

## Keynote speakers

Author: Charpagne, Marie-Agathe

Title: Designing immiscible metallic composites using additive manufacturing

A subset of hetero-structured materials, metallic composites made of immiscible elements such as Fe/Ag, Cu/Cr, Cu/Ta, or Cu/Fe exhibit attractive combinations of strength, ductility, thermal conductivity, and resistance to irradiation among others. Characterized by a positive enthalpy of mixing, they all exhibit liquid phase separation and cannot be synthesized via traditional methods like casting, due to sedimentation and macro-segregation after phase separation. Instead, deposition techniques or solid-state fabrication methods have been employed, but those prevent the fabrication of complex shapes and offer limited microstructure control.

Using additive manufacturing, we intend to leverage rapid solidification as an asset to synthesize Fe-Cu-based immiscible composites in a fully scalable manner. Considering Fe-Cu, 316L-Cu and 304L-CuCrZr alloys, we employ gradient deposition strategies using on-the-fly alloying and combinatorial deposition in direct energy deposition, to quickly probe the composition-process space. We achieve fully dense materials with hierarchical microstructures that exhibit features down to the nanoscale.

This presentation will first explore the printability of these immiscible alloys, focusing on their unique printing defects, hot-cracking phenomena and their cause, and associated mitigation strategies, supported by computational thermodynamics. We will then explore the metallurgical mechanisms governing microstructure development in fully dense alloys, considering liquid phase separation, grain nucleation, dendrite growth, and solid-state phase transformations, informed by multi-scale electron microscopy measurements (EBSD, TEM, STEM-EDX, 4D-STEM). Finally, we will delve into the mechanical behavior of the most promising Fe-Cu-based alloys using micro-tensile specimen testing and nanoindentation, with emphasis on the interaction between slip bands, phase boundaries, grain boundaries, and back-stress development using AFM.

Author: Haase, Christian

Title: Design of alloys for additive manufacturing via solidification-induced microstructure heterogeneities

Additively manufactured metallic components are heterogeneous on multiple length scales due to the layer-wise material deposition and process-inherent thermal conditions that strongly influence the underlying liquid-solid and solid-solid phase transformations. At the microstructural scale, multimodal grain structures, microsegregation and dislocation patterns are often considered detrimental. This presentation will show how such microstructural heterogeneities can be exploited for local microstructure control and alloy design.

For the design of new materials, this results in a high dimensional design space for the identification of optimal composition-process parameter combinations. Exploration of the design space requires fast yet robust methods. The use of high-throughput experiments and simulations to narrow down the possible solutions plays a key role. Furthermore, the data obtained can be used to apply machine learning methods to better understand the process-structure-property relationships and to identify optima via inverse design. To this end, a combination of high-throughput material synthesis using high-speed laser cladding, multi-scale material simulations and data-driven models will be presented and discussed.

Author: Hengsbach, Florian

Title: Computational Designed Printable Die Steel for GigaCasting

Scaling up high-pressure die casting components to a "Giga-size" of up to 150 kg leads to significantly leaner and more sustainable car production. For example, Tesla's Model Y uses two large aluminum casting parts instead of approximately 170 smaller parts that are spot-welded, clinched, or riveted. The reduced number of parts correlates with a decreased number of alloys in the car, minimizing cross-contamination and thereby enhancing sustainability. Given the limited heat dissipation in conventional die inserts based on traditional manufacturing techniques, their lifespan for Giga-Casting applications can be reduced to 5% to 10% compared to standard high-pressure die casting (10 to 20 thousand shots versus 150 to 200 thousand shots).

Conformal cooled die inserts reduce hot spots by promoting uniform cooling across the surface of the die insert. In the context of additive manufacturing, it is essential to develop advanced printable die steels with high thermal conductivity. In my talk, I will present a rigorous mechanistic systems approach that integrates processing, structure, property, and performance, leading to a die steel with excellent printability, high thermal conductivity, and sufficient hardness. In addition to a systematic CALPHAD-design approach, experimental results encompass APT and TEM investigations that demonstrate the hybrid co-precipitation concept of B<sub>2</sub>, Ni<sub>2</sub>AlMn, M<sub>2</sub>C, and Cu.

Author: Kaserer, Lukas

Title: Additive Manufacturing of Refractory Metal Alloys Using Powder Bed Fusion – Laser Beam

The Additive Manufacturing technology Powder Bed Fusion - Laser Beam (PBF-LB) enables the production of complex-shaped components that surpass the limitations of conventional manufacturing methods. PBF-LB is ideally suited for producing functionally optimized parts for cutting-edge high-tech applications, especially when using high-performance materials such as the refractory metals molybdenum and tungsten. However, a drawback of PBF-LB-manufactured pure molybdenum and tungsten components is that they currently cannot compete with conventional powder metallurgical parts due to their coarse-grained, columnar microstructure, which is prone to cracking. To suppress the formation of such an unfavorable microstructure, it is necessary to tailor the material to the unique solidification conditions of the PBF-LB process. In this presentation, the underlying mechanisms for defect formation in molybdenum and tungsten are discussed. Furthermore, different alloying concepts are presented to, first, induce grain refinement, thereby suppressing the formation of a coarse-grained microstructure, and second, to purify the grain boundaries from impurities and thus preventing crack formation. Both theoretical foundations and experimental results are presented.

Author: Nadimpalli, Venkata Karthik

Title: Unlocking Innovation in Materials and Manufacturing via Open-Source AM

Additive manufacturing (AM) systems have historically operated as closed, proprietary platforms, limiting user control over essential process parameters and slowing advancements in material innovation. The Open AM initiative at DTU addresses these limitations through an open architecture model that empowers researchers to modify system parameters, integrate custom sensors, and rapidly iterate designs. This open framework has accelerated materials discovery and fosters a collaborative research environment, facilitating widespread knowledge sharing and scaling of innovations across disciplines. We focus on two technology platforms namely laser powder bed fusion (LPBF) and Vat Photopolymerization (VPP).

In LPBF, open-architecture systems enable precise alloy design and microstructural control. By fine-tuning thermal profiles and alloy compositions, we develop materials with targeted properties such as enhanced hardness, corrosion resistance, and ductility. Open LPBF platforms also support in-situ alloying and sensor integration. In VPP, open-architecture systems extend the resolution limits of AM, achieving high-precision components in polymers, ceramics, and metals. The controlled curing depths, viscosity, and exposure in open VPP systems allow for the fabrication of complex structures with excellent resolution.

The talk will discuss how open AM systems are transforming materials and manufacturing by fostering rapid innovation. By moving beyond the restrictions of closed AM models, open architecture facilitates the development of sustainable, high-performance materials tailored to meet diverse research and industrial needs.

Author: Simar, Aude

Title: Healing damage in Almazium: a new high-strength aluminium alloy produced by additive manufacturing

Aluminium alloys produced by additive manufacturing are largely used in aerospace where damage may occur due to overloads experienced in service. A promising approach to avoid the replacement of damaged parts by new ones is to use a material able to heal its damage sites.

The aim of this research is to design a new high-strength healable Al alloy manufactured by Laser Powder Bed Fusion (LPBF). The high cooling rate inherent to LPBF results in a refined microstructure consisting of  $\alpha$ -Al cells enclosed by a Mg-rich low melting point eutectic network acting as healing agent, similarly to biological vascular systems. After damage, a healing heat treatment (HHT) induces the melting of this healing agent eutectic phase, enabling it to flow inside the defects to seal and weld them through solidification. Alternatively, a Healing Heat and Pressure Treatment (HHPT) can be applied, in which the isostatic pressure closes the cavities while the temperature welds them similarly to HHT. To enhance the strength of the alloy while maintaining its healing capabilities, Zr is dispersed into this Al-Mg alloy and forms hardening precipitates, this new alloy is called ALMAZIUM. The healing capacity of this new alloy is characterized by in-situ heating and in-situ tension under synchrotron X-ray nano-holo-tomography performed at line 16B of Grenoble (ESRF).

The same strategy has recently been adopted to manufacture this alloy by friction stir additive manufacturing with a characterization of damage healing performed by transmission electron microscopy and synchrotron X-ray nano-holo-tomography.

## Presentations

Author: Anwer, Tousif

Title: Development of novel process parameter for laser-powder bed fusion based additive manufacturing of crack prone AISI M2 high speed steel

DOI: 10.5281/zenodo.15277220

AISI M2 is a W-Mo based High-speed steel (HSS) that contains high carbon (0.95-1.05 wt. %) along with tungsten (6.0-6.7 wt. %), molybdenum (4.7-5.2 wt. %), vanadium (1.7-2.0 wt. %), and chromium (3.8-4.5 wt. %) as major alloying elements. It is known for its high hardness (700-800 HV) and wear resistance, even at elevated temperatures (500-600°C). The presence of martensite, along with eutectic carbides in the microstructure, is responsible for these properties. Laser powder bed fusion (L-PBF) is characterized by the rapid solidification of a micrometre-sized molten pool. However, the use of L-PBF to manufacture M2 HSS components possesses significant challenges. Due to rapid solidification and the complex thermal history prevail in this process, along with the formation of hard and brittle martensite and eutectic carbides during cooling, significant residual stresses develop. These stresses invariably lead to cracking and delamination in the L-PBF printed parts.

This study aims to develop a robust set of process parameters for L-PBF to print crack-free, dense M2 HSS parts. Base plate preheating and an optimized scanning strategy were explored to reduce the thermal gradient and minimize residual stresses. The investigation began with single-scan track deposition using 72 different combinations of laser power and scan speed, analysing melt pool dimensions, track stability, and bead modes. A processing window for thin, stable beads in the conduction mode was identified to print cubes. The optimal combination of process parameters was established to successfully print crack-free cubes with 400 °C base plate preheating and a novel scanning strategy. The relative density of the sample reached 99.5%. Microstructural and mechanical characterisation was carried out using X-ray diffraction (XRD), scanning electron microscopy (SEM), electron backscatter diffraction (EBSD), microhardness testing, and compression testing. Based on the developed strategy, industrial adaptation of the M2 HSS forging tooling are explored.

Author: Abdesselam, K. Abdellah

Title: Altering microstructure and enhancing mechanical properties during additive manufacturing of Ti-6Al-4V via in-process laser heat treatments

DOI: 10.5281/zenodo.15305060

In this work, we have explored in-process laser-based heat treatment (LHT) as an alternative to post-process heat treatments such as annealing, in order to alter the hcp  $\alpha'$ / $\alpha$  and bcc  $\beta$  phase content in additive manufactured Ti-6Al-4V. To that end, three samples were manufactured with a laser metal deposition machine, a directed energy deposition technique, with the laser operating at 300 W. The reference sample was not subjected to any LHT. For the remaining two samples, each deposited layer was subjected to either an LHT at 100 W (LHT100) for one sample or an LHT at 300 W (LHT300) for the other, without powder addition.

LHT100 showed an overall improvement in the strength/ductility trade-off. Whereas LHT300 resulted in a lower strength but a much higher ductility and toughness than the other samples. In order to understand the origin of these differences in the mechanical response, the contribution of each of the microstructural features and internal strains to the overall mechanical response is studied in detail. A combined analysis via synchrotron X-ray diffraction, scanning electron microscopy and transmission electron microscopy of the as-built samples revealed that the differences in between the different types of hcp phase fractions between the three samples has the dominant contribution to the difference in their mechanical response. These results, which will be presented in this talk, demonstrate the potential of in-process LHTs for altering microstructures and tailoring mechanical properties.

Author: Abe, Naoma

Title: The effects of hydrogen on the tensile properties of additively manufactured Hastelloy-X for hot parts

DOI: 10.5281/zenodo.15278477

Mitsubishi Heavy Industries, Ltd. Group has made continuous efforts to develop hydrogen-related products, such as hydrogen-firing gas turbine, in pursuit of achieving carbon neutrality. Currently, we are considering the application of additive manufacturing technique for specific hot parts. Thus, we investigated the effects of hydrogen on the tensile properties of additively manufactured Hastelloy-X, one of the Ni-based superalloys for hot parts.

In this study, Hastelloy-X specimens were fabricated by laser powder bed fusion (L-PBF) process. The relative density exceeded 99.9%. After fabrication, the specimens were heat-treated to relieve residual stress. In addition, rolled Hastelloy-X specimens were prepared for conventional manufacturing material. Subsequently, hydrogen was precharged into specimens via gas charging method and slow strain rate tensile tests (SSRT tests) were conducted on

both hydrogen- charged and non-charged specimens at room temperature under atmospheric environment, with the strain rate of  $5.0 \times 10^{-5}$ /s.

The results of the SSRT tests indicated that the additively manufactured specimens were affected by hydrogen, with the relative elongation (the ratio of elongation of hydrogen-charged specimens to non-charged specimens) decreased. This decrease was slightly larger than that observed in the rolled specimen. From this result, it is considered that the microstructure and strength properties specific to the additively manufactured Hastelloy-X may have influenced its hydrogen embrittlement resistance.

Author: Aggarwal, Akash

Title: Investigation of Particle-Melt Pool Impact Dynamics and In-Flight Laser-Powder Stream Coupling in Laser Directed Energy Deposition

DOI: 10.5281/zenodo.15423292

This study aims to advance the fundamental understanding of key phenomena in the Laser Directed Energy Deposition (L-DED) process, with a focus on laser beam shadowing, attenuation, and particle-melt pool interactions. Using in-house high-speed visible imaging and photodiode systems, we investigated laser, powder stream, and melt pool interactions. High-speed in-situ synchrotron X-ray radiography was performed at the P61A Beamline at PETRA III, DESY Hamburg, with a custom L-DED setup to investigate particle impingement and dissolution dynamics. Systems studied included metal-metal combinations (Ti6Al4V in Ti6Al4V, 316L SS in Ti6Al4V, and Cu in Ti6Al4V) and a ceramic-metal case (WC in Ti6Al4V). Additionally, multiphysics modeling with a coupled CFD-DEM framework and photon discretization was performed. Our integrated in-situ experiments and modeling provided unprecedented insights into: (1) particle-melt pool surface penetration dynamics and the influence of Marangoni convection-driven motion within the melt pool, (2) highly oscillatory and chaotic melt flow from high-speed particle impacts, (3) increased velocities of partially vaporized particles due to recoil pressure, leading to deep craters in the melt pool, and (4) inflight laser-particle interactions significantly altering the laser beam, introducing stochasticity and randomness. These findings advance fundamental understanding of the L-DED process and offer pathways for optimization and control.

Author: Arcieri, Nicolò

Title: Al-8Fe-4Ce alloy by laser powder bed fusion

DOI: 10.5281/zenodo.15425821

Among various additive manufacturing (AM) processes, laser powder bed fusion for metals (PBF-LB/M) has stood out in the last few years as a reliable method for processing aluminum alloys containing transition metals (TMs) and rare earth elements (REEs) as major alloying elements. This is mainly due to the inherent characteristics of PBF-LB/M, namely high cooling rates (103-106 K/s) and the ability to create complex-shaped objects. Al-TM-REE alloys processed by PBF-LB/M are attractive as high strength materials for high temperature applications, as they contain a high-volume fraction of fine thermally stable intermetallic phases. They could replace heavier and more expensive materials (e.g. steel or titanium) when the service temperature does not exceed 573 K. However, limited investigations have been performed on Al alloys characterized by simultaneously high contents of TMs and REEs. Therefore, this study aimed to evaluate the feasibility of processing an Al-8Fe-4Ce (wt%) alloy by PBF-LB/M and its mechanical properties. Initially, different parameter sets were investigated to select the optimal processability window to obtain dense, crack-free samples. Although this proved particularly challenging due to the inherently high fraction of intermetallic phases, crack-free specimens with a relative density exceeding 99% were ultimately obtained. The optimal parameter set was then used to fabricate cubic and tensile specimens. As-built samples were characterized by scanning electron microscopy (FESEM) to investigate the effects of the rapid solidification on the microstructure. Phase identification analysis was performed by X-ray diffraction (XRD), while the thermal stability was evaluated using differential scanning calorimetry (DSC). Nanoindentation and uniaxial tensile testing were employed to assess the mechanical properties of the alloy. Finally, post-mortem analysis was carried out on tested tensile specimens to study the failure mechanisms.

Author: Arnoulin, Pauline

Title: control of solid-state phase transformations during the wire arc additive manufacturing process to reduce residual stress and deformation in deposits

DOI: 10.5281/zenodo.15306936

The heating and cooling conditions during the wire arc additive manufacturing process (WAAM) generate complex thermal, metallurgical and mechanical phenomena that induce stresses and strains within the part. They are mainly due to incompatibilities between local deformations induced by thermal expansion gradients. In steels, certain phase transformations, between ferrite, austenite and martensite, can also interfere with the state of stress and strain. To reduce residual stresses and strains, we propose to control solid-state phase transformations, through local chemical composition, to drive metallurgical deformations that counter thermal distortions.

To that end, we study the various phase transformations arising from the martensitic, austenitic and ferritic stainless steels combinations. The microstructure of the 12 alloys produced in situ are analysed and related to the deformation and residual stress state, measured by neutron diffraction, to reveal their correlations. Phase evolution has been shown to have a significant influence on the stress establishment in the part, with up to 66% less strain depending on the transformations encountered.

These results enable us to identify the chemical compositions for which we obtain the least deformation and stress, and therefore the microstructures to be favoured. Finally, this study paves the way for the development of functionally graded materials produced by WAAM for improved final properties.

Author: Assainte, Matthieu

Title: Development of in-situ laser preheating for non-weldable Ni-based superalloys manufactured by L-PBF process

DOI: 10.5281/zenodo.14929428

**Keywords:** LPBF, Cracking, Preheating, In situ measurements Non-weldable Ni-based superalloys processed by L-PBF are susceptible to solidification cracking due to the high cooling rates induced by the process. In addition, strain age cracking can occur during post-heat treatments due to  $\gamma'$  precipitation. Increasing the part temperature during manufacturing is known to decrease the thermal strains induced by the L-PBF process and to promote the growth of  $\gamma'$  precipitates at high temperatures, mitigating solidification and strain age cracking, respectively. This is typically done by heating the build plate, although such a strategy loses its effectiveness for large parts when the top surface is too far away from the substrate.

This study aims to define an in situ preheating strategy to minimize solidification cracking by rapidly scanning the top surface during manufacturing with a five-times wider spot size. The main advantage of this approach is that the preheating is always applied at the top of the component. In addition, this approach induces homogeneous heating of the surface, reducing the cooling rate while creating a large heat affected zone (HAZ) below the surface, acting as an in situ stress-relieving heat treatment.

The temperature within the part during manufacturing was measured using an innovative in situ thermal measurement system, where the part was built around a thermocouple that moved in relation to the building plate. This allowed to map the temperature within the built part for different heights and preheating conditions. This study shows that several preheating layers at regular intervals are necessary to produce a complete part without solidification cracking.

SEM observations were carried out to assess the effect of preheating conditions on  $\gamma'$  precipitation in different areas of the part. This allowed to observe competing factors between  $\gamma'$  precipitation on the one hand, and  $\gamma'$  dissolution

Author: Aydemir, Abdullah

Title: Effect Of LPBF Process Parameters on Post-Heat Treatment Microstructures of Hastelloy X

DOI: 10.5281/zenodo.15401857

The literature in the laser powder bed fusion (LPBF) domain is very much focused on investigating the effect of process parameters on porosity and as built microstructures, and investigating the effect of heat treatments on densely produced samples. However, there is a lack of systematic studies linking the effect of different process parameters to the heat treatment response of alloys. This study aims to bridge this gap by focusing on the recrystallization behavior of Hastelloy X fabricated by LPBF.

Samples with near full density were produced with different laser power, speed, hatch distance, scanning/rescanning strategy. All samples were then uniformly heat treated at 1180 °C for 1h and 2h and air cooled. The Kernel Average Misorientation (KAM) maps of the as-built samples were obtained through Electron Backscattered Diffraction (EBSD) to quantify the stored plastic energy. The post heat treatment microstructures were characterized and presented using scanning electron microscope (SEM). The stored plastic energies, post heat treatment grain morphologies, precipitation (carbide/oxide) types and precipitation densities, and temperature stability were then compared for samples produced with different process parameters. The implications of microstructure engineering through recrystallization in post-process heat treatments of alloys via LPBF process parameter variation were discussed.

