolute joint and is composed of six mechanical components. The steel brackets are designed to conform traditional manufacturing, which leads to a weight of 4.15 kg. Re-design of the brackets, static analyses, topology - post topology optimizations and performance benchmarks were carried out respectively. Finally, the total weight of the consolidated bracket was reduced from 4.15 kg to 0.70 kg. Manufacturing was performed in ARCAM A2X system which is available at ASELSAN. Ti6Al4V powder was used as raw material, where the design and analysis parameters were tuned accordingly. The initial number of six mechanical components were consolidated to one component, reducing the logistical workload drastically.

Keywords: Design for Additive Manufacturing, Electron Beam Melting, Revolute Joint, Topology Optimization.

ON THE MECHANICAL BEHAVIOR AND MICROSTRUCTURAL CHARACTERIZATION OF WIRE + ARC ADDITIVE MANUFACTURING OF MN-SI BASED STEEL ALLOY (ER70S-6)

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ABSTRACT

Wire + Arc Additive Manufacturing (WAAM) is relatively a novel manufacturing technology which uses metallic wire as the feedstock material and normal arc as the heat source to build up large scale near-net-shape parts. This process has attracted the attention of many industries such as aerospace, defense and automotive due to its ability to produce very near-net-shape components without complex tooling and molds offers potential for significant cost and lead time reductions. In this paper, the mechanical and metallurgical properties of the WAAM ER70S-6 are studied during tension loading as well as microhardness testing and its behavior is correlated with microstructural observations. The microstructure of WAAM ER70S-6 is assessed by optical microscopy (OM). The results show that the selected parameters for deposition of ER70S-6, leads to an isotropic mechanical behavior during tension loading. The microhardness level is not changing in different regions of WAAM-fabricated ER70S-6, confirming presence of relatively homogenous microstructure.

Acknowledgments: This work has received funding from the Scientific and Technological Research Council of Turkey (TÜBITAK) under the Grant Agreement No: 3200280 which is gratefully acknowledged.

Keywords: WAAM, Tension loading, optical microscopy, microhardness.

OPTIMIZATION OF STRAIN ENERGY IN CRACK INDUCED STRUCTURE VIA MICRODEFECTS USING PERIDYNAMIC INFORMED TOPOLOGY OPTIMIZATION

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ABSTRACT

Topology optimizations is vastly used to design light-weighted structures that used in industrial applications. Even tough classical continuum mechanics is implemented commonly to solve topology optimization problems, but it brings some restrictions to the modeling, analysis, and solution of complex structures with structural discontinuities. On the other hand, peridynamics (PD) theory can overcome these restrictions because of its nonlocal integration nature. PD eliminate the need for partial derivatives in equation of motion thus it is very suitable to include discontinuities. During additive manufacturing process occurrence of microcrack is inevitable so including microcracks during design stage helps to prevent unwanted future failure. This paper presents an application of peridynamics based topology optimization (PD-TO) to establish a framework to optimize of microcrack characteristics using genetic algorithm. To this end, the PD-TO model is derived using an in-house MATLAB code. By utilizing the genetic algorithm, best microcracks orientations and length are optimized. For each structure, strain energy density distributions are compared between different topologies. As a result, importance of predicting unwanted microcracks during design stage of a macrostructures is presented.

Keywords: Peridynamics, topology optimizations, genetic algorithm, microcracks.

PERIDYNAMIC INVESTIGATION OF SURFACE CRACKS IN OPTIMALITY CRITERION-BASED TOPOLOGY OPTIMIZATION FOR ADDITIVE MANUFACTURING

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ABSTRACT

Topology optimization (TO) is extensively used for reducing the weight of engineering parts that require higher performance in aerospace, automotive, and defense industries. Additive manufacturing (AM), a practical layer-by- layer material deposition process, is commonly employed to fabricate geometrically complex designs obtained from TO. However, AM processes may result in manufacturing-induced structural discontinuities (surface cracks or voids) that must be considered in the design stage. Nevertheless, most TO algorithms cannot realistically handle these structural cracks/defects since they mainly employ classical continuum-mechanics formulations combined with the finite element method (FEM). On the other hand, peridynamics (PD), a non-local meshless approach, can effectively model any structural discontinuity without the need for an additional effort by breaking non-local interactions. In this study, we combine PD and optimality criterion-based TO methods to investigate the effect of surface cracks on the three-dimensional structural design. For a comparative study, these cracks are also modeled using FEM-TO by eliminating the elements in the cracked region. Optimal geometries and total strain energies obtained from PD are compared with those from FEM for each benchmark case with/without surface cracks. Finally, the advantage of PD is revealed for modeling structural discontinuities in TO.