Author: Badin, Sophie

Title: Multi-material additive manufacturing of 316L and 17-4 PH steels: Interface comparison between two distinct technologies

DOI: 10.5281/zenodo.15301889

Additive manufacturing (AM) offers unique flexibility for designing architected and complex-shaped parts. While current research largely focuses on optimizing the spatial distribution of material and void, the potential of AM for integrating complex phase or composition distributions within a single component remains largely underexplored. Yet, this approach opens up new pathways for developing composite or functional materials with locally tailored properties.

This study explores the fabrication of multi-material parts where one metallic alloy is directly deposited onto another during the additive process, combining two contrasting stainless steels: 316L (austenitic) and 17-4 PH (martensitic). Their similar chemical compositions reduce the risk of brittle intermetallic formation at the interface, while their distinct mechanical properties allow for an effective property trade-off. Two radically different AM processes are compared: an indirect process based on metal extrusion followed by sintering (Metal Extrusion Additive Manufacturing), and a direct wire-based laser fusion process (Wire Laser Additive Manufacturing). The former promotes interfacial bonding through solid-state diffusion, while the latter induces partial dilution between the two materials.

Through a multi-scale analysis of porosity distribution, chemical element partitioning, microstructural evolution, and local mechanical properties, we investigate the interfacial characteristics obtained for each process. Particular attention is given to the thickness of the interface, which is controlled by the diffusion behavior specific to each process. This comprehensive approach aims to reveal the key mechanisms governing interfacial behavior and to develop optimized design strategies for multi-material AM. Ultimately, after interface optimization, global mechanical tests such as tensile testing will be carried out as part of future work to evaluate the overall structural performance.

Author: Baganis, Antonios

Title: Phase Formation and Texture Evolution of 316L-CuCrZr Multi-Material Structures

DOI: 10.5281/zenodo.15425565

316L-CuCrZr Laser Powder Bed Fusion multi-material structures have attracted research interest due to their promising material combination however they pose significant issues related to cracking phenomena and hence poor structural integrity. In this study, we propose a compositional modification approach to mitigate cracking by introducing carefully selected premixture layers between 316L and CuCrZr, designed to promote ferrite formation that resists cracking. To characterize such chemically graded materials, advanced characterization methods are required. The presence of ferrite in these multi-material structures is confirmed using Polarization Contrast Neutron Analysis (PNI), while its temporal evolution is investigated via in-situ annealing Synchrotron X-ray diffraction. Neutron Bragg Edge Imaging reveals that the phase transformation from austenite to ferrite correlates with significant texture evolution and a concurrent reduction in the Coefficient of Thermal Expansion, as revealed by in-situ annealing neutron diffraction. The melt pool morphology for different premixture compositions is examined using in-situ radiographic analysis, complemented by in-situ acoustic emission monitoring. Additionally, high-speed imaging enables the estimation of temperature distribution and the solidification behavior of the various compositional steps in the multi-material structures. Post-mortem microstructure characterization, employing EBSD, TKD and STEM-EDS analysis provides a valuable tool to elucidate the mechanism of ferrite formation, while the overall mechanical behavior of the structure is evaluated using nano-indentation mapping.

Author: Basu, Soudip

Title: Microstructure-mechanical property correlations in laser powder bed fusion produced Aluminum alloys

DOI: 10.5281/zenodo.15303076

Additively manufactured (AM) materials exhibit heterogeneities across multiple length scales (mm to nm) that critically affect the performance of AM components, for example under loading. Hence, tailoring these microstructures is important to control the nature of deformation mechanisms and obtain targeted mechanical properties such as strength and ductility. In the present work, we investigated aluminum alloys with increasing microstructural complexity (pure Al, Al-Mg, Al-Mg-Zr-Ti and Al-Mg-Sc-Zr (Scalmalloy)) produced by laser-based powder bed fusion of metals (PBF- LB/M). Advanced characterization tools including scanning and transmission electron microscopy as well as synchrotron X-Ray diffraction were used to investigate the microstructural constituents (e.g. grain structure and precipitation evolution) of as printed and heat-treated materials. To correlate the microstructural constituents to the underlying deformation mechanisms, micro and nanohardness measurements, interrupted electron backscattered diffraction (EBSD) mapping under tensile loading as well as microscale digital image correlation ( $\mu$ DIC) were performed to capture the full-field strain accumulated in the material. In the case of Scalmalloy, a characteristic bimodal microstructure was observed, in which the coarse-grained (CG) regions in the melt interiors accommodated higher strains than the fine-grained (FG) regions along the melt pools. Further, an accumulation of geometrically necessary dislocations (GND) at the interface between FG and CG domains, with higher GND density in the FG regions was observed. Specifically, CG regions carry 32% higher effective strain than FG regions at 23% tensile strain, while FG regions (including interfacial areas) carry 47% higher GND density than CG regions at 14% tensile strain. Although similar strain and GND partitioning trends were found across regions, the corresponding magnitudes varied from region to region, implying that the microstructural neighborhood of the region of interest plays an important role. Micromechanical data from these heterogeneous alloy systems are an important starting point to develop physics-based deformation models or machine learning based statistical models.

Author: Bentamene, Ilies

Title: Insight into 3D strain partitioning in Al alloy designed for Additive Manufacturing using synchrotron X-ray nano-tomography

DOI: 10.5281/zenodo.15304030

The microstructures of aluminum alloys designed for LB-PBF can be strongly heterogeneous. A bimodal grain structure is often observed with fine-grained regions (FG) consisting of submicron grains near the melt pool boundaries, and coarser columnar grains (CG) in the melt pool interiors. This specific grain arrangement leads to a 3D architecture at the mesoscale. The mechanical response of such microstructures was found to be influenced by the microstructure heterogeneity using digital image correlation based on SEM images collected during in situ tensile tests [Buttard2024]. The response of such heterogeneous microstructures is affected by the relative mechanical behaviour of the FG and CG regions.

However, the complexity of the microstructure topology requires a 3D approach to further improve our understanding of the mechanical response of such Al alloys. Here we determined the 3D strain maps, at the scale of few melt pools, in a high strength aluminum alloy designed for LB-PBF. To this end, 3D images were collected using synchrotron X-ray nano-tomography (voxel size of 25nm<sup>3</sup>) at the ESRF (ID16B Beamline) after different strain increments. The high resolution of the 3D images allowed capturing the fine intermetallic network decorating the microstructure. This enabled to perform high resolution digital volume correlation (DVC) since these intermetallics act as a natural speckle and allow subsets as small as 2µm<sup>3</sup> to be used. The evolution of the 3D strain fields as a function of the macroscopic stress is considered and the heterogeneous distribution of strain is explored. Links to the microstructure heterogeneities are discussed as well as the dependences on the applied stress level.

[Buttard2024] Buttard M. et al., Influence of microstructure heterogeneity on the tensile response of an Aluminium alloy designed for laser powder bed fusion. *Acta Materialia* 269, 119786 (2024).

Author: Bernard, Gaëtan

Title: Impact of in-situ/ex-situ TiC-reinforcement in Ti composite manufactured by PBF-LB

DOI: -

Titanium-based metal-matrix composites manufactured by additive manufacturing offer tremendous lightweighting opportunities. However, processing high reinforcement content remains challenging, and damage accumulation negates reinforcement as strain increases. This study reports an improved manufacturing process for Ti-TiC, enabling high reinforcement content, significant fracture strain, and drastically reduced damage accumulation. Ti-TiC samples were produced from different types of TiC powder as well as in-situ from the reaction of Ti and C. Microstructure, mechanical properties, and damage accumulation were characterised in each case. The presence of defects in the feedstock powder was shown to increase damage accumulation. Comminuted particles gave the best results between the different TiC powders, and in-situ produced TiC gave the overall best result. We report a decrease of >90% in damage accumulation between aggregated TiC and in-situ TiC. The Ti-TiC samples displayed a Young's modulus increase of >30%, reaching close to 150 GPa while keeping fracture strain above 3%.

Author: Borges Esteves, Paulo Davi

Title: Thin-Wire Multi-Material Electron Beam Additive Manufacturing

DOI: 10.5281/zenodo.15390255

Metal Additive Manufacturing (MAM) has experienced significant growth in industrial applications in recent years. Laser-based AM methods are more widely adopted in industry due to their simpler operation and lower maintenance requirements however, they face limitations when processing reflective metals such as copper, as well as materials with high melting points like tungsten. Additionally, the atmospheric environment in laser-based processes can pose challenges for reactive materials such as titanium. Electron beam processes, by contrast, address these issues through operation in a vacuum environment and offer higher energy efficiency. Furthermore, with beam oscillation capabilities, the process can be highly tailored. These advantages not only enable the processing of such challenging materials but also open the possibility for multi-material additive manufacturing through precise control of process parameters. This study investigates the potential of Thin-Wire Electron Beam Additive Manufacturing (T-WEBAM) to produce multi-material components (Cu-Fe, Ti-Fe). The research includes high-speed imaging of the melt pool to monitor the material transfer mode, coupled with an analysis of the influence of process parameters on both transfer behavior and melt pool geometry. Additionally, modeling of the volumetric heat source generated by the electron beam, combined with the dynamics of thin wire insertion, was performed to assess the conditions necessary for achieving stable deposition of multi-material tracks. The resulting samples were characterized using optical microscopy, Energy Dispersive X-ray Spectroscopy (EDX), and Electron Backscatter Diffraction (EBSD). The findings demonstrate the feasibility of achieving crack-free interfaces in multi-material additive manufacturing and emphasize the critical role of maintaining a stable liquid bridge transfer to ensure consistent material deposition.

Author: Bruckhaus, Lars

Title: Optimizing process strategies in laser powder bed fusion to reduce crack formation in Fe-based bulk metallic glasses

DOI: 10.5281/zenodo.15312317

Bulk metallic glasses (BMGs) are known for their exceptional mechanical and electrochemical properties, including high strength, excellent corrosion resistance, and catalytic activity. However, their large-scale application remains limited due to size restrictions in conventional casting, as high cooling rates are required to achieve amorphous solidification. Laser Powder Bed Fusion of Metals (PBF-LB/M) offers a promising alternative, as its high cooling rates and small melt pool volumes can overcome these limitations and enable the fabrication of larger amorphous parts. Among BMGs processed via PBF-LB/M, Zr-based alloys are most common due to their good glass-forming ability (GFA) and processability. However, their high sensitivity to oxygen contamination significantly reduces their GFA, necessitating high-purity feedstock and increasing material costs. In contrast, Fe-based BMGs are less sensitive to oxygen and offer a cost-effective alternative, combining good mechanical properties, corrosion resistance, and catalytic performance. Yet, their processing via PBF-LB/M is challenging due to a strong tendency for crack formation caused by residual stress.

This work addresses the processing of a Fe-based BMG using PBF-LB/M and investigates strategies to reduce cracking, both in bulk material and in thin features such as struts, which are particularly relevant for complex, filigree structures, desirable for PBF-LB/M parts. By optimizing key process parameters, such as scan speed, laser power and inter-vector times, as well as process conditions including platform preheating and tailored scan strategies, heat accumulation can be reduced. This results in a lower degree of crystallinity and reduced residual stress, thereby decreasing crack formation and significantly improving printability. To evaluate the thermal and microstructural effects of different processing conditions, differential scanning calorimetry (DSC), metallographic cross-sections, and optical microscopy were employed.

Author: Chen, Yunhui

Title: Microstructure control in Laser Additive Manufacturing revealed by X-rays

DOI: 10.5281/zenodo.15479700

Laser Additive Manufacturing (LAM) is a key technology of the Industry 4.0 revolution. In context to technology that supports a circular economy and net-zero industry, the ability to understand, optimise and exploit LAM has become increasingly attractive. The unique fabrication process offers opportunities for microstructure manipulation of phase morphology, size distributions and volume fractions. These microstructure variations offer the tantalising potential to produce tailored mechanical properties that would be otherwise unattainable through traditional manufacturing methods or earlier LAM technologies. In this study, we investigated base-plate heating, one of the most cost-effective approaches to achieve the manipulation of the thermal field. By elevating the temperature during the process, the thermal gradient is reduced, resulting in lower residual stresses a strategy that has proved to be beneficial in nickel-base superalloys. It demonstrated on the nickel-base superalloy RR1000, and investigated using in-situ X-ray diffraction. Here, the micromechanical and microstructural evolution of a single layer during a build is described using a custom-designed DED-LAM process replicator equipped with a heating system. This is successfully shown to reduce the thermal gradient during processing from  $\sim 570^\circ\text{C}/\text{mm}$  to  $\sim 110^\circ\text{C}/\text{mm}$ . Baseplate heating significantly decreased the  $\gamma'$  volume fraction, particularly near the melt pool which facilitated the development of larger grains and a reduced texture. Furthermore, it markedly reduced residual stresses, reducing the largest magnitude by  $\sim 25\%$  (95% from a cumulative distribution function), and virtually eliminating von Mises stress gradients along the build direction. Any remnant stress patterning was linked to phase-specific stress partitioning at the microstructural length scale. These outcomes demonstrate that base-plate heating enhances control over microstructure, texture, and residual stress, offering significant potential for performance improvements in additive manufacturing applications, envisioning the pathway to industrialise LAM for wider applications.

Author: Chmielewska, Julia

Title: High-Throughput Design and Additive Manufacturing of Refractory MPEAs

DOI: 10.5281/zenodo.15310975

Refractory multi-principal element alloys (MPEAs) are promising candidates for structural applications in extreme environments, but their implementation in additive manufacturing (AM) is challenged by composition-dependent phase formation and poor manufacturability. This work presents a high-throughput alloy design and manufacturing combining computational screening and experimental validation to identify ternary MPEAs within the Hf-Mo-Nb-Ta-Ti-Zr system with 100% BCC phase above  $1000^\circ\text{C}$ , narrow solidification ranges ( $\Delta T < 50^\circ\text{C}$ ), and low susceptibility to cracking for improved processability.

Out of 3,421 simulated compositions, six were selected for arc melting and subsequent characterization. Among them, Nb<sub>25</sub>Ti<sub>20</sub>Zr<sub>55</sub> and Hf<sub>45</sub>Nb<sub>30</sub>Ti<sub>25</sub> demonstrated stable single-phase BCC microstructures and favorable thermal and mechanical behavior. Phase stability was validated by in situ high-temperature XRD and DSC, while nanoindentation and confirmed promising strength and ductility.

Preliminary DED trials suggest promising laser processing, with initial results indicating the potential for ductile, crack-free deposition, refined microstructures, and limited elemental segregation. These findings support a pathway from computational alloy design to additive manufacturing, contributing to the development of refractory MPEAs for aerospace, energy, and high-temperature applications.

Author: Clavier, Valentin

Title: Thermo-mechano-metallurgical modeling of the wire arc additive manufacturing of titanium alloy parts

DOI: 10.5281/zenodo.15305256

The multiple benefits offered by Wire Arc additive manufacturing (WAAM) have led to a growing interest in this technology. This applies to the manufacturing of titanium alloy components for aerospace or naval fields, where there is a need for more efficient methods for the production of large and complex parts. Direct Energy Deposition processes such as WAAM involve important heating and cooling cycles which induce complex physical phenomena. The current lack of understanding of these phenomena and the lack of control of the process parameters can lead to the formation of defects like porosity in the parts and the development of residual stresses and distortions which could affect strongly the mechanical properties. To overcome this problem in the case of titanium alloy parts manufacturing, the development of a thermo-mechano-metallurgical modeling is proposed.

Based on the previous work of El Cheikh in 2012 and Theodore in 2023, a disk model is adapted to the WAAM process and material (Ti-6Al-4V alloy) used in this study to predict the geometry of the deposits as a function of manufacturing parameters (i.e., wire feed speed, welding speed, voltage and current). An original equivalent volumetric heat source model is also developed based on Goldak's double ellipsoid distribution. The use of this equivalent heat source coupled with the finite element method gives relevant information on the temperature distribution, the thermal gradients, and the geometry of the welding pool during the manufacturing. To validate the thermal modeling, a 30 layers Ti-6Al-4V wall has been deposited with temperature monitoring through thermocouple measurements and compared to the simulations. The obtained results will further constitute inputs for metallurgical and mechanical modeling and eventually enable the optimization of the WAAM process in order to produce parts with higher quality.

Author: Crego Lozares, Jose Manuel

Title: Optimizing process parameters for interfacial integrity in Cu–Ni bi-metallic additive manufacturing

DOI: 10.5281/zenodo.15308952

Copper (Cu)-based alloys are often coupled with the Nickel (Ni)-based superalloys to form bi-metallic components with both high thermal and structural properties. Contemporary efforts focus around application of additive manufacturing (AM) methods, as conventional manufacturing (CM) routes can't reproduce complex bi-metallic component designs. However, like CM components, they suffer from interfacial cracking, the origin of which is frequently linked to the copper presence in the crack regions. Literature highlights temperature of the melt pool and of the heat affected zone (HAZ) as the main driver for enhanced copper diffusion and its affinity to facilitate cracking. Intrinsically, AM process parameters are expected to be pivotal in controlling the temperature of the build and, hence, copper diffusion. In this work, we used process optimization to minimize the cracking through energy redistribution during the deposition and control of the melt pool dynamics of CuCrZr single tracks on Inconel 718 substrate. Our results show that process optimization has eliminated macro-scale cracking, while concurrently micro-cracks were still observed adjacent to the melt pool boundary. Crucially, these micro-cracks were successfully eliminated using further process optimization. This milestone sets the foundation for developing complex interfaces securing defect-free process parameters

Author: Ducottet, Sylvain

Title: macro-scale thermal modeling for optimization of preheating strategies during laser powder bed fusion of inconel 738 parts

DOI: 10.5281/zenodo.15303635

During additive manufacturing by laser powder bed fusion (L-PBF), a part undergoes rapid thermal cycling with significant heating and cooling rates. This thermal history leads to the initiation of microcracks that degrade the material properties. To mitigate this issue, various studies have explored the effect of preheating strategies. For instance, mesoscale models (molten pool scale) have predicted a reduction in cracking risk when the substrate (i.e. the most recently solidified layer) temperature is increased from 200 °C to 600 °C, with experimental data supporting these predictions.

The aim of this study is to optimize the preheating strategy in L-PBF and thereby minimize the risk of hot cracking in Inconel 738 parts. To this end, a macroscale finite-element heat-flow model has been developed to simulate the part-scale temperature evolution during the preheating phase. Several parameters, such as the laser power, the thickness of the deposited powder layers, and the laser scanning time, can be tailored to faithfully replicate experimental conditions reported in the literature. The work of M. ASSAINTE et al. (this conference) was selected for model calibration.

M. ASSAINTE et al. employed mobile thermocouples to measure temperature within the part during both fabrication and preheating stages. In the simulation, virtual mobile sensors are placed along the same trajectory as the experimental thermocouples, enabling point-by-point temperature comparison and optimal model calibration. Ultimately, a correlation between the build-front temperature and the microcrack density is established, enabling optimization of the preheating strategy during L-PBF fabrication.

Author: De Raedemacker, Sophie

Title: Healing mechanism and strength improvement of a new high-strength healable Al-Mg alloys produced by LPBF

DOI: 10.5281/zenodo.15301786

Additively manufactured aluminum alloys are commonly employed in aerospace and aeronautics, where they are susceptible to damage from operational overloads. An emerging approach to reduce the need for part replacement is the use of materials capable of healing at damage sites.

This research focuses on the development of a novel high-strength healable Al alloy produced by Laser Powder Bed Fusion (LPBF). The rapid cooling rates characteristic of LPBF promote the formation of a fine microstructure, consisting of  $\alpha$ -Al cells encased in a magnesium-rich eutectic phase with a low melting point. This eutectic network acts as a healing agent, functioning similarly to biological vascular systems. In the event of damage, a healing heat treatment (HHT) triggers the melting of the eutectic phase, allowing it to infiltrate cracks or voids and subsequently solidify, effectively sealing and repairing the defects.

To improve both mechanical strength and healing functionality, zirconium (Zr) is incorporated into the Al-Mg alloy, leading to the formation of strengthening precipitates. In this work, the static mechanical properties of the resulting Al-Mg-Zr alloy, referred to as Almazium, were assessed in the as-built state and after various healing heat treatments (HHT) involving different temperatures and durations. Under optimized printing conditions, the addition of Zr significantly enhanced the yield strength, increasing it from 150 MPa to an average of 366 MPa in the as-built samples. The HHT parameters were carefully optimized to limit the coarsening of strengthening precipitates, as excessive growth could impair the alloy's mechanical properties.

Finally, the healing capability of Almazium was evaluated through in-situ damage-healing cycles performed during synchrotron X-ray nano-tomography experiments at beamline ID16B of the ESRF. This approach allowed for direct observation of damage initiation, localized healing processes, and the potential re-opening of previously healed regions under subsequent mechanical loading.

Author: Dethier, Sarah

Title: Critical assessment of the defect tolerance of beta-metastable titanium alloys processed by additive manufacturing compared to cast alloys

DOI: 10.5281/zenodo.15308188

Titanium alloys constitute a very attractive choice for aerospace, aeronautics and biomedical applications mainly due to their excellent strength-to-weight ratio. Classical alloys, such as Ti-6Al-4V, exhibit a high strength but a low hardening capacity, ductility and fracture toughness. Many efforts have been made to develop new beta-metastable titanium alloys, in which the simultaneous activation of Transformation-Induced Plasticity (TRIP) and Twinning-Induced Plasticity (TWIP) effects increases significantly the hardening capacity and the resistance to plastic localization.

Several studies have demonstrated that Ti-12wt%Mo presents a uniform deformation 3 to 4 times larger than classical Ti-6Al-4V alloy and a true fracture strain twice higher than the one of other classical titanium alloys. Moreover, this alloy exhibits an extraordinary resistance to damage as well as a unique fracture mechanism through shear bands instead of the common ductile fracture, dictated by nucleation-growth-coalescence of cavities.

On the other hand, additive manufacturing such as L-PBF is commonly used to elaborate complex geometries to reduce even more the weight of the designed parts. However, defects such as porosity are almost inevitable during these processes causing a considerable decrease in the mechanical properties. Recent work has demonstrated that 3D printed Ti-12wt%Mo maintains its improved mechanical properties even when defects are present from the beginning of straining due to a large resistance to coalescence.

In this study, additively manufactured samples as well as cast-and-wrought samples were considered to assess the influence on the mechanical response of Ti-12wt%Mo. This study deals with the influence of the process and the resulting microstructure on the mechanism of localization of deformation and the subsequent fracture mechanisms. The L-PBF

process parameters have been tuned to also assess the influence of density on the mechanical behavior, and determine the defect tolerance of Ti-12wt%Mo.

Author: Dhiman, Sahil

Title: Controllable Microstructural Variations in Additively Manufactured Ti-6Al-4V via Laser Powder Bed Fusion

DOI: 10.5281/zenodo.15315103

Laser powder bed fusion (LPBF), a premier additive manufacturing (AM) technology offers the ability to produce complex metallic components. However, its widespread use is often limited by challenges in controlling the local microstructure, largely due to the intricate thermal cycles inherent in its layer-by-layer build process. In this work, we demonstrate a method for achieving controllable microstructure in Ti-6Al-4V by employing distinct LPBF “processing strategies” and leveraging the design flexibility of the process. By locally tailoring the thermal conditions spatially and temporally, we successfully generated two targeted microstructures:  $\alpha'$  martensite (hard domains that enhance strength) and lamellar  $\alpha+\beta$  or globular  $\alpha$  (soft and tough domains that improve ductility and toughness). These microstructures were engineered to form in situ as alternating layered bands, arranged either longitudinally or radially. The mechanical performance of the fabricated parts was found to depend strongly on the spatial orientation and thickness of these microstructural bands. This approach provides a promising pathway to simultaneously improve strength and ductility in multi-phase materials like Ti-6Al-4V fabricated by LPBF.

Author: Dohyung, Kim

Title: Elemental segregation-induced variation of phase stability in additively manufactured steels

DOI: 10.5281/zenodo.15010476

Metal components produced by laser-based metal additive manufacturing (AM) techniques suffer from rapid cooling during solidification and cooling, resulting in unique solidification structures such as cellular structure and micro-elemental segregation on cell boundaries. It has been reported that the elemental segregation on the cell boundaries decorated with a high density of dislocation is responsible for the higher strength of the additively manufactured metallic materials. It also acts as a preferential nucleation site for precipitates during solidification, cooling, and post-heat treatment. In another aspect, elemental segregation may induce a different phase stability than the nominal composition expected. In this study, the unique behavior of two kinds of high-manganese alloys fabricated by laser powder bed fusion (LPBF) and direct energy deposition (DED) will be introduced. First, the high pseudo-elastic behavior of Fe-Mn-Si-based shape memory alloy produced by LPBF was investigated. In addition, we investigated the origin of the deterioration of tensile ductility of high-manganese steel after annealing heat treatment. From our study, we found that both are closely related to elemental segregation-induced variation of phase stability and stacking fault energy. The results in this study may give new insight into the design of novel alloys suitable for AM and heat treatment processes.

Author: El Haddaoui, Samuel

Title: DEDp and LPBF additive manufacturing of a TiC-reinforced case-hardened steel matrix composite

DOI: 10.5281/zenodo.15304804

Iron-Based Metal Matrix Composites (IMMCs) exhibit high specific stiffness as well as excellent wear and thermal resistance. These properties make IMMCs suited for structural components subjected to friction such as gears, bushes and bearings. However, ensuring homogeneous dispersion of the reinforcements and reliable interfacial anchoring is still challenging (Chen S. 2025). Achieving a homogeneous composite powder composition at the LPBF melt pool scale also remains complex. DEDp offers greater flexibility in processing powders, but the larger melt pool combined with the need for coarser powders can result in unmolten particles.

In the current work a 16NCD13 + 3.2 wt% TiC IMMC has been manufactured with both LPBF and DEDp. TiC promotes high hardness, low density, and excellent metallurgical compatibility with steels. The 16NCD13 matrix, a low-alloy case-hardening steel containing chromium and molybdenum, promotes the precipitation of mixed secondary carbides, thereby enhancing high-temperature mechanical strength (Chengru L. 2023). Two powder processing routes were considered: (1) for DEDp, a premixed composite powder blend with 15-35  $\mu\text{m}$  TiC particles was optimized to allow suitable powder projection and ensure proper TiC dilution in melt-pool, (2) for LPBF, 16NCD13 powders were grafted with nanosized TiC particles.

Good density, crack-free microstructures with a uniform distribution of TiC reinforcements were obtained using both the LPBF and DEDp processes. The addition of carbide increased the hardness from 350 HV (pure 16NCD13) to approximately 600 HV. However, the resulting microstructures are different:

(1) DEDp forms large dendritic cells ( $\sim 8\mu\text{m}$ ) composed of tempered martensite with micrometric titanium-rich precipitates. Lower layers consist of tempered martensite due to thermal cycling, resulting in lower hardness values. (2) LPBF leads to fine grains ( $\sim 200\text{nm}$ ) and homogeneously distributed nanometric precipitates. Austenitization followed

by water quench were applied to both microstructures.

Author: Evans, Alexander

Title: Determining peak tensile residual stresses in laser powder bed fusion using diffraction-based analysis

DOI: 10.5281/zenodo.15308508

Laser powder bed fusion (PBF-LB) metal additive manufacturing process is well known to generate large residual stresses in a range of alloys due to the complex and localized thermal cycles. In general, these residual stresses are considered deleterious during manufacturing and subsequent service operation. In several alloy classes including austenitic stainless steels and nickel alloys, tensile residual stresses are generated with magnitudes equal to the yield strength of the processed material depending on geometry and process parameters, which can be located at surfaces/subsurface of a built structure. Knowledge of the magnitude and location of these peak tensile residual stresses is crucial for optimizing in-process or post process mitigation strategies, validating process models, and for consideration in structural integrity assessments. Several diffraction-based approaches have been demonstrated to characterize the magnitude and location of the maximum tensile residual stresses. These approaches include laboratory X-ray diffraction with electrolytic layer removal, energy dispersive synchrotron diffraction and neutron diffraction on PBF-LB prisms of several alloys, resolving the position and magnitude of the peak tensile residual stress. This work provides important considerations when determining these peak tensile residual stresses in newly developed alloys, novel processing strategies and when using more standard residual stress analysis methods.

Author: Farag, Mohammed

Title: Architected metal matrix composites from Zr-modified Al7075 and zinc via LPBF and HIP for extrinsic healing applications

DOI: 10.5281/zenodo.15303462

This work presents the development and characterization of architected metal matrix composites (MMCs) combining high-strength Zr-modified Al7075 and zinc alloys with the objective of facilitating future extrinsic healing applications. The lattice structures were first designed and produced using Laser Powder Bed Fusion (LPBF), capitalizing on the enhanced printability afforded by zirconium modification.

After manufacturing, zinc was infiltrated into the lattices, followed by Hot Isostatic Pressing (HIP). HIP parameters were optimized to enhance densification, promote interfacial bonding, and ensure uniform zinc distribution within the aluminum matrix.

Extensive characterization methods were employed to assess the resulting composites, including X-ray computed tomography for internal inspection, scanning electron microscopy (SEM) combined with energy-dispersive spectroscopy (EDS) for microstructural and chemical analysis, and mechanical testing to evaluate performance. Local strain fields were subsequently examined using Digital Volume Correlation (DVC) obtained from in-situ testing.

The preliminary findings reveal that zinc has been successfully integrated and consolidated within the lattice frameworks, achieving reduced porosity and improved mechanical properties. Although the evaluation of healing behavior is still ongoing, the chosen architecture and materials lay a solid foundation for future investigations into extrinsic healing mechanisms.

Author: Farquhar, Lucy

Title: Multi-Material Additive Manufacturing of Dual-Steel Complex Internal Geometries

DOI: 10.5281/zenodo.15302710

Multi-material additive manufacturing is a technique gaining popularity to produce parts, optimised through use of multiple materials, to create very specific properties. It offers dimensional freedom to create complex geometries, between the different alloys, that were previously impossible to manufacture by any other method. This can lead to properties which are not achievable in conventional single alloy parts, by manipulation of alloy placement. In this case, manufacture of parts such as this is achieved using a selective powder deposition device, produced by Schaeffler Aerosint. Where powders are adhered, through a negative pressure, to drums and then selectively deposited using an ejection of Argon gas. The resulting geometries manufactured are therefore limited by the resolution of the recoater, the alignment between the powders, and alignment of the powders with the laser. As well as part size being limited by the time taken for the powder deposition.

In this work, 316L and 17-4PH stainless steels are used to create multi-material parts with differing internal geometries between the alloys. The aim is to manipulate strength, ductility, and toughness, through production of metal 'composite' structures, containing material layers or fibres. The geometries are designed, such that material features are as fine as possible, within the available resolution of the recoater. This also allows for maximising the number of repeated patterns within the samples, which are small enough to be manufactured within a continuous build job. The resulting microstructure for each geometry is then analysed, to assess the accuracy of the interfaces produced. The

samples are then heat-treated, subjected to mechanical testing, and compared to their single-material counterparts. The influence of varying material geometry on strength, toughness and crack propagation is then discussed.

Author: Felber, Christian Johannes

Title: Additive manufacturing of in-situ particle reinforced ODS/NDS alloys utilizing the process atmosphere

DOI: 10.5281/zenodo.15276335

Oxide and nitride dispersion strengthened steels (ODS/NDS) show great potential for applications in the energy and aerospace sector. Manufacturing of these alloys is challenging as a homogeneous particle distribution in the materials is required which is typically only achieved by Powder Metallurgy routes or Additive Manufacturing (AM). Various strategies including powder decoration and powder blending are used in AM to process ODS alloys. Utilization of the process atmosphere in AM processes (PBF-LB, DED-LB) has recently received attention to process in-situ ODS alloys. In our work, we study the ability to use reactive process atmospheres (e.g. CO<sub>2</sub>, N<sub>2</sub>) to process in-situ ODS and NDS alloys with tunable properties. The particle properties (e.g. size and distribution) are affected by the thermal field during processing, which is controlled by manufacturing parameters.

For this purpose, Fe-Ti alloy specimens are processed by PBF-LB/M and DED-LB/M under Ar, CO<sub>2</sub> and N<sub>2</sub> atmosphere. The extent of the material-gas interaction is determined by the composition of alloy and atmosphere as well as the manufacturing parameters. Increasing melt pool surface temperatures and melt pool lifetimes enhances the interaction with the process gas and increases the gas uptake from the atmosphere. In-situ oxygen-, nitrogen- and carbon-rich particles are formed in the melt pool affecting microstructure and improving strength by particle reinforcement and grain refinement. Particle size and distribution are correlated to the melt pool lifetime and cooling rates. The composition of the in-situ formed nanoparticles changes with Ti, O, C, N concentrations in the melt pool.

Author: Garrivier, Natan

Title: Multimodal Synchrotron Characterization of the Formation and Distribution of Retained Austenite in LPBF-Manufactured Ferritic-Martensitic Steel

DOI: 10.5281/zenodo.15297714

Recent advancements in metallic additive manufacturing (AM) for nuclear fusion reactor components demands extensive control over microstructural evolution during laser-based processes. In this work, we show that without operando and multimodal characterization, critical transformations in ferritic-martensitic (FM) steels during Laser Powder Bed Fusion (LPBF) remain hidden – specifically, the formation of localized metastable austenite driven by carbon segregation. Using time-resolved operando synchrotron X-ray diffraction (XRD), combined with 2D and 3D synchrotron XRD, and X-ray fluorescence (XRF) microscopy, we map the emergence and spatial distribution of these unwanted phases. Our results demonstrate that rapid thermal cycling and scanning strategy intricately influence austenite formation and microstructural heterogeneity, meaning direct consequences for material performance and structural integrity in-service. This study highlights that post-mortem analyses alone are insufficient to qualify AM processes for nuclear applications. Only by combining real-time tracking of phase dynamics with high-resolution chemical and crystallographic mapping can critical insights be captured across multiple length and time scales. The methods and results presented in this work establish a blueprint for future qualification frameworks for AM components in extreme environments, emphasizing that predictive control of process-structure-property relationships is unreachable without a fully integrated, operando, multimodal approach.

Author: Georgiou, Kostas

Title: Development of Metal Matrix Composites based on Al2618+ for Laser Powder Bed Fusion Additive Manufacturing

DOI: 10.5281/zenodo.15259586

The demand for high-performance aluminum alloys in AM has surged due to their critical role in aerospace and high-temperature structural applications. However, the processability of high-strength Al-Cu-Mg alloys in LPBF remains a challenge due to their susceptibility to hot cracking, high thermal conductivity, and rapid solidification effects. This study investigates the development of advanced Al2618+ MMCs reinforced with TiC and TiB<sub>2</sub> nanoparticles to overcome these limitations and enhance the alloy's mechanical and thermal performance.

Al2618+, a Zr-modified derivative of Al2618, has shown promise for LPBF with improved densification and a refined microstructure. The introduction of Al<sub>3</sub>Zr precipitates effectively mitigates hot cracking and refines grain morphology, yet further reinforcement is needed to optimize strength, wear resistance, and high-temperature stability. In this work, TiC and TiB<sub>2</sub> nanoparticles are integrated into Al2618+ via ball milling, acting as heterogeneous nucleation sites to promote grain refinement and suppress columnar growth. The introduction of the nanoparticles is expected to enhance mechanical properties through load transfer, Orowan, and Hall-Petch strengthening mechanisms, leading to improved hardness, wear resistance, and overall microstructural stability. A comprehensive characterization approach of the Al2618+/TiC and Al2618+/TiB<sub>2</sub> composites is undertaken,

including powder PXRD, SEM, and HRTEM to analyze phase stability, nanoparticle dispersion, and microstructural evolution. The powder's flowability, morphology and rheological properties are also evaluated to ensure suitability for LPBF processing. To quantify the performance improvements, mechanical testing on printed samples will be conducted.

This research advances the development of next-generation aluminum MMCs tailored for AM, paving the way for stronger, more reliable, and thermally stable components for aerospace and high-performance structural applications. Acknowledgements: This work has been carried out within the framework of the AM2C3 Horizon Europe Twinning Project funded by the European Union (101159727).

Author: Gheysen, Julie

Title: Defects in Direct Liquid Metal Deposition of Aluminium Alloys

DOI: 10.5281/zenodo.15275224

Common metal additive manufacturing technologies require intensive energy sources such as lasers to achieve the melting and bonding of a metallic feedstock. This leads to a sizeable carbon footprint, especially for reflective materials such as aluminium. Moreover, it induces complex and turbulent melt pool dynamics which lead to stochastic formation of defects which are, hence, difficult to suppress.

We explore an alternative approach, which is similar to what is now practiced on a large scale with thermoplastic polymers, namely Fused Deposition Modelling. In our technology, a metallic wire is fed through a nozzle and melted using resistive heating. It then exits the nozzle producing a small drop which bonds and solidifies onto the previously deposited layer. This is challenging for metallic materials due to their combination of low viscosity and high capillary forces, which induce instabilities such as bulging, i.e. the breakup of deposited lines into droplets, or the propensity of metals for chemical reaction, in particular with air. To overcome these instabilities, we take advantage of the 1-5 nm thick passivating oxide skin which forms rapidly on the surface of liquid aluminum alloys. This oxide layer is stable and prevents, below a certain size scale, the flow of metal in ways that would increase its surface area.

Aluminium alloy wire is used to manufacture walls using this direct liquid metal deposition process and different defect formation mechanisms, which include the bulging instability or the evolution of hydrogen pores, are studied. It is found that these defect formation levels can be reduced using a combination of proper wire preparation and storage, coupled with appropriate process parameter selection.

Author: Gilani, Negar

Title: Expanding the Possibilities of Multi-Metal Additive Manufacturing with Molten Metal Jetting

DOI: 10.5281/zenodo.15309199

Molten Metal Jetting (MMJ) is an emerging Additive Manufacturing (AM) technique that is attracting growing interest due to its ability to directly fabricate complex components with high resolution. MMJ operates by melting bulk metals in crucibles to produce molten droplets, which are deposited at precise locations onto a moving substrate to form three-dimensional objects. These superheated droplets remelt the underlying material upon impact, enabling full consolidation. By using metals in their raw form and eliminating the need for post-processing steps, the technique offers a streamlined and sustainable manufacturing route.

MetalJet, an in-house developed MMJ system used in this study, features dual printheads for multi-metal printing in a single operation, representing the first system of its kind. We demonstrate the platform's capability to deposit microdroplets of tin, indium, silver, and copper onto ceramic, polymer, and metallic substrates. The results highlight the critical influence of substrate temperature on inter-droplet bonding and adhesion to the substrate. Electrical resistivity measurements show values comparable to bulk metals, while X-ray computed tomography revealed part densities up to 99.73% through an optimised deposition strategy. Surface roughness, an important parameter for applications such as radio frequency devices, was reduced to as low as 4  $\mu\text{m}$ . These findings position MMJ as a promising platform for the sustainable fabrication of complex, miniaturised, and high-performance multi-material components.

Author: Giroud, Tiphaine

Title: Martensitic stainless steel with precipitation hardening and high mechanical strength for additive manufacturing

DOI: 10.5281/zenodo.14999868

The combination of Additive Manufacturing (AM) design freedom and a new generation of high-performance metal powders offers a great opportunity to achieve an industrial leap regarding performance, weight reduction, decarbonization, cost, ...To support those challenges, Aubert & Duval is evaluating the AM powder version of MLX®19 grade that has originally been developed for forged mechanical parts.