Keywords: Topology optimization, peridynamics, crack modelling, additive manufacturing, finite element method

POLYACRYLIC ACID-BASED SHAPE-MEMORY, SELF-HEALING HYDROGELS FABRICATED BY STEREOLITHOGRAPHY

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ABSTRACT

Additive manufacturing of smart materials holds great promises for numerous applications, such as soft robotics, aerospace, sensors, and healthcare industries. Polyacrylic acid-based hydrogels are attractive smart materials widely used in the medical field owing to their supreme biocompatibility, good moisture absorptivity, and suitability for physiochemical modification.[1,2] Herein, we present a stereolithography (SLA)-based additive manufacturing strategy of shape-memory and self-healing hydrogels copolymerized of hydrophilic acrylic acid within hydrophobic hexadecyl acrylate (C16A) chains. SLA printing of the hydrogels can be performed in a commercial resin printer, and the crosslinking of the copolymer can be achieved via hydrophobic interaction without chemical crosslinks.[3] The melting temperature of the hydrophobic, crystalline domain in the hydrogels can be tuned between 37~41 ºC by changing C16A content, which allows them to possess a shape-memory effect near their melting point. This unique property of the hydrogels provides us with a magic possibility to switch their shapes near human body temperature (36-45 ºC). Additionally, the printed hydrogels exhibited 4-6 MPa of tensile strength and 2.5-250% of stretchability together with a brittle-to-ductile transition by increasing the C16A content. Finally, the temperature-induced self-healing ability of the printed hydrogels after physical and structural damages makes them remarkably interesting for various biomedical applications.

POLYMER-METAL HONEYCOMB COMPOSITES PRODUCED BY ADDITIVE MANUFACTURING AND ELECTROPLATING

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ABSTRACT

Polymer-metal honeycomb composites (PMHC) that combine polymer additive manufacturing and electroplating have been reported in this study. Digital Light Synthesis, a recently developed rapid vat photopolymerization process, printed rigid polyurethane honeycomb structures. Electroless Cu coating followed by NiCo electroplating up to a thickness of 100 µm provided the composite structure. The coating process improves the elastic modulus and strength of the honeycomb parts and enables their use in lightweight structural applications. The developed PMHC structures provide a route for the cost-effective manufacturing of structural parts by eliminating the need for a metal 3D printer. Tuning the lattice geometry and coating parameters offers a versatile design space for implementing a wide range of structural parts with the desired mechanical response.

Keywords: Additive Manufacturing, Digital Light Synthesis, Composite Materials, Honeycomb Structures, Electroplating

POST-PROCESSING OF SURFACE TOPOGRAPHY DATA FOR AS-BUILT METAL ADDITIVE SURFACE TEXTURE CHARACTERIZATION

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ABSTRACT

Surfaces of additively manufactured metal parts from powder-based processes typically show powder particle agglomerations and other features, resulting in high surface roughness. Proper characterization of those surfaces is necessary in order to assess part quality with respect to coatability, mechanical performance or corrosion resistance for use in aerospace, automotive, medical and more industrial applications.

Optical surface texture measurement allows for collection of areal surface data, while the established contact stylus method only captures line profile data.

When applying optical methods for surface topography measurements, proper data acquisition and post-processing in order to assess surface texture may be complex. A number of variables can be adjusted, such as different measurement settings, approaches to outlier removal, evaluated area size or form removal.

This work shows the influence of selected measurement and post-processing variables on data obtained from confocal microscopy for as-built Ti6Al4V and AlSi7Mg0.6 from laser powder bed fusion.

The aim is to show the influence of variation in measurement and post-processing on calculated surface texture parameters and stress the importance of proper documentation in order to achieve meaningful, reproducible data for quality assurance.

Keywords: Laser Powder Bed Fusion, Surface Texture Characterization, Optical Metrology, Confocal Microscopy

PRELIMINARY INVESTIGATION OF TRIBOLOGICAL CHARACTERIZATION OF 3D PRINTED AN AMORPHOUS THERMOPLASTIC WITH DIFFERENT INFILL DENSITIES

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ABSTRACT

Amorphous thermoplastic has been widely used in the automotive industry and outdoor applications such as sliding doors, due to its strong weather resistance, mechanical properties, and lightweight. This study aims to increase the lightness and also retain the wear resistance by producing samples with different infill densities. The samples were produced with a fusion filament production system with different filling densities. Friction tests were performed on pin-on disc device according to ASTM G99 standards. The hardness of the samples was measured with a Shore D test device. Worn surface examinations were made using digital microscope images. Wear rates based on the weight losses were evaluated after the wear test. The expected result of this study is to obtain a light and wear resistance product with less cost and material.

Keywords: Amorphous thermoplastic, Friction, worn surface, Fused filament fabrication

QUALIFICATION METHOD FOR THE PROCESS DEPENDENT FACTORS AND AFFECTING THE FATIGUE BEHAVIOR OF LASER POWDER BED FUSION METHODS FOR TI6AL4V

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ABSTRACT

A main limiting factor for the adoption of additively manufactured (AM) parts into structural applications is the challenge of qualification. The other challenging factor is fatigue chracterization of part. The fatigue chracterization of LPBF metals is a fundemental step toward technology acceptance for structural applications. To speed qualification of LPBF, a rapid method that quantifies impacts of process variables on part structure, properties, and performance is required. Using a list of design requirements developed from literature, build experience, and needs from several major roadmapping efforts, a test artifact was designed to evaluate geometry-specific microstructure, dimensional accuracy, residual stress, chemistry, surface integrity, powder removal, and distortion. The LPBF artifact includes: four sides for geometric feature accuracy and surface integrity analysis, indication marks for accurate sectioning for metallography, and additional features specifically designed to evaluate residual stress, powder removal, mechanical properties and distortion. Microstructure is quantifiable on features including overhangs, islands, thin features, channels, lattice structures and bulk areas representing different thermal histories. This single geometry can be used for many purposes, including optimization of LPBF input variables, qualification and more. Ongoing work is continuing to improve the artifact design, testing its implementation across LPBF platforms, and using the artifact to concretely define process sensitivity currently limiting standardization and adoption of LPBF due to costs associated with defining process windows in terms of qualification and certification.

Keywords: Qualification, Laser Powder Bed Fusion, Ti6Al4V, Fatigue

SURFACE CHARACTERIZATION OF ELECTRON BEAM MELTING PROCESSED γ-TIAL

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ABSTRACT

In recent years, γ-TiAl alloys find various application areas in aviation industry as they provide high temperature strength and oxidation resistance. Moreover, a significant weight gain is achieved when γ-TiAl alloys are preferred in comparison to their nickel based superalloy counterparts utilized in aero-engines. However γ-TiAl is extremely brittle at room temperature and thus severe material loss can not be avoided when a conventional subtractive production method is applied. Therefore a near-net shaping technology such as electron beam melting (EBM) is required to produce γ-TiAl parts in a certain geometry. On the other hand, due to the nature of EBM, the surface roughness of the produced parts is higher compared to its counterparts and requires secondary operations. In this study, EBM technology was applied to produce Ti-48Al-2Cr-2Nb representative turbine blade geometry with various process parameters in order to obtain better as-built surface quality. The EBM process variables, used to manufacture the highest quality Ti-48Al-2Cr-2Nb turbine blade surfaces, were determined according to the roughness and subsurface micro porosity measurements.

Keywords: Electron Beam Melting (EBM), Ti-48Al-2Cr-2Nb, Surface Roughness, X-ray computed tomography (XCT)

SURFACE ROUGHNESS ASSESSMENT OF POST-PROCESS EFFECTS ON LPBF ALLOY 718

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ABSTRACT

Laser Powder Bed Fusion (L-PBF) is one of the promising Additive Manufacturing (AM) technologies to build relatively smooth surfaces belong to complex geometries with its overall technology readiness level. However, this may depend on the other parameters such as built orientation, support structures etc. Despite many advantages of AM, surface roughness of L-PBF'ed parts may still not be met in as-built condition the tight requirements of aviation industry.

In this study, the surface roughness assessment of L-PBF'ed as-built Alloy 718 parts using virgin powder is evaluated by utilizing several post processes beyond the industrial preferences, in aviation standards. The surface roughness is consequently optimized based on orientation in order to define robust manufacturing tolerances in AM of aviation parts. Closed clearances or smooth surface profiles are perfectly needed in those parts to improve several aspects such as fatigue life span. In the scope of this study, Grit Blast, Glass Bead Peen, Chemmill, Ultrapolish, Streamfinish and some of their combinations on five different sloping angles were studied, surface quality were evaluated with profilometer in addition to weight loss effects based on the stock loss method. The outcomes of the study will be used as reference in the future works of TEI.