The MLX®19 grade is a precipitation hardening stainless steel combining ultra-high tensile strength and good corrosion resistance. This stainless steel has been designed for severe service conditions with targeted properties similar to 300M performance required for structural aerospace components: ultimate tensile strength (UTS) range between 1800 and

1950 MPa, toughness (KIC) from 50 to 80 MPa.m<sup>1/2</sup>.

In this study, MLX®19 powder produced by gas atomization was processed by Laser Powder Bed Fusion (LPBF). MLX®19 proved its suitability for AM processes, thanks to its absence of cracks. LPBF process gives rise to specific non-equilibrium microstructures with the absence of  $\eta$ -Ni<sub>3</sub>Ti precipitates. Specific heat treatments were applied to precipitate the hardening  $\eta$ -Ni<sub>3</sub>Ti phase and optimize mechanical properties. Transmission electron microscopy (TEM) analysis was used to monitor the evolution of precipitation. XRD and EBSD analyses revealed that austenite is finely and homogeneously distributed after heat treatment. These microstructural features lead to an increase in UTS of 80 MPa after heat treatment, compared with conventional processes such as forging. Forged and AM-treated parts show similar corrosion resistance. This study demonstrates that LPBF processing is suitable for MLX®19 parts with satisfactory properties, paving the way for the application of additively manufactured MLX®19 components in various industries.

Author: Grimm, Philip

Title: Casting assisted design of a high-performance Sc-free Al-Mg-Si-Zr alloy for laser powder bed fusion

DOI: 10.5281/zenodo.15303545

In this study, we present the successful design of a tailored Al-Mg-Si-Zr alloy for laser powder bed fusion (PBF-LB/M), combining high strength and adequate ductility with excellent processability. High-strength commercial aluminum alloys, such as 2024 or 7075, exhibit poor printability and are prone to hot cracking, which makes them challenging to process via PBF-LB/M. This leads to a high demand for customized Al-based alloys. Moreover, from a sustainability perspective, the use of rare-earth elements, such as scandium, should be avoided.

This work demonstrates an approach for designing alloys for PBF-LB/M, based on centrifugal casting. Without the need for pre-alloyed powder, various compositions were produced by applying this rapid cooling technique to roughly estimate their thermophysical properties, microstructure, and mechanical properties. Key characteristics such as freezing range, 0.2% compressive yield strength, ultimate strength and corresponding strain were determined by differential scanning calorimetry and compression tests. Based on the initial results, the most promising composition predicted to balance high-performance and superb printability, was atomized into powder and successfully employed in PBF-LB/M. Relative densities of more than 99.5% without crack formation were achieved for several laser powers and scanning velocities, along with promising mechanical properties, including a compressive yield strength of almost 400 MPa in the as-built state.

Author: Gruber, Konrad

Title: Improving fatigue resistance of reused AM Inconel 718 using carbide additives and HIP

DOI: 10.5281/zenodo.15267262

Inconel 718 is widely used in industrial additive manufacturing (AM) due to its favorable combination of mechanical properties and printability. However, its fatigue life is limited by residual stresses, porosity, and microstructural defects inherent to laser powder bed fusion (LPBF). Although hot isostatic pressing (HIP) reduces porosity and microstructural variability, it may also lead to grain coarsening and increased twinning. To address these issues, we incorporate 0.6 wt.% micron-scale niobium carbide and titanium carbide into reused Inconel 718 feedstock powder. These carbides dissolve during LPBF and promote the formation of fine, nano-scale carbide-nitride precipitates during subsequent heat treatment, stabilizing the microstructure against abnormal grain growth. Neutron diffraction data indicate that these nano-precipitates help redistribute residual stresses more favorably. Fatigue testing shows a 150-200% improvement in fatigue life over conventional LPBF Inconel 718. The fatigue limit also exceeds that of wrought and aged counterparts by about 200 MPa in the 10<sup>4</sup>-10<sup>6</sup> cycle range. These improvements are notable, as AM alloys generally perform poorly in low to mid-cycle fatigue due to their intrinsic defects. The proposed approach of feedstock modification combined with optimized heat treatment enables the development of AM nickel-based alloys suited for fatigue-critical applications, while also supporting powder reuse and enabling powder upcycling by enhancing the performance of reused feedstock beyond typical expectations.

Author: Grünewald, Jonas

Title: Using beam shaping for microstructure tailoring in laser-based powder bed fusion of metals

DOI: 10.5281/zenodo.15312741

In laser-based powder bed fusion of metals (PBF-LB/M), ring- and point-ring-shaped beam profiles are increasingly used as an alternative to the common Gaussian beam profile. The changes in the shape of the energy input influence both the process and the resulting component characteristics. The modified energy input alters the temperature distribution and its evolution during processing, which in turn influences the solidification behavior of the material and can consequently modify the as-built microstructure. If it is known how the microstructure changes through the use of different beam profiles, this is a large step towards tailoring microstructures and component properties. Accordingly, load path-dependent topology optimizations would be

possible. In our contribution, we first show how different microstructure characteristics (texture, grain size, etc.) change depending on the beam profiles and scanning strategies used to process AISI 316L. Via the relative redistribution of laser power of a point-ring-shaped beam profile from the core to the surrounding ring, it is, for example, possible to rotate the texture from a  $\langle 100 \rangle$  || BD to a  $\langle 111 \rangle$  || BD preferred texture. Second, we show that different microstructures can be combined within one component. Due to epitaxial grain growth in PBF-LB/M, the microstructure of the underlying layers strongly influences the formation of the microstructure in the subsequent layers. The transition zones between the two microstructure areas differ depending on the grain size in deeper layers. If the microstructure of deeper layers contains larger grains, the transition zone is disproportionately larger.

Author: Gussone, Joachim

Title: High strength Al recycling alloys for additive manufacturing

DOI: 10.5281/zenodo.15310688

The recycling of aerospace scraps is challenging, as it is composed of different grades of Al alloys, where sorting is laborious and often not economical feasible. One promising strategy for achieving high recycling rates, potentially up to 100 %, is cross-alloying of the two Al grades (2xxx and 7xxx alloys) mainly used in modern airframes. In this way, the formation of the intermetallic T-phase is promoted in a eutectic reaction, which opens up the potential for the creation of fine structures that contribute to high mechanical properties. To explore this approach, thermodynamic calculations were carried out to identify suitable compositions with high recycling potential. Selected compositions were then cast into cylindrical samples, and laser treatments simulating laser powder bed fusion (LPBF) were performed to assess the suitability for additive manufacturing.

The microstructure of the laser treated samples showed columnar Al grains oriented along the solidification direction, featuring a very fine dendritic substructure. T-phase forming interconnected networks was observed in the interdendritic regions and at the Al dendrite colony boundaries. It can be anticipated that similar microstructures, which may be detrimental for the mechanical properties, will also be formed during LPBF. To mitigate this, spheroidization heat treatments were carried out, breaking up the interconnected T-phase networks.

Furthermore, the laser treatment experiments revealed distinct cracking phenomena. In the almost fully eutectic model alloy, large cracks perpendicular to the scan vector direction were observed, indicating a cold cracking mechanism and a very brittle material behavior. Interestingly, the alloy that allows a 100% recycling rate performed better than alloys with reduced amounts of T-phase, which appeared more prone to hot cracking.

Based on these findings, a candidate for a high strength AM alloy was selected. In the next step, pre-alloyed powder will be produced for the validation of the processability by LPBF.

Author: Haghdadji, Nima

Title: Microstructure engineering in duplex stainless steels via laser powder-bed fusion additive manufacturing

DOI: 10.5281/zenodo.15124687

Duplex stainless steels, characterized by approximately equal fractions of austenite and ferrite in their equilibrium state, exhibit an exceptional combination of superior corrosion resistance and mechanical properties. However, when these steels are produced using laser powder bed fusion additive manufacturing, the rapid cooling rates typically lead to a non-equilibrium microstructure dominated by delta-ferrite. Additionally, fluctuations in energy distribution contribute to chemical and interfacial instabilities. While this metastable microstructure results in lower ductility and toughness in the as-built state, it serves as an optimal precursor for a controlled transformation into ultrafine austenite during heat treatment. Here, we uncover critical insights into how printing parameters influence the morphology, size, and dislocation density of solidified delta-ferrite, as well as their impact on the phase transformation pathway, morphology, size, and interface characteristics of the resulting austenite. These findings offer a framework for tailoring microstructures in multi-phase materials fabricated through additive manufacturing.

Author: Hejazi, Bardia

Title: In-situ very high cycle fatigue experiments of additively manufactured Ti-6Al-4V using X-ray computed tomography

DOI: 10.5281/zenodo.15261296

X-ray computed tomography (XCT) is an invaluable method for evaluating the properties and performance of components both during service and after failure in a non-destructive manner. XCT is particularly useful for the investigation of additively manufactured (AM) components, which often have production defects that are inherent to the manufacturing process, such as lack of fusion defects. Understanding the mechanisms of fatigue crack growth throughout the life cycle of such components is crucial and so to address this need, we designed and performed experiments to investigate the fatigue life and fatigue crack growth behavior of Ti-6Al-4V components under very high cycle fatigue (VHCF) testing. The titanium samples were additively manufactured with intentional internal defects to control crack initiation location. XCT of the component was carried out to identify crack initiation sites and characterize

the dynamics of crack growth. The findings from this work will benefit industries that rely on the AM of titanium alloys, aiding in the improvement of component design and manufacturing processes.

Author: Hryha, Eduard

Title: Degradation, reuse and recycling of 316L powder in PBF-LB

DOI: 10.5281/zenodo.15425040

Metal powder constitutes the most common feedstock used in metal additive manufacturing (AM), including powder bed fusion (laser beam PBF-LB, and electron beam - PBF-EB), binder jetting (BJT) and powder blown directed energy deposition (DED). Metal powder can be produced by a variety of methods, characterized by different productivity and cost, where variety of powder properties can be obtained for the same alloy system. Further on, metal powder is exposed to the processing conditions that are determined by process parameters and hardware solutions and hence differ significantly between different AM technologies. Understanding of the change in powder properties during AM processing and alloy composition and its impact on final properties of the component is required to assure successful industrial implementation of powder-based metal AM.

Powder degradation in PBF-LB is strongly related to the spatter formation and its accumulation in the reused powder. Spatter formation on the other hand is strongly related to the component geometry and process parameters. However, what is important from powder degradation point of view is spatter oxidation, as it can be significantly affected by processing conditions, especially processing gas composition and oxygen potential. Hence, powder degradation is rather complex, and powder disqualification is typically determined by bulk oxygen content, that is not always representing real state of powder degradation as powder is continuously mixed with fresh virgin powder to keep bulk oxygen content below the requirements. Hence, presented work exploits possibility of powder recycling - namely, reatomization of disqualified powder and AM process waste into AM powder. Reatomization trials were performed in nitrogen and argon for 316L and enabled to obtain powder with chemical and physical properties as good or even better than virgin powder. PBF-LB processing of recycled powder showed excellent powder printability and mechanical properties showed significant improvement in comparison to the reused powder.

Author: Issariyapat, Ammarueda

Title: Optimizing in-situ alloying in laser powder bed fusion: a study on Ti-W alloy feasibility and mechanical performances

DOI: 10.5281/zenodo.15307247

The laser powder bed fusion (LPBF) technique is renowned for its ability to fabricate parts in a single step using a layer-by-layer laser-based production process. A key factor in optimizing LPBF lies in feedstock preparation, specifically through in-situ alloying, where elemental mixtures are adjusted to achieve tailored compositions. However, achieving uniform dispersion of fine elemental particles remains challenging due to inherent agglomeration, which can disrupt process efficiency and compromise alloy homogeneity— particularly when incorporating high-melting-point elements with slow diffusion rates. Additionally, the constraints of rapid solidification and limited molten pool dimensions further intensify these challenges, underscoring the need for strategic powder modification and precise mixing techniques.

This study investigates the feasibility of fabricating titanium-tungsten (Ti-W) alloys via LPBF in a single-step manufacturing approach. Tungsten ( $T_m = 3422\text{ °C}$ ), a refractory element with double the melting point of titanium ( $T_m = 1670\text{ °C}$ ), was selected to examine alloy formation and its impact on mechanical properties. Various powder mixing strategies were evaluated to determine their effects on powder distribution, morphology, contamination levels, and mixing efficiency. Furthermore, the influence of input volumetric energy density ( $E_v$ ) on alloy homogeneity, residual W particle distribution in Ti matrix, and microstructural evolution was analyzed. Key parameters such as density, phase fraction, and texture development were assessed to understand their role in optimizing mechanical performance.

Our findings highlight that proper W integration through refined mixing strategies significantly enhances the strength of Ti while maintaining balanced ductility. This study provides valuable insights into advancing LPBF processing for refractory metal additions to Ti, paving the way for enhanced mechanical performance through in-situ alloying and multi-metal fabrication in additive manufacturing.

Author: Jabir Hussain, Ahmed Fardan

Title: "Welding" the un-weldable: insights into PBF-LB processing of CM247LC

DOI: 10.5281/zenodo.15426059

Additive manufacturing (AM) of the non-weldable Ni-base superalloy CM247LC via powder bed fusion - laser beam (PBF-LB) is challenging due to the solidification cracking during PBF-LB processing and strain age cracking (SAC) during post-processing heat treatment. Solidification cracking stems from thermal stresses during melt pool solidification, while SAC is driven by  $\gamma'$  precipitation coupled with residual stresses from the PBF-LB process.

This study employed multi-faceted approaches to mitigate these issues. Initial optimization of laser parameters (power,

speed, hatch spacing) showed that low line energy density (<0.2 J/mm) and strong melt pool overlap (50-80%) reduced solidification cracking by promoting shallower melt pools. While lower volumetric energy density (VED) correlates with lower residual stresses, potentially alleviating SAC, it also increases lack-of-fusion porosity, necessitating alternative solutions for SAC. Electron Backscatter Diffraction (EBSD) identified that textured columnar grains reduce high-angle grain boundaries susceptible to solidification cracking.

Novel scan strategies were then explored. Reducing laser stripe width from 5 mm to 0.2 mm significantly lowered crack density by promoting texture and reducing residual stresses by 30%. A demonstrator component with 0.2 mm stripes successfully underwent post-build heat treatment without SAC, unlike components with conventional 5 mm stripes. In-situ remelting strategies also showed promise in minimizing solidification cracking but complex behavior of residual stresses.

Ongoing work investigates advanced scan strategies, such as laser beam shaping, for enhanced microstructure control to suppress both cracking forms. Results emphasize that processing CM247LC requires tailored approaches, distinct from weldable alloys, with grain structure and texture being crucial for defect mitigation. These insights offer a framework for advancing AM of crack-prone superalloys by balancing parameter optimization, scan strategy innovation, and microstructural engineering to produce robust, high-performance components.

Author: Jacques, Pascal J.

Title: Machine learning approach for the development of new  $\beta$ -metastable Ti alloys best-suited for additive manufacturing

DOI: 10.5281/zenodo.15313437

It is now well established that  $\beta$ -metastable titanium alloys exhibit improved mechanical properties owing to the simultaneous activation of Transformation-Induced Plasticity (TRIP) and Twinning-Induced Plasticity (TWIP) effects as plasticity mechanisms, resulting in a significant increase of both the hardening capacity and the resistance to plastic localization. The relationship between the alloy chemical composition and the activated plasticity mechanisms has been based for decades on the “d-electron design strategy” developed by Morinaga et al.

We have recently proposed a new machine-learning (ML) model that combines ab initio calculations and an experimental dataset to predict the activated plasticity mechanisms in  $\beta$ -Ti alloys more efficiently than the classical Bo- Md approach. This model was used to design new  $\beta$ -metastable Ti alloys that are well-suited for use in additive manufacturing, particularly in aerospace applications. The adequacy of the predictions was first validated in the cast and wrought state, by measuring the mechanical properties and characterizing the evolution of the microstructures with strain. The same grades were then tested using L-PBF after casting and atomization. Different profiles of properties (maximization of strength, of ductility, ...) were developed, exceeding the properties of the generic TA6V.

Author: Jamili, Amir Mohammad

Title: Hybrid additive manufacturing of Ti-Cu structures, combining powders with metallic foils

DOI: 10.5281/zenodo.15806850

Additive manufacturing has emerged as a promising method for fabricating multi-material metallic structures. Unlike conventional additive manufacturing techniques that rely on metallic powders, the use of metallic foils offers advantages such as altered cooling rates, and modified mixing behavior, all of which can significantly influence the resulting microstructures and properties. Due to its favorable thermal and electrical properties, copper-containing multi-material systems attract both academic and industrial interest. Combined with the excellent mechanical performance of titanium alloys, the fabrication of copper-titanium multi-material components presents a unique opportunity to achieve superior thermal and mechanical characteristics. In this study, a multi-material structure was fabricated using a combination of CuCrZr powder and Ti-6Al-4V foils. Unlike the cracked powder-powder sample, the defect-free powder-foil interface shows potential for forming deformable amorphous and ultra-fine intermetallic, depending on local thermodynamic conditions. Microstructural analysis, supported by in-situ XRD measurements, showed the presence of an amorphous TiCu phase at the interface, coexisting with copper-rich intermetallics such as  $\text{Cu}_2\text{Ti}$  and  $\text{Cu}_3\text{Ti}_2$ . Computational fluid dynamics correctly simulate the observed mixing patterns and confirmed that the foil-powder combination leads to a cooling rate as high as  $32500 \text{ K}\cdot\text{s}^{-1}$ . This rapid cooling, in combination with the local chemical compositions, promotes the formation of the amorphous TiCu phase. The characteristics and formation mechanisms of the nanoscale CuTi and  $\text{CuTi}_2$  intermetallics compounds were thoroughly investigated. Nanoindentation-based local mechanical testing finally demonstrated that the amorphous phase is ductile, which explains why the enhanced resistance to thermal shock and interfacial cracking. This study shows in the context of multi-material printing the advantages of using powders-foils for some alloys instead of powders-powder.

Author: Jhabvala, Jamasp

Title: Acoustic detection of phase transformation and crystallization for laser powder-bed fusion

DOI: 10.5281/zenodo.15423611

To ensure process stability and reproducibility in laser powder-bed fusion (LPBF), various in-situ and ex-situ monitoring techniques have been developed. Among the in-situ methods, optical and acoustic approaches are the most prominent. A key advantage of acoustic techniques over optical methods is their ability to detect internal part emissions, providing deeper insights into the material behavior.

In this work, we show examples of LPBF processing conditions in which acoustic emission indicated changes in microstructure. These include the occurrence of martensitic transformations in Ti-6Al-4V, and the formation of crystalline phases in Bulk Metallic Glasses (BMGs). To help in the interpretation of the acoustic signals, ground truth data was extracted from operando synchrotron X-ray diffraction experiments, and from Finite Element (FEM) thermal simulations.

Author: Jin, Xueze

Title: An Al-Zn alloy with outstanding processability by laser powder bed fusion

DOI: 10.5281/zenodo.15267629

Aluminum alloys— particularly Al-Zn alloys— are well known for their susceptibility to hot cracking during laser powder bed fusion (LPBF) processing. In this talk, we demonstrate that increasing the Zn content beyond previously explored limits can, contrary to expectations, result in a highly processable alloy. Specifically, the study focuses on the LPBF processing window of an Al-20Zn-0.1Cr (wt.%) alloy. We show that dense, crack-free, and isotropic polycrystalline microstructures can be achieved across a broad range of volumetric energy density (VED) conditions.

The formation of these crack-free and isotropic microstructures is attributed to the pronounced segregation of Zn solutes and pure Zn particles at grain and cell boundaries, which effectively bridge Al dendrites during solidification. Additionally, the presence of Zn/Cr nanoparticles within grain interiors further contributes to grain boundary pinning. This pinning effect remains significant even under high VED conditions, as the residual Zn content— despite some evaporation during processing— still far exceeds its room-temperature solubility.