Keywords: L-PBF, Alloy 718, Surface Roughness, Stock Loss.

SURFACE TREATMENT EFFECTS ON CHEMICAL MILLING PERFORMANCE OF L-PBF PRODUCED TI6AL4V ELI

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ABSTRACT

Titanium is one of the most desirable engine material in compressor sections of engines due to its low density and high strength. Titanium suffers from oxygen entrapment by the reason of heat treatment, high temperature exposure and produced oxygen rich layer referred as alpha case. Laser Powder Bed Fusion (L-PBF) supports to produce the desired geometries that have high complexity. As casting method, L-PBF also encountered with alpha case due to high temperature melting but not high amount like casting. Since L-PBF produced parts that have high surface roughness, melted powders on surfaces, it is hard to remove alpha case totally. In this study, Ti6Al4V ELI parts were produced by L-PBF and measured alpha case levels before and after chemical milling. Abrasive blasting was used to facilitate chemical attack on parts surface to make smooth surface before chemical milling and chemical concentrations were changed to get proper and alpha case free surfaces.

Keywords: Additive Manufacturing, L-PBF, Titanium, Alpha Case, Chemical Milling

TEETH SUPPORT STRUCTURES EFFECT ON DIMENSIONAL DEVIATION OF LPBF PRINTED COMPONENTS WITH OVERHANG FEATURES

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ABSTRACT

Support structures are the special structures that provides the integrity of overhang features in terms of dimensional accuracy and manufacturability without any collapse. Support structures need to be removed without forming any defect on main part after the build and minimizing the usage of these structures are in the scope of different studies. One of the prevalent support structure types is the teeth support structures which includes spaced repeated teeth for providing easy removal and better remnant. In this study, laser powder bed fusion technology is utilized to produce overhang features in the angle of 30° and different teeth parameters are used to find optimum teeth support dimension for achieving intended dimensional accuracy. The support thickness and spacing between two support pieces are the variables for forming different type of teeth support ranging. The manufactured parts are scanned with a 3D scanner blue light device. Results show that the optimum teeth support parameters.

Keywords**:** dimensional deviation, contactless support, LPBF

THERMAL SIMULATION AND EXPERIMENTAL VERIFICATION STUDY FOR TI-6AL-4V ALLOY PROCESSED BY METAL LASER MELTING

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ABSTRACT

Prediction of the effect of process parameters is a challenging problem in selective laser melting (SLM) method. Although the simulation technics are the most widely used methods to predict temperature gradients / melt pool dimensions and their relations with parameters, they are also required some experimental verification manufacturings. In the present study, 3D thermal simulation of metal laser melting process and its experimental verification was conducted for different process parameters to provide a relation between pool dimensions, temperatures and process parameters. Both simulations and experimental manufacturing steps were conducted for 3 layers that each one includes 4 adjacent laser tracks for different scanning speed, laser power and hatching distance combination. Temperature gradients and melt pool dimensions were revealed as simulation results. Afterall, special substrate was designed to manufacture all Ti-6Al-4V multi tracks at once within all parameter combinations. Cross- sectional areas of multitrack specimens were investigated in optic microscope to observe melt pools and top surfaces of specimens were investigated by Scanning Electron Microscope (SEM). Both cross sectional investigations approved that our simulation results are accurately predict real manufacturing temperatures and pool dimensions within small errors.

Keywords: SLM, melt pool, simulation, Ti-6Al-4V

THERMO-MICRO-MECHANICAL SIMULATION OF A TI-6AL-4V SINGLE WALL STRUCTURE MANUFACTURED BY DIRECTED ENERGY DEPOSITION

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ABSTRACT

In this study, thermo-micro-mechanical (TMM) finite element (FE) process model for a single wall deposition is developed to investigate the residual stresses and deformations occur during laser-based directed energy deposition (DED) process of Ti-6AL-4V. The effects of some process parameters (i.e., laser power and scanning speed) on the residual stress and deformation fields are also examined. The special focus is to evaluate the influence of solid-state phase transformations on the flow behavior of Ti-6AL-4V. At this point, the Johnson-Cook (JC) constitutive material model combined with a rule of mixtures is used to account for the effect of phase transformations on the flow behavior by considering strain, strain rate, temperature. The proposed TMM model provides useful information for a better understanding of process-microstructure-property relations in a DED-processed part.