Overall, this talk introduces new pathways for designing Al-Zn alloys with enhanced processability via LPBF.

Author: Jin, Zhengyi

Title: A novel medium-carbon steel adapted to laser powder bed fusion: microstructure, mechanical and wear properties

DOI: 10.5281/zenodo.15304096

Laser powder bed fusion (PBF-LB/M), one widely used metal additive manufacturing (AM) technology, enables the layer-by-layer fabrication of components with complex geometries. Therefore, this versatile manufacturing method is particularly well-suited for tooling applications with their intricate shape, such as cooling channels. However, the PBF-LB/M fabrication of medium and high carbon steels used for tooling is challenging, due to evolving residual stresses eventually leading to pronounced cracking. Residual stresses primarily arise from the thermal contraction inherent to the PBF-LB/M process (repeated heating-cooling cycles) and for tool steels additionally from the austenite-to-martensite transformation.

In this study, we present a novel high-strength medium-carbon tool steel adapted to PBF-LB/M, which can be processed into crack-free and highly dense parts (99.7%) without pre-heating the substrate plate. The as-built microstructure of the steel consists mainly of martensite and residual austenite, whereby residual austenite is transformed to martensite during loading. The resulting transformation induced plasticity (TRIP) effect causes strong work-hardening behavior. This is one reason why the PBF-LB/M fabricated steel shows good mechanical properties with a yield strength of  $1317 \pm 69$  MPa and an ultimate compressive strength of  $2061 \pm 13$  MPa. Despite the lower macrohardness, the PBF-LB/M fabricated steel shows a significantly higher wear resistance than the H11 reference steel in dry abrasive wear testing.

Author: Jo, Haeju

Title: Characterization of microstructure and mechanical properties of L-DED processed Ni-Al alloy with different Ni/Al ratios for design of Ni-Al functionally graded materials

DOI: 10.5281/zenodo.15208664

Ni-Al bimetallic structures, which combine the excellent high-temperature mechanical properties of Ni-based alloys and the light-weight of Al-based alloys, exhibit significant potential for applications in aerospace, automotive, and defense-related industries. However, differences in the coefficients of thermal expansion and the formation of intermetallic phases between the two alloys impair stable interfacial bonding and structural integrity. While welding and cladding processes have been extensively applied to address these issues, their applicability is limited when fabricating intricate geometries.

To overcome these challenges, the laser-directed energy deposition (L-DED) process was introduced. This technique enables the simultaneous deposition of different metal powders at specified ratios, allowing for the fabrication of functionally graded materials (FGMs) with gradually varying mixing ratios. In this study, this capability of L-DED was utilized with ultimate goal of fabricating Ni-Al FGM structures.

Understanding the microstructure and mechanical properties of L-DED samples at each specific powder mixing ratio is essential for optimizing the graded design of FGMs. Accordingly, Inconel 625 and Al-10Si-1Mg powders were deposited at various mass ratios, and appropriate process parameters like laser power, scanning speed and dwell time were selected considering thermal stability. The resulting microstructures and mechanical properties were analyzed to establish foundational data for the optimized design of Ni-Al FGM structures.

Author: Jung, Jongwook

Title: Effect of microstructure on the shape memory effect of Fe-17Mn-10Cr-4Ni (wt.%) alloy fabricated by L-DED

DOI: 10.5281/zenodo.15259951

Fe-based shape memory alloys (SMA) are gaining attention as a potential low-cost alternative to Ni-Ti alloys, particularly for applications in construction and actuation systems. In Fe-based SMAs, shape memory effect (SME) is significantly influenced by microstructural features, including dislocations, precipitates, and grain morphology and texture. Unique microstructural features inherited from laser direct energy deposition (L-DED) process may have the potential to enhance the SME of the Fe-based SMA. In this study, microstructure and shape memory properties of Fe-17Mn-10Cr-5Si-4Ni (wt.%) fabricated by the L-DED process were investigated.

Fe-17Mn-10Cr-5Si-4Ni (wt.%) SMA produced by L-DED under various volumetric energy density (VED) conditions were investigated. SME of Fe-based SMAs is known to be based on the  $\gamma$ -FCC to  $\varepsilon$ -HCP phase transformation. However, rapid-solidification rate of L-DED process may lead to the formation of the  $\delta$ -BCC phase, which does not involve on the  $\gamma$ -FCC to  $\varepsilon$ -HCP phase transformation. To suppress the formation of undesired  $\delta$ -BCC phases, phase fractions of the alloy produced under different VED conditions were analyzed. Tensile and bending tests for evaluating mechanical properties and SME were conducted along both L-DED building and scanning directions aiming to examine anisotropic mechanical properties and the SME. It was found that the solidification cell structures occurred by the rapid-solidification rate of the L-Ded could significantly enhance the SME, probably because the cell boundaries could act as back-stress sites that could enhance the reverse phase transformation from  $\varepsilon$ -HCP to  $\gamma$ -FCC.

Author: Jung, Jongwook

Title: Effect of process parameters on microstructure and shape memory properties of Fe-17Mn-5Si-4Ni-1VN alloys fabricated by L-DED

DOI: 10.5281/zenodo.15300341

In this study, Fe-17Mn-5Si-10Cr-4Ni-1VN alloys were fabricated by L-DED. The alloys were fabricated under a constant volumetric energy density with various process parameters, while systematically varying laser power and scan speed. The influence of the process parameters on microstructure, mechanical properties, and SME was comprehensively evaluated.

Author: Kalicki, Bartosz

Title: powder2POWDER: a new opportunity for alloy development and powder upcycling

DOI: 10.5281/zenodo.15424061

Developing novel alloy compositions is a challenging task, particularly when the final product must be in the form of spherical metal powders containing reactive elements such as Ni or Ti. In most cases, a new alloy requires homogenization before undergoing expensive atomization processes. Preparing homogenized feedstock can be even more costly than atomization itself, especially when a specialized feedstock form is needed for processing reactive alloys, as in EIGA processes.

Ultrasonic atomization offers a more flexible approach, enabling the processing of reactive materials without requiring specific feedstock shapes. However, for custom alloys, significant time is still required to prepare feedstock using arc or induction melting. This presentation will explore an alternative approach: producing spherical alloy powders directly from powder blends using ultrasonic atomization combined with the powder2POWDER (P2P) module. This module integrates powder feeding directly with the system's plasma torch, enabling continuous powder processing.

The presentation will focus on case studies involving reactive Ti-based alloys, such as TiMo and TiNbZrTa systems. Powder morphology, particle size distribution, and chemical composition will be characterized before and after P2P processing. Based on these case studies, initial guidelines will be proposed for blending powders to achieve homogeneous, spherical powders suitable for additive manufacturing processes.

Author: Kim, Minki

Title: Effect of Hf and Ce Additions on Microstructure and Mechanical Properties of Direct Energy Deposited High Manganese Steel

DOI: 10.5281/zenodo.15253875

Additive manufacturing (AM) is a layer-by-layer fabrication method that enables the manufacturing of components of complex 3D shapes while minimizing material waste. Among various AM techniques, Laser Direct Energy Deposition (L-DED) is a metal additive manufacturing process in which metal powder and a high-energy laser are simultaneously delivered to form a deposited structure. On the other hand, High-manganese steels (HMnS) are known for their excellent tensile strength, ductility, and high work-hardening capability. However, their high Mn content leads to segregation during casting, thereby reducing hot workability. The rapid cooling rates associated with the L-DED process have been reported to mitigate segregation issues, making it a promising approach for processing HMnS. Recently, it was shown that HMnS could be successfully fabricated by L-DED process. Although near defect-free alloy could be fabricated, the as-deposited alloys exhibited coarser grain sizes compared to conventionally processed HMnS steels which was produced by rolling, resulting in relatively low yield strength and elongation. On the other hand, hafnium (Hf) and cerium (Ce) are commonly known as grain refinement elements in cast steel and iron due to their ability to form fine oxides that can act as nucleation sites. In this study, Fe-10Hf and Fe-10Ce (wt.%) powders were mixed with Fe-24Mn-4Cr-0.4C (wt.%) base powder at a ratio of 99.5:0.5 to achieve target compositions of Fe-24Mn-4Cr-0.4C-0.05Hf and Fe-24Mn-4Cr-0.4C-0.05Ce (wt.%) in the final L-DED processed alloys. Using these mixed powders, L-DED was carried out and the resulted alloys were examined to assess the influence of Hf and Ce additions on the microstructure and mechanical properties of the high-manganese steel produced by the L-DED.

Author: Kong, Zichen

Title: Thermohydraulic modelling of the WLAM process - Application to the prediction of grain structure development on Inconel alloys

DOI: 10.5281/zenodo.15161090

The Wire Laser Additive Manufacturing (WLAM) process produces components with an excellent quality finish and a high degree of precision. A laser heat source is applied onto a metal filler wire used as feedstock, leading to its progressive melting. The bead is then continuously deposited using an appropriate building strategy. Initially, the wire was inserted laterally, leading to some limitations. In a recent breakthrough, this wire is introduced at the center of several laser beams regularly distributed offering advantages in process control with regard to bead dilution, microstructure development and part geometry, notably when processing complex shapes. Nevertheless, this evolution also leads to major challenges as complex conditions in energy deposition are encountered, affecting temperature fields and fluid flows with influences on grain structure.

An approach to model heat transfer, fluid flow and microstructure formation in WLAM is proposed providing means to control the manufacturing process. The three-beam WLAM configuration is addressed, where the primary laser light is divided into equivalent beams which converge to the wire prior its plunging. This numerical modeling is conducted in a level set framework, using periodic adaptive remeshing of the finite elements (FE) mesh. A novel approach is implemented, defining a volume source domain, where an imposed velocity field is applied to mimic the feeding effect onto the flow rate. Similarly, the energy conservation equation accounts for the prior wire heating stage. As a complementary part, a cellular automaton (CA) method coupled with temperature resolution, predict microstructure development by epitaxial grain growth. This CA-FE methodology is applied to the single-track deposition of an IN718 bead before tackling the case of multi-pass depositions. The influence of process parameters on temperature field, melt pool and grain structure is discussed. In addition, a validation is proposed based on comparisons of simulations results with experimental observations.

Author: Le Bas, William

Title: Mechanical characterisation of aluminium alloys manufactured by direct liquid metal deposition

DOI: 10.5281/zenodo.15294652

Additive manufacturing technologies for metals use high power intensity sources such as lasers, electron beams, or wire arcs to melt and fuse metal powders or wires. This results in high energy consumption, especially for aluminium alloys, as they are highly reflective and complex melt pool dynamics which lead to stochastic formation of defects.

Direct Liquid Metal Deposition (DLMD) is being developed as an alternative additive manufacturing technology. DLMD uses a metallic wire which is fed into a heated nozzle wherein it is fully melted and then deposited on a moving build plate. Subsequent layers can then be deposited on top of each other building up the part. The aluminium oxide stabilises the flow of liquid metal allowing it to be deposited continuously on the build plate.

In this talk, the design and the challenges of a DLMD apparatus and its application to the manufacturing of aluminum alloys will be presented.

Walls of eutectic AlSi12 were manufactured using DLMD and characterised by tensile testing and microstructural

analysis. In the build direction the average ultimate tensile stress of the printed parts was  $171.5 \pm 5$  MPa and elongation was  $17.0 \pm 8$  % and perpendicular to the build direction was  $174.5 \pm 7$  MPa and elongation was  $14.1 \pm 8$ %. The mechanical properties are seemingly isotropic, implying that there is complete bonding between deposited layers, and that the impact of the intermediary oxide layer, which might drive brittle failure of the material along the build direction, is minimal. Fractography was then performed to highlight the damage mechanism and the influence of defects introduced during the process.

Author: Lee, Wookjin

Title: Microstructure and mechanical properties of aluminum lattice structures fabricated via 3D printing-based investment casting

DOI: 10.5281/zenodo.15259804

Metallic lattice structures show broad application prospects in aerospace, automotive, biomedical, and other various high-performance engineering fields due to their excellent structural characteristics such as high specific strength, stiffness, and energy absorption capacity. However, their complex geometries present significant challenges for making them with conventional casting or machining processes. To overcome such limitations, a 3D printing-based investment casting process is developed and demonstrated in this study. The process involves the fabrication of a high-precision sacrificial pattern via 3D printing, followed by making mold to cast metal, allowing for accurate reproduction of complex 3D internal structures of lattice structures.

In this study, the 3D printing-based investment casting process was utilized to fabricate aluminum lattice structures. A high-resolution sacrificial pattern was designed and fabricated through a digital light processing method. After fixing the pattern within the mold, a plaster was cast and hardened to form the shell mold. Then, the sacrificial pattern was burned out, leaving a cavity for metal casting. Subsequently, molten AlSi7Mg aluminum alloy was vacuum infiltrated into the cavity using Ar gas with 1 atm pressure, followed by vacuum casting. The lattice structures were designed in a body-centered cubic forms with different lattice unit cell sizes and strut thicknesses. The effects of lattice unit cell size and strut thickness on the microstructure, local and overall mechanical properties were investigated.

Author: Leonardi, Selma

Title: Microstructure and micromechanical properties of microcellular AlSi10Mg produced by LPBF

DOI: 10.5281/zenodo.15294684

In this work, the microstructure and micromechanical properties of a microcellular AlSi10Mg alloy produced by Laser Powder Bed Fusion (LPBF) are studied. Notably, the investigated material contains random distributions of cylindrical pores up to 20 % in volume, whose arrangement and geometry are generated numerically by a Random Sequential Absorption (RSA) algorithm prior to LPBF fabrication. In particular, the geometric pores have circular shape and their average size is around 400  $\mu\text{m}$ . They are manufactured using a general contour-hatch strategy.

The influence of the LPBF scanning process is thoroughly investigated in this study. In particular, the effect of the contour scanning on the resulting alloy microstructure is examined, using both scanning electron microscopy (SEM) (combined with EBSD analysis) and nanoindentation testing. It is shown that the different scanning sequences (i.e., contour and hatching) lead to different grain morphologies and crystallographic textures, and result in highly heterogeneous micromechanical properties (nano-hardness)

Finally, the results of the microstructural analysis on the as-built AlSi10Mg microcellular alloy are compared against those obtained on the same alloy after conventional T6-like heat-treatment, highlighting the beneficial effect of heat-treatments in mitigating microstructural heterogeneity.

Author: Lupi, Giorgia

Title: Unforeseen precipitation sequences in ex-situ/in-situ TiB<sub>2</sub>-reinforced Al2618 composites manufactured by PBF-LB/M

DOI: 10.5281/zenodo.15298115

Wrought aluminum alloys are of particular interest for powder-based additive manufacturing (AM) such as laser powder-bed fusion (LPBF), but many of them suffer from poor manufacturability due to their hot-cracking susceptibility. One strategy to address this challenge is slightly modifying the alloy composition of the powders by introducing alloying elements such as Ti and B to form TiB<sub>2</sub> particles. These particles not only reduce hot-cracking susceptibility but also enhance elastic modulus and strength of the material. However, the amount of TiB<sub>2</sub> that can be introduced in situ into the powder is limited by the reaction between B and Ti in the molten metal. An alternative is the ex-situ addition of TiB<sub>2</sub> to the powder. In this work, a hybrid approach has been developed to produce a novel TiB<sub>2</sub> reinforced Al2618 composite powder by combining the beneficial effects of both the composite production methods. More specifically, it offers the opportunity to refine grains via the in-situ addition of Ti and B in gas-atomized powder and the possibility to add high percentage of TiB<sub>2</sub> by the ex-situ methods to target high elastic modulus/strength. Subsequently, the composite

powder was processed by LPBF, followed by T5 and T6 heat-treatments. Microstructural analysis revealed deviations from the typical precipitation sequence of Al2618, attributed to the excess of Ti in the pre-alloyed powder. T5 heat-treatment promoted the formation of Al<sub>3</sub>Ti and S' precipitates at cell boundaries. T6 heat-treatment resulted in Ti-Si-rich phases forming needle structures arranged in a corona-like pattern and Al-Mg-Ti particles that inhibit the precipitation of the S' phase. The T5 condition exhibited high strength, while the T6 condition demonstrated the lowest coefficient of thermal expansion and highest thermal conductivity. The combined in-situ/ex-situ strategy led to a notable increase in elastic modulus and strength compared to conventional Al2618, while maintaining satisfactory ductility and fracture toughness.

Author: Madrid, Claudio

Title: Blue Laser Directed Energy Deposition of a CuCrZr Alloy: Effect of Process Parameters on the microstructure

DOI: 10.5281/zenodo.15313227

CuCrZr is a commercial high-performance copper alloy valued for its combination of excellent thermal and electrical conductivity, corrosion resistance and working temperature resistance up to 400°C. This makes it suitable for key applications in aerospace, automotive or energy. However, laser-based additive manufacturing of copper alloys remains challenging due to their high reflectivity and thermal conductivity, which may result in poor laser absorption, unstable melt pool behavior as well as difficulties in achieving fully-dense parts and controlling the microstructure. Aiming at overcoming these limitations, this study investigates the optimization of processing windows in blue laser-wire directed energy deposition (LW-DED). Owing to its short wavelength, the blue laser offers about 13 times more absorption in copper than the traditional infrared laser (IR) permitting more stable deposition conditions and enhanced process efficiency. LW-DED permits fabricating near-net shape components of medium up to large sizes as well as the reparation of end-of-life parts for a circular production. Nevertheless, the high thermal conductivity of CuCrZr leads to rapid heat dissipation during deposition which makes challenging its processing. Consequently, lack of fusion as well as anisotropic or coarse microstructures may be obtained. This study focuses on the influence of the blue laser DED strategy on melt pool behavior, porosity and microstructure development in order to optimize the processing window. For this purpose, conventional lab characterization combining microscopy and mechanical characterization is employed together with advanced high-energy synchrotron X-ray diffraction. The latter allows for detailed examination of the phases within the bulk and a time-resolved study of the microstructural evolution during mechanical loading.

Author: Marola, Silvia

Title: Insights on Interface Features in 3D-Printed Multi-materials

DOI: 10.5281/zenodo.15309464

Multi-material components, integrating the properties of different materials within a single product, represent a major innovation in Additive Manufacturing (AM). The multi-material approach exploits the unique characteristics of each material to enhance performance aspects such as mechanical strength, weight reduction, corrosion resistance, and thermal or electrical conductivity. However, integrating different metal alloys through AM remains challenging due to substantial differences in physical and metallurgical properties, which can compromise the quality and durability of multi-material interfaces. The study of interfaces in additively manufactured multi-material structures becomes thus crucial for understanding the mechanical, thermal, and chemical performance of the final component.

This research aims to investigate the interfacial bonding mechanisms, defect formation, and property gradients that arise in additively manufactured multi-material samples obtained by coupling Ni-based, and Cu-based alloys using PBF-LB/M processes. Employing advanced characterization techniques (FEG-SEM, XRD, micro and nanoindentation and FEG-SEM in-situ tensile tests) coupled with CALPHAD-based simulations, the microstructural features and mechanical integrity of the interfacial regions were assessed. Results indicate that material properties and interface adhesion are influenced by printing parameters, deposition sequence of the alloys, intermixing effects at the interface region. Post-printing annealing treatments were evaluated to assess opportunities for thermal-stress relaxation.

This study contributes to the development of high-performance multi-material AM components for applications ranging from automotive to aerospace, electronics, and medical devices.

Author: Matteo, Seita

Title: A 3D analysis of the microstructural interfaces in "meta polycrystals"

DOI: 10.5281/zenodo.15283896

Metal additive technologies such as laser powder bed fusion (LPBF) enable the manufacture of materials with site-specific microstructures. This capability offers new opportunities to design metal alloys with tailored mechanical properties and improved performance. Using stainless steel 316L as a case-study material, we produce samples with site-specific crystallographic textures by manipulating the local solidification conditions across the build. We use this strategy to design "meta polycrystals" that comprise different quasi-single crystal blocks with controlled shape, size,

and crystal orientation. In an effort to interpret the mechanical response of these materials, we study the interfaces between the quasi-single crystal blocks using 3D electron backscatter diffraction. Our results shed light into the solidification mechanisms at play during LPBF and the unique mechanical response of our “meta polycrystals”.

Author: Mehrpouya, Mehrshad

Title: Microstructural grading for tuning of the functional behavior of LPBF printed NiTi-based SMAs

DOI: 10.5281/zenodo.15313323

Shape memory alloys (SMAs) have captured significant attention since their discovery, primarily due to their remarkable ability to recover large strains and exhibit the pseudo-elasticity effect. They are a group of smart materials, where their prominence stems from NiTi's exceptional properties, including high corrosion resistance, excellent ductility, customizable martensitic transformation pathways, strong work-hardening capability, and impressive shape recovery performance. On a parallel level, the advent of additive manufacturing (AM) has opened new avenues for NiTi, with laser powder bed fusion (LPBF) emerging as the most promising AM technique for fabricating highly intricate structures. Over the past decade, significant research efforts have focused on optimizing LPBF processing parameters and controlling the composition and microstructure of NiTi SMA alloys. Nevertheless, NiTi-based alloys remain challenging due to various reasons including their compositional sensitivity, and the dependency of the functionality on the transformation temperature and stress intervals. Therefore it is of great importance to control this transformation and further tune it to achieve highest functionality of the part. In this regard, microstructural and compositional grading stands out as a method for achieving progressive movement and wider temperature/ stress windows for the martensitic transformation. To achieve this, optimization of process parameters such as laser power, scanning speed, and Re-melting can create such grading in the functionality of NiTi-based alloys. In this work, state-of-the-art powder bed fusion machine equipped with laser beam (PBF-LB) was used to print Ni-rich NiTi-based powder at 55.8 at.% of Ni. There were three sets of process parameters utilized for the production of functional wires that has two-state activation achieved through optimization of the martensitic transformation. The results provide insight into the capabilities of powder bed fusion in achieving grading in the behaviour of different sections of different parts through customizing the respective microstructural features.

Author: Mehta, Bharat

Title: Alloy Design for Improved Precipitation Hardening in Additively Manufactured Al-Alloys

DOI: 10.5281/zenodo.15260347

The powder bed fusion-laser beam (PBF-LB) process generates higher thermal gradients and solidification rates compared to conventional casting, leading to greater solute supersaturation and finer microstructures in Al-alloys, particularly for transition series elements. This enhanced supersaturation can be analyzed using the Scheil solidification model with solute trapping in Thermo-Calc software. This study examines the benefits of increased Zr supersaturation as an alloying element by comparing cast and additively manufactured (AM) samples, where AM samples exhibited a threefold increase in Zr solubility. This higher solubility enhances precipitation hardening, doubling the strengthening effect due to fine  $L1_2$   $Al_3Zr$  nanoprecipitates. The precipitation kinetics and resulting strengthening were accurately modeled using TC-PRISMA and validated against experimental results from Al-Mg-Zr and Al-Mn-Cr-Zr systems. These findings underscore the significance of rapid solidification in designing novel, precipitation-hardened Al-alloys.

Author: Mirzabeigi, Narges

Title: Enhanced As-Built Microstructure and Residual Stress Characteristics of IN718 Processed via Laser-Based Powder Bed Fusion with Laser Beam Shaping

DOI: 10.5281/zenodo.15309178

Beam shaping technology holds great potential for improving productivity, minimizing spatter formation, and controlling melt pool morphology in laser-based powder bed fusion of metals (PBF-LB/M) by modifying the laser intensity profile from the conventional Gaussian distribution. This adjustment affects key microstructural features such as grain size, shape, and orientation, which influence mechanical properties like tensile strength and anisotropy. Simulations show that changing the laser intensity profile modifies the thermal gradient in the melt pool, thereby altering grain growth. Since both the thermal gradient and the resulting microstructure are linked to residual stress in the final part, beam shaping could be a useful tool for managing as-built residual stress. However, the connection between beam shaping and residual stress has only been briefly studied, leaving a significant opportunity for further research.

In this study, we investigate two rotational symmetric laser beam profiles– Gaussian and Ring– and one axially asymmetric, simulation-optimized profile designed to achieve a uniform melt pool temperature, referred to as the chair-shaped beam. All beam profiles have a diameter of 250  $\mu\text{m}$ , measured using the second-moment method. The selected process parameters result in build rates between 11.2 and 14.4  $\text{mm}^3/\text{s}$ , with porosity levels kept below 1%.

Extensive microstructural and residual stress analyses were carried out. Microstructural characterization of the as-built volumetric parts was performed using optical microscopy and electron backscatter diffraction (EBSD). To qualitatively assess residual stress and deformation, double-sided cantilever specimens were fabricated. Quantitative residual stress measurements were obtained using the hole-drilling method on samples processed with selected parameter sets. Furthermore, melt pool temperature behavior was monitored in situ using a custom-developed on-axis Multi-Spectral Imaging system. The results reveal variations in grain orientation, size, and morphology, along with a significant difference, up to 15 %, in the measured von Mises residual stress among samples produced with different laser beam profiles.

Author: Mishurova, Tatiana

Title: Characterization of additively manufactured parts by high-flux MetalJet X-ray sources

DOI: 10.5281/zenodo.15422495

Additively manufactured (AM) parts require a large effort for the understanding of their complex microstructures and geometries. Also, often AM is associated with high residual stress in the parts, evaluation of each is a particular challenge. The main disadvantage of X-ray diffraction (XRD) analysis with conventional laboratory sources lies in their low photon flux, which leads to long measurement times, especially in the investigation of polycrystalline materials. Fast in-situ analyses, the examination of large sample series or of components with complex geometry are therefore usually reserved for measuring stations at synchrotron sources, but their availability is limited. Powerful laboratory high-flux sources such as rotating anode tubes or liquid metal anode (MetalJet) are an alternative in this respect. MetalJet measuring stations of the HZB are equipped with various zero and two-dimensional detectors, enabling in-situ and ex-situ measurements with different sample environments in the angle- and energy-dispersive diffraction mode, as well as simultaneous diffraction and imaging experiments. The XRD setup allows non-destructive, depth-resolved structural and residual stress analysis, while the imaging setup enables detection of defects and geometrical features of the parts. The potential of these measuring stations for research on AM materials and components is demonstrated through various experimental examples.

Author: Moutablaleh, Hadi

Title: Multimaterial Laser Powder Bed Fusion of Ti6Al4V and NiTi Components

DOI: 10.5281/zenodo.15197253

Laser Powder Bed Fusion (LPBF) is the most widely adopted additive manufacturing technique in the industry for producing high-quality, complex metallic components. Recent advancements in powder deposition techniques have enabled the use of LPBF for producing multi-metal parts. Among the materials of interest, titanium-based alloys such as Ti6Al4V exhibit properties that make them particularly suitable for aerospace and medical applications. When combined with shape memory alloys (SMAs) like NiTi, the resulting hybrid components can exhibit enhanced mechanical performance and multifunctionality. For instance, this hybrid component can be applied in Co-based hip implants, where the integration of NiTi can mitigate the detrimental stress-shielding effect through its superelastic behavior. In this study, Ti6Al4V and NiTi alloys are processed together using an Aconity Midi+ LPBF system equipped with an Aerosint multi-powder recoater capable of precisely depositing up to three different powders per layer. The primary challenge lies in ensuring interface integrity and managing the interdiffusion between the two materials during fabrication. The effect of the applied volumetric energy density (VED) on the microstructural and mechanical properties of the diffusion zone is investigated. Also, the local superelastic behavior of the component is characterized. The results offer valuable insight into the development of multimaterial NiTi–Ti6Al4V components with minimal interfacial defects, enabling their potential use in diverse industrial applications.

Author: Niendorf, Thomas

Title: Prospects and challenges in additive manufacturing of shape memory alloys

DOI: 10.5281/zenodo.15300530

Shape memory alloys (SMAs) are characterized by unique properties stemming from a fully reversible phase transformation between a high-temperature austenitic phase and a low-temperature martensitic phase. Depending on the alloy composition and the actual loading condition, specific effects can be exploited: the shape memory effects and superelasticity. Conventionally processed SMAs are used in numerous applications, however, SMAs processed by any kind of additive manufacturing (AM) technique still suffer roadblocks toward application.

The present paper highlights most important findings elaborated in recent years. Focus will not only be on the general processability of SMAs in AM, but also on apt microstructure design and functional/structural degradation. Here, it will be shown that the unique characteristics of AM are beneficial to obtain highly anisotropic microstructures that are desired for superior shape memory properties. At the same time gradient microstructures can be established paving the way toward novel actuator designs. Based on the results presented, future prospects and prevailing challenges, respectively, will be thoroughly discussed.

Author: Nothomb, Nicolas

Title: Dissimilar friction stir welds of L-PBF Zr-modified Al7075 and wrought Al7075 and improvements of L-PBF Zr-modified Al7075 using pre-alloyed powder

DOI: 10.5281/zenodo.15301270

With Scalmalloy®, A20XTM and other new commercial high strength aluminium alloys, the peculiar trend for new Al alloys specifically designed for L-PBF is currently evolving at a rapid pace. However, 7xxx series aluminium alloys are not in the spotlight due to their L-PBF processing difficulties, especially Zn and Mg evaporation. However, 7xxx alloys present a huge potential for reaching even higher strength after L-PBF processing compared to commercial alloys. Furthermore, 7xxx alloys are widely used in the aerospace sector in their wrought form making them interesting candidates to build additive manufacturing parts in this field.

Our study is based on preliminary results on a Zr-modified Al7075 alloy obtained by powder mix and processed by L-PBF. After a careful process optimisation, a relative density of 99.9% was achieved, along with an exceptional 515 MPa yield strength following the application of a tailored post-L-PBF heat treatment. In this work, two different related topics are explored.

Firstly, the friction stir welding (FSW) of L-PBF Zr-modified Al7075 with wrought Al7075 is analysed in depth. Usually, welding of L-PBF manufactured alloys with wrought parts by classical fusion welding techniques causes unacceptably large porosities. There is thus a real need to make sound reliable dissimilar welds, what will be done by FSW in this work. Welding L-PBF Zr-modified Al7075 to wrought Al7075 parts is indeed required for industrial applications. Static mechanical behaviour of these FSW welds were obtained and analysed using Digital Image Correlation (DIC) technique. Secondly, preliminary results show the improvement of the Al7075+1.8%Zr alloy will be discussed. The improvement is obtained by pre-alloying the powder itself and by compensating the Zn and Mg losses during L-PBF. The characterization of the new improved alloy has led to a hardness above 200HV, significantly higher than wrought 7075 T6 material.

Author: Novotny, Tobias

Title: Improving Microstructure Uniformity in Complex Inconel 718 and AlSi10Mg Geometries with PBF-LB/M Feedback Loop Control

DOI: 10.5281/zenodo.15308670

In laser-based powder bed fusion of metals (PBF-LB/M), the part geometry influences the heat dissipation from the process zone and the cooling time between layers. Restricted heat flow and short layer times lead to local overheating and corresponding variations in microstructures. To achieve consistent microstructures in complex parts, the process parameters need to be adjusted dynamically based on the thermal conditions.

In this study, near infrared (NIR) process emissions are monitored by an off-axis camera (EOS Exposure OT) and a feedback loop control system (Smart Fusion) is employed to correct deviations by adjusting laser power accordingly. Through a pixelwise comparison of the gray values measured in the last layer with a specified target, the controller computes a locally corrected laser power for the next layer.

To investigate the effect of this closed loop control on microstructure formation, geometries prone to overheating are manufactured from Inconel 718 and AlSi10Mg. Differences in gray value profiles between the two materials and between the open loop and closed loop processes are analyzed. The controlled processes show a consistent thermal profile over the build height while overheating is found in the uncontrolled state. Porosity, microstructure and hardness in the open loop and closed loop conditions are compared. Microstructures are analyzed by means of optical microscopy, scanning electron microscopy and electron backscatter diffraction (EBSD). In the open loop condition, a significant hardness increase indicative of in-situ precipitation is measured in Inconel 718 samples. In contrast, hardness is reduced in the overheated AlSi10Mg owing to the partially dissolved Si-rich network. In both materials, the feedback loop control leads to more homogenous microstructures and hardness profiles.

Author: Özsoy, Andaç

Title: Deconvoluting cracking mechanisms in fusion processing of steel-copper multi-materials

DOI: 10.5281/zenodo.15261380

This study investigates various cracking mechanisms and their prevalence in fusion processing of steel-copper multi-materials using operando X-ray diffraction and imaging during laser powder-bed fusion (LPBF) of 316L-CuCrZr multi-material. Operando X-ray imaging helped identify three main types of cracking: (i) solidification cracking, (ii) metal-induced embrittlement (MIE), and (iii) liquation cracking. All cracking types are closely related to the phase formation during processing, leading to two underlying mechanisms. First, liquid-liquid phase separation (LLPS) and the monotectic reaction in the 316L-CuCrZr system lead to the formation of Cu-rich and Fe-rich liquids with vastly different solidification ranges, causing solidification cracking at the melt pool centers. Second, LLPS and the monotectic reaction distribute the Cu-rich liquid uniformly between the Fe-rich dendrites, leading to MIE and/or liquation cracking. X-ray computed tomography indicated that smaller but more frequent cracks form due to MIE/liquation cracking compared

to solidification cracking. Further experiments showed that by avoiding phase separation via process adjustments, cracking can be drastically reduced. However, the complete elimination of cracking necessitates chemical alterations of the material feedstock, as observed in the crack-free examples in the literature. These findings serve as a guideline for understanding the underlying reasons of cracking in steel-copper multi-materials and optimizing processing to effectively mitigate cracking, while also quantifying the extent to which these adjustments can achieve this outcome.

Author: Sonawane, Akash

Title: Process modelling & heat treatment simulations of Scalmalloy® fabricated by laser powder bed fusion (L-PBF)

DOI: 10.5281/zenodo.15310932

Standard-Scalmalloy® (Al-4.5Mg-0.75Sc-0.35Zr-0.45Mn) produced via laser powder bed fusion (L-PBF) has proved to be a game changer due to its bimodal microstructure combined with nano Al<sub>3</sub>(Sc,Zr) precipitates giving high mechanical properties along with good ductility [1]. In addition to these exceptional static strength properties, D. Schimbäck et al [2] fabricated Scalmalloy® with high fatigue properties by controlling melt puddle dynamics. Despite these advantages (static & fatigue), the implementation of 3D-printed Scalmalloy® for aerospace application is challenged due to the time / cost associated with the laser powder bed fusion and post processing, for example:

As-built: low built rates ~30cm<sup>3</sup>/hr, porosity due to keyhole melting, lack-of-fusion microstructure imperfections, evaporation of volatile elements like Magnesium.

Post built - heat treatment (HT) at 325°C for 4hr or alternatively Argon medium based hot isostatic pressing (HIP) heat treatment (at 325°C for 4hr [3])

This lack of in-depth understanding of the root causes of low built rates, keyhole porosity formation is an impediment for designing Scalmalloy® engineering parts for safety-critical applications in aerospace, mainly fatigue driven. The approach proposed in this study aims to identify the high built rate conditions for Scalmalloy® by understanding the underlying melt pool dynamics using multiphysics simulations coupled with thermodynamics. First, the solidification path of the Scalmalloy® is calculated relying on the Scheil-Gulliver assumption taking into account the solute trapping that is representative of high cooling rates of L-PBF. Second, the intrinsic material properties like thermal conductivity, dynamic viscosity, surface tensions, evaporation enthalpy are computed using Thermocalc® as a function of temperature. Finally, a multi phase Volume of fluid (VoF) framework is proposed, taking inputs from thermodynamics, for computationally deriving correlations between process-induced melt pool physics and LPBF process parameters. The model links process parameters to temperature-time profile, solidification conditions and identifies conditions that cause lack-of-fusion defects, melt- and solidification-induced voids, as well keyhole porosity formation.

Similarly to tackle the expensive and time consuming post processing, an innovative accelerated liquid-medium heat treatment (LHT) is also proposed. This is done via post process precipitation simulation that deals with identifying the HT parameters that try to predict how to maintain the Al<sub>3</sub>(Sc, Zr) precipitates density and size distribution while shortening the HT sequence tremendously by a factor > 10 (i.e. 15 min. instead of 240 min). This involves use of thermo-metallurgical precipitation model and strengthening model to estimate the corresponding increase in static mechanical properties post LHT. The outcomes of the LHT simulations can in principle be transferred (further developed) to other interesting Aluminum alloys fabricated by LPBF, thereby reducing the post fabrication efforts.

Author: Steinmeier, Paul

Title: In-situ alloying of Ti-6Al-7Nb with copper using laser powder bed fusion for enhanced biocompatibility in permanent implants

DOI: 10.5281/zenodo.15308098

Laser Powder Bed Fusion (L-PBF) enables the development of novel materials through in-situ alloying directly from elemental or mixed powders, which presents a significant advantage in the development of new alloys.

However, in-situ alloying presents element-specific difficulties, such as different melting points and the tendency to form brittle phases due to incomplete mixing. These challenges can be overcome by optimising the particle size distribution of the starting powders and by using multiple exposures in the process, resulting in better mixing and a finer microstructure. In addition, to achieve dense bulk materials and reduce edge effects, it is necessary to adjust process parameters such as laser power, scan speed and hatch distance for the powder mixtures. Research has shown that the in-situ alloying of Ti-6Al-7Nb and copper results in a significantly refined microstructure and improved mechanical properties compared to the base material. Furthermore, this alloy system combines the proven biocompatibility and mechanical reliability of Ti-6Al-7Nb with the known antibacterial properties of copper, offering a promising alternative to Ti-6Al-4V by eliminating the potential cytotoxicity of vanadium. The initial low elongation at break was significantly improved by post-process heat treatment, allowing the mechanical properties to be tailored to different clinical needs. In addition, the introduction of copper provides an antibacterial effect while maintaining good cytocompatibility and improved bone growth into the implant.

This contribution provides insight into the difficulties of in-situ alloying of Ti-6Al-7Nb+xCu by L-PBF. Our results show how both mechanical performance and biological functionality can be optimised by adjusting process and alloy parameters,

supporting the development of next-generation infection-resistant metallic implants for biomedical applications. To investigate the influence of copper, a CALPHAD-approach was used and EDX, EBSD, XRD and LOM investigations were performed, which were contextualised with experimental results from tensile tests, hardness measurements and corrosion investigations.

Author: Pan, Zhihao

Title: In-situ microstructure engineering in stainless steel 17-4 PH fabricated by laser powder bed fusion

DOI: 10.5281/zenodo.15310412

The current study explores the potential for in-situ microstructure engineering in precipitation-hardening stainless steel 17-4 PH during the LPBF process. Two approaches -laser modulation and laser remelting - were employed during fabrication. Key processing parameters, including duty cycle and frequency for laser modulation, or remelting enthalpy for laser remelting, were systematically investigated. Microstructural variations resulting from these strategies were characterized using various methods. The findings show that the as-built microstructures and the resultant properties can be effectively tailored, offering new pathways for property optimization in additively manufactured 17-4 PH components.

Author: Park, Jiyong

Title: Effects of Process Parameters on Microstructure and Superelasticity of L-DED processed Fe-36Mn-9Al-7Ni Shape Memory Alloy

DOI: 10.5281/zenodo.15226908

Laser Direct Energy Deposition (L-DED) process is one of the metal additive manufacturing processes that manufactures 3D components using high-power laser to melt metal powder directly onto a substrate. L-DED process has promising advantage that can create complex, high-quality metal components with good dimensional accuracy rapidly. On the other hand, superelastic shape memory alloy (SMA) is an alloy that can recover large deformation to its original shape when the applied load is removed. Superelasticity allows the SMA to withstand cyclic deformations without undergoing permanent deformation, making it an ideal candidate for various applications, including biomedical devices and aerospace components. Among several alloy systems, Fe-Mn-Al-Ni SMA is a promising one due to its low raw material cost and excellent superelastic properties. However, it has been known that to manufacture of the Fe-Mn-Al-Ni SMA using laser-based additive manufacturing process is challenging due to the cracking problems. In this study, Fe-36Mn-9Al-7Ni (wt.%) superelastic SMAs were produced by the L-DED process with various laser parameters. The microstructure and mechanical properties were investigated. We found that a pronounced excellent superelasticity could be obtained from L-DED processed Fe-SMA when the laser process parameters were optimized.