Keywords: Additive manufacturing, directed energy deposition, thermo-micro-mechanical model, residual stress and deformation, finite element method

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TOPOLOGY OPTIMIZATION OF THE CONSOLIDATED STRUCTURAL BRACKET AND VALIDATION BASED ON MIL-STD

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ABSTRACT

The rapid advancement in topology optimization (TO) and additive manufacturing (AM) have altered the design workflow predominantly such as lightweighting and part consolidation. Due to strict design requirement, defense industry emerges the potential of these tools and have turned their attention through these approaches. This study presents the design workflow of a MIL-STD810 shock and vibration resistant structural bracket by means of TO in order to achieve mass reduction and part consolidation. The output of TO is redesigned where high level of combined loading conditions and design for AM (DfAM) rules were taken into account. Bracket was directly fabricated by Stereolithography (SLA) in order to check manufacturability. Afterwards, finite element analysis (FEA) is carried out to ensure the mechanical strength of the optimized structural bracket. Electron Beam Powder Bed Fusion (E-PBF) is utilized to manufacture it made of Ti6Al4V for further validation stage. With successful implementation of this study step by step, it is stated out that the mass of structural bracket is decreased by %52 while the first natural frequency is 2.2 times higher than the original one.

Keywords: Design for Additive Manufacturing, Electron Beam Melting, MIL-STD, Topology Optimizatio

USING COBOTS FOR ADDITIVE MANUFACTURING OF BUILDING ELEMENTS

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ABSTRACT

Additive manufacturing aided construction has various benefits over traditional practices. The entire construction process can be shortened with improved quality control through digital fabrication. Production of high-quality complex geometries becomes possible without special formworks, easing the incorporation of functionality to the

3D printed components. The labor cost, especially critical for high-income regions, can be minimized. However, the structures which are mainly used in additive manufacturing makes the process harder in the scale of civil engineering due to product size, the amount of material used and the type of material. Therefore, adjusting the structure might help the process with another commonly used technique. Using collaborative robots (cobots) and platforms instead of the basic 3-D printing structure helps the mechanism reach further areas with work and cost-efficient construction using their ability and safety features and allow an active collaborative construction environment with humans.

Keywords: Collaborative robot (cobot), Additive Manufacturing, Building elements, end-effector, nozzle.

VERIFICATION TESTS OF TI6AL4V ALLOY BY TIG BASED WAAM METHOD

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ABSTRACT

The research and development for metal additive manufacturing of large-scale parts has been expanded in the recent years. Wire arc additive manufacturing (WAAM) has great potential by high deposition rate, reduced lead time and cost-effective solutions. With the ability to achieve lower buy-to-fly ratios, WAAM is substantial alternative for high-cost metals manufactured for aerospace industry. One of the essential alloys in this industry is Ti6Al4V with its high specific strength value. In this study, multilayer Ti6Al4V wall is deposited by TIG based WAAM method. Vertical and horizontal tensile test specimens are extracted from this wall according to ASTM E8 standards by wire-electrical discharge machining (Wire-EDM) and turning operations. Several verification tests such as X-ray inspection, alpha case measurement, microstructure analysis, and tensile tests are conducted. Very low amount of porosity is detected while suitable tensile test results compared to literature are achieved. It is appeared that developing the WAAM capabilities for full scale Ti6Al4V parts provide many advantages.

Keywords: WAAM, TIG, Titanium, Ti6Al4V, Additive Manufacturing

WIRE + ARC ADDITIVE MANUFACTURE OF 17-4 PH STAINLESS STEEL: EFFECT OF PROCESSING CONDITIONS ON THE GEOMETRICAL AND MECHANICAL PROPERTIES

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ABSTRACT

Wire + Arc Additive Manufacture (WAAM) is a well-known Additive Manufacturing method used to manufacture meter-sized parts at a comparatively lower cost, with less material wastage. A wide variety of metallic alloys can be processed using WAAM. 17-4 PH is a precipitate hardening stainless steel with high corrosion resistance and strength. It is important to understand how this alloy behaves when processed via WAAM. This study investigates how fracture critical parts can be successfully manufactured via WAAM. Single bead tracks were investigated for geometrical accuracy. Walled geometries were deposited to extract tensile coupons for mechanical characterization. A cylindrical part was successfully manufactured which underwent solutionizing and ageing heat treatment. The part was scanned in as-built and heat-treated conditions to account for deformation. The part underwent nondestructive testing to analyze internal defects such as porosity. This study shows that WAAM is a very suitable process for manufacturing medium to large-sized parts with relatively simple geometry.