Author: Park, Minsu

Title: Influence of carbon addition on microstructure and shape memory properties of Co-Cr-Fe-Mn high entropy alloy produced by L-DED

DOI: 10.5281/zenodo.15220410

The Co-Cr-Fe-Mn high entropy alloy, a type of Co-Cr-Fe-Mn-Ni-based high entropy alloy where Ni is replaced by Co, is known to exhibit a shape memory effect (SME) through martensitic transformation between face-centered cubic (FCC) and hexagonal closed-packed (HCP) structure. Recently, it was shown that Co-18Cr-20Fe-19Mn and Co-18Cr-20Fe-19Mn-0.6C (wt. %) alloys could be successfully fabricated by L-DED and exhibited the SME. Notably, the carbon-containing alloy demonstrated enhanced shape memory behavior, achieving a maximum total recovery strain of approximately 3.5 %, compared to about 0.79 % of that from the carbon-free alloy.

Carbon addition has been reported to enhance the SME of Fe-Mn-Si alloys, another well-known FCC/HCP-type shape memory alloy. It has been known that the carbon addition enhances the SME by acting as an interstitial atom and by forming carbides. In Fe-Mn-Si alloy, carbon could increase strength of austenite matrix as an interstitial solute element, thereby suppressing permanent slip and facilitating FCC to HCP martensite transformation. Also, when carbide precipitation occurs, stacking faults are formed due to the lattice misfit between the carbide and the matrix.

In this study, the effect of carbon content on the microstructure and the shape memory properties of Co-18Cr-20Fe-19Mn alloys was investigated. The Co-18Cr-20Fe- 19Mn-xC (x= 0, 0.2, 0.4 and 0.6 wt. %) alloys were fabricated by L-DED. Microstructure and shape memory behavior of the alloys with different carbon contents were investigated.

Author: Pasebani, Somayeh

Title: Joining Inconel 718 and GRCo42: A framework for developing transition compositions to avoid cracking and brittle phase formation

DOI: 10.1016/j.matdes.2025.113733

Distinct regions of high temperature strength and high thermal conductivity are required for components such as combustion chambers. Inconel 718 and GRCo42 are commonly used for such components. However, the bimetallic joining of these alloys has been shown to result in a liquid miscibility gap at the interface, which at select compositions can lead to brittle phase formation and cracking. In this work, CALPHAD modeling is used to predict regions of brittle phase formation in the Inconel 718-Ni-GRCo42 and Ni-Cu GRCo42 multi-component ternary systems, with experimental validation of the modeling provided by arc melting. Through characterization of arc melted sample microstructure combined with CALPHAD modeling, the solidification paths throughout the system are elucidated and a brittle phase and crack free compositional region is identified. Based on these results, a compositionally graded path consisting of two transition compositions is identified. Powder Laser Directed Energy Deposition is used to fabricate the Inconel 718-GRCo42 joint with the identified transition compositions, and the joint is subject to characterization in terms of composition profile, defects, grain morphology, present phases and microhardness. Results confirm the transition compositions circumvent brittle phase formation found in bimetallic Inconel 718-GRCo42 joints, thus overcoming the thermodynamic barrier of bimetallic joining.

Author: Pasiowiec, Hubert

Title: Microstructure and mechanical properties of 316L steel-Inconel 625 gradient materials manufactured by laser powder bed fusion

DOI: 10.5281/zenodo.15427979

Laser powder bed fusion (LPBF) process facilitates the production of gradient materials by gradually varying the ratio of different metal alloys. Combining 316L steel and Inconel 625 nickel-based superalloy with a gradual changing the mixing ratio in LPBF printouts allows for obtaining the desirable properties at particular zones, according to the requirements related to different stresses acting on individual cross-sections of machine parts operating at high temperature. To prove this concept, in this study the microstructure and mechanical properties of 316L steel-Inconel 625 gradient materials LPBF processed were investigated.

The gradient samples were LPBF processed by using AYAS 120 LM machine, starting from 316L steel, followed by four transition zones with a thickness of 450  $\mu\text{m}$  each, containing 20, 40, 60 and 80 wt.% of Inconel 625, and ending with single Inconel 625. Microstructural analysis were carried out using LM and SEM. The gradient material was characterized by fine grains with cellular structure, elongated in the build direction. Porosity in each zone was  $<0.1\%$ . The hardness increased gradually from 230 HV0.5 for S316L to 301 HV0.5 for Inconel 625. In the transition zones, numerous precipitates were present at the cell boundaries. Sporadically, in the vicinity of particles, the microcracks were observed. Tensile tests were conducted at room temperature, 600, 700 and 750°C with the load perpendicular to the gradient direction. The YS, UTS and elongation decreased with the increase of tensile test temperate. The values of YS and UTS were between those for the individual gradient component materials, while the elongation was similar to Inconel 625 but lower than for 316L steel.

The results have shown that the 316L steel-Inconel 625 compositional gradient resulted in desired gradient in hardness and tensile properties better than 316L steel.

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Author: Perego, Folco

Title: In-situ tailored grain refinement of 316L stainless steel via site-specific titanium inoculation using laser directed energy deposition

DOI: 10.5281/zenodo.15420166

Controlling grain structure in metal additive manufacturing is critical to mitigating anisotropic mechanical properties caused by long columnar grains forming along the build direction, reducing hot cracking susceptibility, and enhancing strength via the Hall-Petch effect. This study investigates in situ grain refinement of 316L stainless steel fabricated by Directed Energy Deposition (DED) through direct injection of titanium (Ti) particles into the 316L melt pool. Unlike premixed powders— which can lead to non-uniform transport due to differences in density, morphology, and carrier gas interaction, and limit composition flexibility— direct Ti injection enables real-time control over alloying. A comprehensive parametric study was conducted by varying nozzle velocities up to 6000 mm/min, Ti mass flow rates, and the number of remelting passes to assess their effects on the transition from coarse columnar to fine equiaxed grains. Experimental results showed that Ti addition promotes equiaxed grain formation primarily via heterogeneous nucleation, attributed to the formation of nano-precipitates such as titanium oxides within the melt pool.

Complementary Multiphysics simulations provided insights into melt pool dynamics, convection- and diffusion- driven

Ti dissolution, and informed Thermo-Calc predictions to assess phase stability and avoid brittle Fe-Ti intermetallics. Low Ti mass flow rates refined grains effectively without inducing phase transitions, whereas higher Ti contents led to brittle intermetallic phases, cracking, and partial transformation from austenite to ferrite.

This integrated experimental-modeling approach demonstrates a viable strategy for achieving tailored microstructural control in DED through Ti inoculation and optimized processing parameters.

Author: Pereira Martendal, Caroline

Title: Co-processing metals with distinct compatibility levels through multi-material laser powder bed fusion

DOI: 10.5281/zenodo.15280700

Additive manufacturing (AM) combines geometric flexibility with minimal material waste due to its near-net shape capabilities. Among AM techniques, laser powder bed fusion (LPBF) stands out for its fine resolution and ability to process a wide range of metals and alloys with near-full density. One of the key innovations driving the evolution of AM is the development of multi-material processes, particularly multi-material LPBF (MMLPBF), which expands design possibilities, enables the fabrication of functional parts without additional assembly, and offers more efficient use of cost- and energy-intensive feedstock. Despite its potential, MMLPBF of geometrically complex 3D parts poses significant challenges due to its dependence on precise deposition methods and the intricate physical interactions that arise between different materials. These material-dependent interactions can modify the processing window and increase the likelihood of defects when compared to conventional single-material printing. As such, this study investigates the MMLPBF processing of bimetallic combinations that exhibit varying degrees of dissimilarity in terms of miscibility, thermal and physical properties. Microscopy and diffraction techniques are employed to evaluate how processing strategies influence part quality across distinct material systems – from closely related alloys like 17-4 PH and 316L stainless steels to more dissimilar combinations such as aluminum alloy and steel. In such a dissimilar pair, poor miscibility and contrasting thermophysical properties promote the formation of brittle intermetallic compounds and residual stresses at the interface, making the reliable fabrication of a sound bond a complex task.

Author: Polatidis, Efthymios

Title: Additive manufacturing: a tool for engineering microstructures and mechanical behavior

DOI: 10.5281/zenodo.15425140

Laser Powder Bed Fusion (L-PBF) is a versatile metal additive manufacturing technique that not only enables the creation of intricate geometries but also allows for precise control over microstructural properties. By adjusting processing parameters, L-PBF facilitates the engineering of crystallographic textures and grain orientations, enhancing the mechanical performance of metallic parts. Austenitic steels exhibit Transformation Induced Plasticity (TRIP) and Twinning Induced Plasticity (TWIP) effects under deformation, which are influenced by crystallographic texture. Therefore, this contribution will provide an overview of a project on the utilization of L-PBF to produce austenitic stainless steels with tailored crystallographic textures, optimized for specific load states to improve their mechanical behavior. The study requires identifying optimal microstructures and L-PBF processing routes using machine learning methods, that enhance these effects under complex stress states. The findings are leveraged to produce site-specific, texture-optimized components with superior mechanical responses compared to conventionally manufactured parts. C.S. and E.P. acknowledge the financial support from the Swiss National Science Foundation (SNSF), Project number: 200021\_188767. EP acknowledges support by the research project co-funded by the Stavros Niarchos Foundation (SNF) and the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the 5th Call of “Science and Society, Action, Always Strive for Excellence”, Theodore Papazoglou.

Author: Poncelet, Olivier

Title: Tailoring L-PBF process parameters to investigate surface roughness effects on AlSi10Mg waveguides

DOI: 10.5281/zenodo.15427628

The Laser Powder Bed Fusion (L-PBF) process enables the fabrication of highly complex geometries, making it a promising technique for producing advanced waveguides. However, compared to conventional manufacturing methods, L-PBF typically results in higher surface roughness, which can potentially increase electrical losses—particularly in high-frequency applications.

In this study, AlSi10Mg rectangular waveguides operating in the 26.5-40 GHz frequency range (Ka-band/WR28) were fabricated using different L-PBF process parameters and scanning strategies. By tuning these parameters, we controlled the surface roughness of the inner walls, either globally or selectively, to evaluate the impact of roughness distribution on waveguide performance. The resulting samples exhibited a range of roughness levels and surface textures. Despite the higher intrinsic roughness of L-PBF parts, our measurements show that electromagnetic losses remained relatively low across all tested configurations. These findings suggest that the performance of L-PBF waveguides can be acceptable—even without extensive post-processing—in certain high-frequency bands.

Additionally, thermal treatments were applied to modify the microstructure of the AlSi10Mg alloy and enhance its electrical conductivity. Improvements in microstructural homogeneity led to slight but measurable enhancements in waveguide performance, highlighting the complementary role of thermal post-treatments in optimizing both structural and functional properties.

Overall, this work demonstrates that by tailoring process parameters and applying targeted heat treatments, it is possible to mitigate the limitations of L-PBF-induced roughness and produce functional high-frequency waveguides with minimal additional processing.

Author: Prestes, Isabel B.

Title: Metallic metamaterials with tunable coefficient of thermal expansion produced via multi-material L-PBF

DOI: 10.5281/zenodo.15273387

Metamaterials with tunable coefficient of thermal expansion (CTE) are achievable by combining two materials with a large CTE difference in a specific lattice structure. These metamaterials have potential applications in components that require high dimensional accuracy in space applications, for example. Due to recent advances in the AM field, there are now technologies that allow these metamaterials to be printed in metal multi-material Laser-Powder Bed Fusion (L-PBF) process.

In this work, metamaterials with both negative and very positive CTE made out of an Invar + IN718 combination were studied. The samples, which ranged from single unit cells to multi-unit-cell segments, were printed in an L-PBF machine equipped with a multi-material "Aerosint" recoater. Their CTE was evaluated by dilatometry and digital image correlation (DIC) and the results were compared with FEM simulations. The structural integrity of the metamaterials was analyzed by shaker test, thermal cycling and tensile tests in bi-metallic specimens.

Single unit cells behave differently from metamaterials and a good agreement with the simulations depends on a proper selection of the samples' geometry and the corresponding boundary conditions for the simulations. The multi-unit-cell segments present a behavior closer to a metamaterial than single unit cells. The samples subjected to shaker test and thermal cycles did not fail and presented no cracks or plastic deformation. Tensile tests show that a good metallurgical bond is achieved between the two materials, since failure did not happen at the interface.

These findings give general guidance for developing tunable-CTE metamaterials. At the end of this work, one of the studied metamaterials was applied in an actuator for a satellite experiment.

Author: Raquin, Arthur

Title: Reduction of anisotropy in Ti-6Al-4V WAAM deposits by dual wire TIG using vibrations

DOI: 10.5281/zenodo.15223540

Ti-6Al-4V is a widespread material in industrial sectors such as aerospace and defense. This alloy exhibits an excellent strength to weight ratio, especially as a wrought material. However, the use of direct energy deposition processes typically leads to unfavorable coarse columnar microstructures with a strong texture which reduces ductility and increases mechanical properties anisotropy.

Multiple ways of refining the as-built microstructure have been studied such as melt pool shape control, hammer peening, inoculant additions or vibration. Refinement by vibration is generally obtained according to literature by vibrating the substrate and leads to heterogeneous results (due to: vibration node, attenuation). This study aims to increase the efficiency of vibration-induced refinement by directly vibrating the melt pool during deposition using dual wire-tungsten inert gas process.

For this purpose, the second filler wire, which is positioned at the back of the melt pool, is vibrated in order to affect locally the solidification. High frequency vibration of the melt pool may produce cavitation within the liquid alloy, and increase dynamic nucleation. This dynamic nucleation promotes homogeneous nucleation of grains in the melt pool and disrupts epitaxial growth at the liquid/solid interface of the melt pool.

The effect of vibration process parameters such as amplitude and frequency on the additive manufactured deposits will be presented. Anisotropic microstructure will be investigated with EBSD analysis.

Author: Rajput, Uma

Title: Magnetic Performance of Fe-Si-B Amorphous Ribbons: A Precursor Alloy for Additive Manufacturing of Soft Magnetic Components

DOI: 10.5281/zenodo.15295600

This study investigates the magnetic behavior of Fe-Si-B amorphous ribbons with varied compositions, emphasizing their suitability for future additive manufacturing (AM) of soft magnetic components. The work aims to identify compositional ranges offering optimal soft magnetic properties.

Magnetic characterization was carried out using both DC and AC measurement techniques. DC magnetization curves measured by vibrating sample magnetometry revealed consistent saturation magnetization ( $M_s$ ) across compositions and coercivity values ( $H_c$ ) ranging from 5 to 10 A/m. AC hysteresis measurements at 0.5 T (5-10 kHz) showed energy losses as low as 0.8 mJ/kg, with a noticeable minimum occurring near the eutectic composition. This trend was attributed to the enhanced magnetic softness and reduced magnetoelastic coupling at those specific stoichiometries. A comparative analysis of the ribbon samples (as-cast condition) indicated a direct correlation between composition, frequency-dependent energy loss, and coercivity. Boron- or silicon-rich compositions demonstrated higher losses and increased sensitivity to frequency, while eutectic-range samples maintained superior low-loss performance under dynamic conditions. Further heat treatment has been performed to improve microstructure and optimize annealing temperature for such alloy composition. These observations highlight the significant influence of alloy composition on magnetic softness. This magnetic characterization presented in this work ultimately supports the goal of producing soft magnetic motor components, especially in the development of efficient stators and rotors for electrical machines via 3D printing.

Author: Rementeria, Rosalia

Title: Microstructural homogeneity and robustness of novel low alloy steel powders processed via L-PBF

DOI: 10.5281/zenodo.15388423

Low alloy steels undergo fast solid-state transformations leading to a plethora of microstructures as a function of the temperature, cooling rate and alloy composition. During additive manufacturing, particularly in processes such as laser powder bed fusion (LPBF), controlling the evolution of these microstructures becomes exceptionally challenging, primarily due to the intricate dependence of phase transformation kinetics on the highly localized and dynamic thermal conditions inherent to the process. As a consequence, spatial heterogeneities in thermal histories across the build volume often lead to significant microstructural and mechanical property variability within fabricated components. Such variability poses a critical barrier to use parts in the as-built conditions for structural applications, where consistency and predictability of material performance are paramount.

The present study investigates the use of medium manganese alloyed powders as compared to DP600 low alloy standard compositions for LPBF to provide both microstructural homogeneity and robustness. Microstructural homogeneity is evaluated in terms of FEG-SEM microstructure classification and nanohardness measurements, whereas microstructural robustness is evaluated in terms of the yield strength of the material. Both experimental analyses and CALPHAD simulations were used, focusing on the impact of varying the volumetric energy density on microstructure evolution and the resulting tensile properties. This research led to the development of the commercial steel powder AdamIQ™ SAM 3, whose performance characteristics are showcased to demonstrate its suitability for industrial use.

Author: Rezaei, Ali

Title: Laser powder bed fusion of nanoparticle-enhanced sustainably-manufactured AA7075 alloy

DOI: 10.5281/zenodo.15292898

High-strength aluminum alloy series are prone to solidification cracking during the laser powder bed fusion (LPBF) additive manufacturing (AM) process. As such, poor printability continues to hinder the industrial use of LPBF-processed high-strength aluminum alloys. Addition of appropriate nanoparticles is known as an effective solution to prevent solidification cracking through heterogeneous nucleation of equiaxed grains. On the other hand, the presence of nanoparticles influences laser-material interactions, making it more challenging to achieve high relative density parts. In this study, 1 vol.% ZrH<sub>2</sub> nanoparticles were added to a low-cost, environmentally sustainable AA7075 aluminum alloy powder with a non-equiaxed morphology. The powder morphology differs from the conventional spherical powders typically used in AM and will further influence the final relative density. To systematically study the melting mode behavior of AA7075+ZrH<sub>2</sub> (7A76) alloy, a normalized processing diagram coupled with a temperature prediction model was employed. Results indicated that the relative density of the alloy is greatly dependent on the melting mode behavior. Transition melting mode was found to be effective in minimizing elemental evaporation of Mg and Zn and achieving a defect-free 7A76 with a relative density of 99.98%. This reported relative density is the highest achieved in literature to date. Furthermore, partially-melted nanoparticles were found in the microstructure, which act as nucleation sites, participating in the crack prevention mechanism.

Author: Ricard, Matthieu

Title: Microstructure-property relationships in a new Al Alloy designed for Laser Powder Bed Fusion

DOI: 10.5281/zenodo.15411987

Additive manufacturing enables the fabrication of sophisticated 3D-structures with unprecedented degrees of freedom. However, most common alloys are susceptible to hot cracking. Herein, we present a novel Al-Cr-Fe-Zr aluminium alloy

specifically designed for laser powder bed fusion (LPBF), with mechanical properties exceeding those of Al alloys from the 6XXX series. Emphasis is placed on the multi-scale characterisation of the as-printed microstructure and its ageing response during a post-fabrication heat treatment. EBSD maps reveal the typical bimodal grain structure of Zr-containing Al alloys processed by LB-PBF. Micron-scale equiaxed grains are found near the melt pool boundaries, while coarser columnar grains are observed in the melt pool interiors. The intermetallic population is characterised using a combination of SEM, XRD, and TEM. The nature and spatial distribution of the different intermetallic particles are investigated and differences are found depending on the position within the melt pool. Finally, atom probe tomography experiments are carried out in different regions of the melt pool to investigate the solid solution composition and its evolution upon ageing. These atomic scale measurements show that the solid solution is highly supersaturated due to solute trapping. This supersaturation of the solid solution in the as-printed state provides an opportunity to enhance the mechanical properties via direct ageing. The microstructural evolutions responsible for the increase in strength of this novel alloy during direct ageing are clarified.