Keywords: Additive manufacture, WAAM, Stainless steel, 17-4 PH

WIRE ARC ADDITIVE MANUFACTURING OF THIN-WALLED LOW ALLOY STEEL COMPONENTS USING SOLID AND METAL CORED WIRES

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ABSTRACT

Wire Arc Additive Manufacturing method is an innovative technique that can easily produce large complex shaped metal parts with significantly reduced cost and build time compared to powder bed additive manufacturing methods. The approach allows additively manufacturing metal parts that can be welded. Metal cored wires which include a basic outer shell and filled with the desired alloying elements can be an important wire choice to reduce wire cost and provide additional flexibility. Due to their geometry, the generated arc profile and resultant thermal profile can be significantly different from the solid wires. This study presents a hardness test comparison of parts manufactured with the WAAM method at the same parameters using commercial AWS A5.18 ER 70 S-6 solid welding wire and AWS A5.18 E 70 C-6 M metal cored wire. It was observed that the metal cored wire results in higher hardness values compared to solid wire processed under identical conditions.

Keywords: WAAM, Additive Manufacturing, Gas Metal Arc Welding (GMAW), Hardness, Metal Cored Wire

APPENDIX

Extended abstracts underwent a thorough review process, with selected ones being transferred to The *Journal of Additive Manufacturing Technologie*s upon verification of the author's agreement. Below is the list of published articles at *Journal of Additive Manufacturing Technologie*s.

Title	Given Name (Author 1)	Family Name (Author 1)	DOI
On the mechanical behavior and microstructural characterization of wire + arc additive manufacturing of Mn-Si based steel alloy (ER70S-6)	Masoud	Abbaszade	10.18416/JAMTECH.2212648
Heat pipe embedded cold plate design with additive manufacturing technologies	Murat	Parlak	10.18416/JAMTECH.2212675
Surface treatment effects on chemical milling performance of L-PBF produced Ti6Al4V ELI	Buket	Parlak	10.18416/JAMTECH.2212677
Functionally graded ceramics by lithography-based ceramic manufacturing (LCM)	Serkan	Nohut	10.18416/JAMTECH.2212678
Defect detection with image processing and deep learning in polymer powder bed additive manufacturing systems	Ecesu	Arslan	10.18416/JAMTECH.2212684
Contact-free support structures effect on dimensional deviation of LPBF printed components with overhang features	Orhan	Gülcan	10.18416/JAMTECH.2212686
Coordination of spatial and temporal laser beam profile towards ultra-fine feature fabrication in laser powder bed fusion	Ali	Aktas	10.18416/JAMTECH.2212687
Characterization of metal powder reused multiple times for laser powder bed fusion	Emre	Ozeren	10.18416/JAMTECH.2212688
Surface roughness assessment of post-process effects on L-PBF alloy 718	Alican	Taş	10.18416/JAMTECH.2212690
Effects of design parameters on surface roughness of additively manufactured thin-walled structures	Vahap	Yoğurtçuoğlu	10.18416/JAMTECH.2212692
A numerical and experimental investigation on buckling behavior of additively manufactured ribbed casings	Burak	Sivri	10.18416/JAMTECH.2212694
Energy Density Determination for L-PBFP of Ti-6Al-4V Alloy for Various Beam Diameters and Hatch Distances	Mehmet	Mollamahmutoglu	10.18416/JAMTECH.2212695
Post-processing of surface topography data for as-built metal additive surface texture characterization	Theresa	Buchenau	10.18416/JAMTECH.2212697
Laser weldability of laser powder bed fused AlSi7Mg0.6	Kenan Kaan	Yetil	10.18416/JAMTECH.2212702
Combination of peridynamics and genetic algorithm based topology optimization methods for AM-friendly designs	Abdullah	Kendibilir	10.18416/JAMTECH.2212704
Peridynamic investigation of surface cracks in optimality criterion-based topology optimization for additive manufacturing	Abdullah	Kendibilir	10.18416/JAMTECH.2212705
Electromagnetic Characterization of 3D printed Metamaterial Absorber with Conductive Paint	Abdullah	Gözüm	10.18416/JAMTECH.2212706