Author: Richter, Julia

Title: On the microstructural stability of metastable CrMnNi steels processed by laser-based additive manufacturing techniques

DOI: 10.5281/zenodo.15309312

Beam-based additive manufacturing (AM) techniques in general are characterized by small melt pool sizes and concomitantly high cooling rates leading to unique microstructures. Although, depending on the utilized technique, the resulting microstructures can be highly different from each other, AM-built materials are often characterized by an improved chemical homogeneity in contrast to conventional manufactured counterparts. In combination with a high dislocation density, that can be found in processes such as the laser-based powder bed fusion of metals (PBF-LB/M), these microstructural features will directly influence the mechanical behavior. Especially, metastable CrMnNi steels, whose deformation behavior is often assisted by twinning or transformation-induced plasticity, are sensitive to their microstructural features. In the present study, the influence of different beam-based AM methods such as PBF-LB/M and directed energy deposition (DED) on the microstructural evolution of CrMnNi steels is investigated. Based on different chemical compositions, the stability of the austenitic phase was varied leading to different dominant deformation mechanisms (dislocation glide, twinning or phase transformation) under quasi-static loading. The presence of different sized microstructural features leads on a macroscopic scale to a highly different deformation behavior that can be traced back to the employed process. The results presented on AM materials are compared with conventional counterparts from literature.

Author: Rittinghaus, Silja-Katharina

Title: Microstructural evolution in Electron Beam Powder Bed Fusion of a nickel-based ODS superalloy

DOI: 10.5281/zenodo.15311042

The use of oxide dispersion strengthened (ODS) alloys in Electron Beam Powder Bed Fusion (PBF-EB, EBM) has been scarcely explored despite their potential to enhance high-temperature performance. This is primarily attributed to the inherent challenges in processing ODS materials in additive manufacturing, which are compounded by the inherent susceptibility of high-temperature alloys to cracking, as well as difficulties in achieving uniform oxide particle distribution and maintaining microstructural homogeneity. This study investigates the influence of different scan strategies on the microstructure and mechanical properties of difficult-to-weld Inconel 738LC, both with and without  $Y_2O_3$  dispersion. The primary aim is to assess how ODS affects the material's microstructure and its performance under PBF-EB processing conditions. This work explores the effects of different scan strategies, such as line and spot melting, on microstructural features including grain size and oxide dispersion. The heat input during processing, particularly with respect to potential effects on the formation of  $\gamma'$  phases, is also considered. Processing challenges related to the inclusion of ODS, such as maintaining a homogeneous microstructure and minimizing defects, are discussed. Approaches to studying the behavior of nanoparticles, including potential modeling techniques, are presented. Mechanical properties such as hardness and high-temperature compressive strength are evaluated to quantify the effect of scan strategies and ODS on the alloy's performance. The results indicate that the scan pattern has a significant influence on grain structure, anisotropy, and crack formation, while the inclusion of ODS presents challenges, particularly in terms of process stability and defect formation. This study provides insights into the role of ODS in PBF-EB and underscores the complexities associated with processing this type of materials. The findings offer a deeper understanding of how processing can be optimized to pave the way for improved high-temperature performance.

Author: Rocco, Alessandro

Title: An in-situ synchrotron study of the tensile deformation of LPBF-manufactured AlSi10Mg

DOI: 10.5281/zenodo.15301641

This work presents the results of an in-situ synchrotron experiment in which an AlSi10Mg alloy was deformed in tension. The in-situ tensile test was conducted on a miniaturized dog-bone specimen at the MAX IV synchrotron facility (Lund, Sweden). The DanMax beamline was used to scan the specimen and allowed for a spatial resolution of ~250 nm per voxel. A customized tensile rig was used, and multiple scans were acquired to image the entire gauge volume.

The specimen was fabricated via laser powder-bed fusion (LPBF) and subsequently annealed at 520°C for about 2 h. Its microstructure consisted of an  $\alpha$ -Aluminum matrix in which globular Silicon particles were embedded. In particular, the Si particles had an average particle size less than 5  $\mu\text{m}$ , and could be spatially resolved by Synchrotron X-Ray tomography. The alloy also contained a small amount of matrix porosity, with most pores having a spherical shape and an average size ranging between 5-80  $\mu\text{m}$ .

FE-based Digital Volume Correlation (DVC) was then used to assess strain fields at the microscale, using the reconstructed volumes. Various techniques were tailored to this specific application, including the use of adapted meshes consistent with the final crack geometry, and the stitching of reconstructed volumes (acquired at different heights) via integrated-DVC. Damage mechanisms leading to final failure were quantified based on the evolution of strain results. It is shown that the presence of large defects within the matrix triggered damage accumulation and promoted the formation of a macroscopic crack, which ultimately led to specimen failure. The mechanisms of void nucleation, growth and coalescence were also investigated through the analysis of DVC residuals across the different scans. Last, the microscale strain maps were rationalized on account of the melt-pool geometries revealed by the Si particle distribution.

Author: Rodríguez Sánchez, Marcos

Title: LPBF OF NOVEL SOFT MAGNETIC METALLIC GLASSES

DOI: 10.5281/zenodo.15309472

Fe-based soft magnetic metallic glasses MGs have shown an excellent trade-off between magnetization saturation and coercivity values and are thus envisioned as potential candidates to increase the efficiency of electromagnetic components. Laser powder bed fusion (LPBF) allows to manufacture relatively large BMG parts while retaining an amorphous microstructure due to high local cooling rates. However, in practice, the thermal cycles generated in the layer-wise LPBF process tend to cause undesired crystallization. To date, commercial Fe-based MG compositions have a very narrow processability window and crystallization cannot be avoided due to their limited glass forming ability (GFA), which typically yields amorphous/crystalline composites after LPBF processing.

A novel composition with a sufficiently high GFA to be printed by LPBF in a fully amorphous state has been developed. This work aims to explore the relationship between LPBF processing conditions, defects, (micro)structure and soft magnetic properties of said alloy. The feedstock amorphous powder is processed using several strategies: single and double scans per layer of deposited powder and varying delay times at the end of each vector. A high amorphous fraction is achieved for all printed samples and no signs of crystallization were found in specific combinations of parameters and scanning strategies. Unprecedented magnetic coercivity values 100 times lower than those obtained with commercial alloys were achieved on this alloy. Complementary experimental techniques such as image analysis, computed X-ray tomography, X-ray diffraction, calorimetry, EBSD, TEM, magnetic and micromechanical testing were used to characterize the (micro)structural and multi-scale properties evolution with respect to the processing parameters.

Author: Rosar Longin, Julien

Title: Dynamic behavior of the 7075 high strength aluminum alloy produced by LPBF

DOI: 10.5281/zenodo.15295492

High strength aluminum alloys of the 7000 series show unsurpassed strength-to-weight ratio and therefore attract much of the attention of the aerospace industry where lightweight design is paramount in material development. Despite successful addition of grain refiners and a systematic process parameters optimization, the industrial use of Laser Powder Bed Fusion (LPBF) high-strength aluminum remains very limited.

Indeed, further characterization remains necessary. This is especially the case for the study of the dynamic mechanical properties, that is to say under high strain rate ( $\dot{\epsilon} > 100 \text{ s}^{-1}$ ). Such studies are necessary to produce finite element models that can simulate high speed events simulation, such as crashworthiness of vehicles, explosive welding and ballistic protection.

High strain rates can result in differences in strength, ductility, and toughness. Although Ti6Al4V is quite covered in the literature and AlSi10Mg - despite controversies- is being studied as well, the dynamic characterization of LPBFed high strength aluminum alloys is yet to be completed. Using Split Hopkinson Pressure Bars (SHPB), the objective of this study

is to compare the mechanical dynamic behavior of the conventional wrought 7075 with the LPBFed 7075 from Zr-modified pre-alloyed powder, boosted in Zn and Mg to account for their vaporization during processing. Two prealloyed powder compositions are compared: one with 1wt% Zr and one with 2wt% Zr. Those two new alloys achieve a hardness above 200 HV0.3 after T6 heat treatment, promising even higher performances than wrought 7075. The build direction is also known to have an influence on the microstructure, resulting in anisotropic mechanical (quasi-static) properties. The dependence on build direction is then also considered at high strain rates. In addition, two different thermal states (as-fabricated and T6) are studied within the strain rate range of 500-2500 s<sup>-1</sup>, where strain rate hardening and thermal softening compete with each other.

Author: Sadanand, Saumya

Title: Crystallization mechanisms during LPBF of Finemet

DOI: 10.5281/zenodo.15308980

Soft magnetic materials (SMMs) are known for their excellent properties, notably high saturation flux density and low coercivity, which are key requirements in the search for new alternatives to enhance energy efficiency in electric motors. In particular, Fe-based SMMs are well-suited to meet this need, as they can significantly increase motor efficiency by reducing core losses. Despite their promise, these materials require further research to overcome production challenges, as the necessity for high cooling rates to achieve a significant amorphous phase fraction restricts their production to thin ribbons formed through rapid solidification techniques such as melt spinning. Recently, there has been growing interest in the additive manufacturing (AM) of Fe-Si-B-based bulk metallic glasses, particularly using laser powder bed fusion (LPBF), not only for optimizing process parameters to fabricate simple geometries but also for producing relatively large, net-shaped rotors.

In this work, for the first time, we attempt to understand the complex crystallization mechanisms during LPBF of the Fe-based nanocrystalline Fe<sub>73.5</sub>Si<sub>13.5</sub>Nb<sub>3</sub>Cu<sub>1</sub> alloy (Finemet). The effect of scan speed on the (micro)structure has been investigated by using a constant laser power of 60 W combined with two different scan speeds, 500 mm/s and 890 mm/s, respectively. To quantify the (micro)structural evolution, the local elemental distribution, and the phase formation, a combination of complementary characterization techniques— including scanning electron microscopy, transmission electron microscopy, and differential scanning calorimetry—has been employed.

The findings from this study provide an important stepping stone towards a deeper understanding of the crystallization mechanisms in Finemet, paving the way for tailoring microstructures and optimizing their resulting properties.

Author: Sajithkumar, Ananthakrishna

Title: Processing optimization in directed energy deposition of aluminium alloy powders

DOI: 10.5281/zenodo.15302872

Aluminium alloys present significant challenges for metal additive manufacturing (AM) due to their susceptibility to solidification cracking and porosity. To address this, a comprehensive framework has been developed to optimize Directed Energy Deposition (DED) parameters, beginning with gas atomized Al6061 powders as a representative system. Single-track DED experiments are systematically performed across a matrix of laser powers and scan speeds, guided by a central composite design embedded within a response surface methodology framework. Melt pool geometries, including width, depth, and aspect ratio, are characterized to understand the primary process responses. Planned cross-sectional microstructural analysis will quantify Secondary Dendrite Arm Spacing as a metric for cooling rate assessment, thereby linking thermal conditions to microstructural refinement. Based on the identified optimal processing window, subsequent work will involve layer-wise printing trials with customized toolpath strategies to evaluate their influence on solidification cracking behaviour and internal defect distribution. By combining validated feedstock insights, quantitative microstructure-process mapping, and toolpath-driven thermal management strategies, this work aims to advance the tailored processing of aluminium alloys for structural and defect-sensitive additive manufacturing applications.

Author: Schlenger, Lucas

Title: Multiscale numerical feedforward optimization of the Laser Powder Bed Fusion process

DOI: 10.5281/zenodo.15250623

Laser Powder Bed Fusion is an additive manufacturing technique used to produce solid metal parts from metallic powder. It excels at producing complex geometries in small batches. However, processing conditions are still being optimized using time and labor intensive trial and error approaches. Even after optimization, the contrast between the complex geometry and the limited set of optimized processing conditions, yields a compromise between printability and melt pool homogeneity at best. We propose a multiscale modeling approach to obtain a physics driven prediction of processing conditions tailored to a specific geometry. The workflow consists of two distinct modeling techniques utilized to capture the physics of the process both, on the part scale, and on the melt pool scale. The optimization

strategy, which couples the two modelling approaches, aims to minimize melt pool variations in the vicinity of geometric features. In-situ high speed thermal imaging unveils the effectiveness of the approach and illustrates a reduction of 89% of systematic melt pool variations throughout the print of a complex geometry. Moreover, stochastic melt pool variations could be quantified. As a whole, this approach allows for the drastic reduction in systematic melt pool variations in complex parts, and will resultingly allow the fine tuning of microstructures in the presence of varying thermal boundary conditions.

Author: Schönrrath, Hanna

Title: Advances in processing Titanium-based sulfur bearing BMGs by laser based powder bed fusion

DOI: 10.5281/zenodo.15373865

Laser-based powder bed fusion of metals (PBF-LB/M) has enabled the manufacturing of demanding materials. By functionalizing the inherently high cooling rates of the process, the fabrication of bulk metallic glasses (BMGs) has become feasible. These materials exhibit exceptional properties, including an elastic limit of up to 2-3%, and an advantageous strength-to-weight relation. However, despite cooling rates of 106 K/s exceeding the critical cooling rate of BMGs drastically, the alloy selection is still limited. While significant progress has been made with good glass-formers such as Zr-based alloys, the manufacturing of alloys with lower glass-forming ability remains challenging.

In this work, we investigate the processing conditions for a Ti-based sulfur containing BMG, which possesses a markedly lower critical cooling thickness of approximately 1 mm. This alloy offers an attractive combination of biocompatibility, corrosion resistance, and high wear resistance however, the limited glass-forming ability poses significant challenges for PBF-LB/M. The impact induced by tailored processing parameters is evaluated, including the variation in laser power, scanning velocity, layer thickness, and the application of inter-vector delay times. A detailed analysis of the achievable cooling rates is provided by pyrometry. The cooling rates fulfil the theoretical requirements for vitrification. The impact on the resulting amorphicity is assessed by differential scanning calorimetry and X-ray diffraction. A relative density of > 99.5 % and amorphicity similar to cast materials are achieved, however, cracks are observed in the manufactured samples. Our findings contribute to a deeper understanding of processing parameter - microstructure relationships in PBF-LB/M of BMGs with low glass-forming ability.

Author: Setiawan, Ignatius Andre

Title: LPBF process windows mapping for shape memory and superelastic NiTi alloys: A comparative study

DOI: 10.5281/zenodo.15260168

Additive manufacturing (AM) forges the pathway of nickel-titanium (NiTi) based technology valorization as an effective manufacturing solution for the otherwise difficult-to-process material. Creating a hierarchical structure of Ni-Ti is currently a quite explored domain in AM technology, in which the laser powder bed fusion (LPBF) process is a preferred method to fabricate the intricate structure due to its ability to maintain a high-resolution accuracy. NiTi alloys exhibit two notable smart properties: superelasticity and shape memory effect. Depending on the Ni content, the pre-alloyed powders for the LPBF process inherently favor one of these functionalities. Ni-43.15Ti wt.% typically demonstrates superelastic behavior at room temperature, while those with a composition of Ni-44.15 wt.% tend to exhibit shape memory effects. The printing process, on the other hand, might also cause the selective evaporation of Ni, which may directly impact the transformation temperature and consequently affect the functional behavior of the printed parts. Therefore, a comparative study of these two commercially available powders that focuses on print quality, the degree of Ni loss, and the subsequent transformation temperature is essential for understanding and controlling performance outcomes. A design of experiment (DOE) which explores the overall print quality on various applied laser power (P) and scanning velocity (v) is conducted. The resulting prints are then characterized to assess their subsequent overall structural integrity using X-ray computed tomography (XCT), transformation temperatures using differential scanning calorimetry (DSC), and Ni content using energy-dispersive spectroscopy (EDS). This study highlights how the printing parameters affect the overall quality and functional performance of the printed NiTi alloy.

Author: Sharma, Harshita

Title: Thermodynamics-based modification of the Koistinen-Marburger model for martensitic transformation in metal additive manufacturing

DOI: 10.5281/zenodo.15297898

Additive manufacturing (AM) processes result in complex phase transformations due to rapid thermal cycles and steep localized thermal gradients. Predictive modeling of these phase transformations is essential since the microstructural evolution and the resulting mechanical properties are extremely sensitive to processing conditions. This study focusses on predicting site-specific austenite-to-martensite transformation in two steel alloys, Maraging M300 and H13 tool steel, during laser powder bed fusion (LPBF) AM. These alloys are selected for their industrial relevance and distinct martensitic transformation characteristics.

The Koistinen-Marburger (K-M) equation is commonly used to estimate the formation of martensite during cooling. This equation employs an empirical k-parameter that does not account for alloy chemistry and the non-equilibrium nature of AM processing. To address this limitation, a thermodynamically-informed modification of the K-M model is proposed, in which the k-parameter is reformulated as a function of the entropy change ( $\Delta S$ ) associated with the austenite-to-martensite transformation. The  $\Delta S$  term is extracted from CALPHAD-based Thermo-Calc® calculations. Location-specific thermal history is obtained using a Finite Element Method (FEM) simulation performed using Simufact Additive®. This enables alloy-specific, temperature-dependent modelling of transformation kinetics under AM conditions. Experimental validation was conducted through EBSD and XRD characterization of LPBF fabricated samples to validate the predictive capability of the modified model.

By enhancing the K-M parameter based on thermodynamics of martensitic transformation, this formulation aims to capture more realistic transformation kinetics encountered in LPBF. The flexibility of the modified equation allows for its extension to other alloy systems with minimal reparameterization. Overall, the proposed model advances the quantitative prediction of phase transformations during rapid solid-state cooling, enabling more reliable microstructural control in AM components.

Author: Shojaati, Mohammad

Title: On the Effect of Process Parameters on Manganese Content and Shape Memory Behavior of LPBF-Fabricated Fe-Based Alloys

DOI: 10.5281/zenodo.15426003

In this study, the effect of laser process parameters on Mn content and the shape memory behavior of Fe-20Mn-5Si-5Ni-9Cr-0.8V-0.2C-0.1N were studied. Laser Powder Bed Fusion (LPBF) method was employed to fabricate the parts using an EOS M290 system. The process aimed to achieve fully dense parts (> 99.9%) with different Mn contents (between 15 to 20 wt%). Mn content measurements done with XRF revealed that scanning strategy (including stripe width, strip overlap, scan length, and rotation angle) significantly influence the Mn content in a part, despite being printed with identical power, speed, hatch spacing and layer thickness. The underlying causes were analyzed in the context of melt pool dynamics and vaporization tendencies of Mn during repeated scan path exposures. Next, differential scanning calorimetry (DSC) was employed to study the influence of Mn variation on shape memory transformation temperatures. Clear shifts in martensitic start ( $M_s$ ), finish ( $M_f$ ) and austenitic start ( $A_s$ ), and finish ( $A_f$ ) temperatures were observed, with higher Mn content lowering the transformation range. Mechanical properties assessment showed that high-Mn samples had slightly reduced the strength, but improved ductility compared to low-Mn samples. Hardness measurements showed minor variation but aligned with the observed microstructural differences. Finally, the shape memory effect (SME) was assessed using a three-point bending recovery test. High-Mn samples exhibited significantly different behavior compared to low Mn samples, owing higher stability of Austenite in the high Mn samples. Moreover, in-situ heat treatment occurring due to high energy input in low-Mn samples resulted in formation of carbides and affected the shape memory behavior in the low Mn sample as compared to carbide free high Mn sample. This study highlights the sensitivity of Fe-Mn-Si shape memory alloys to Mn content and demonstrates how LPBF process parameters can be utilized to tailor chemical composition and mechanical behavior of this group of alloys.

Author: Sofras, Christos

Title: Solidification pathway induced microstructural differences in austenitic stainless steels produced by L-PBF.

DOI: 10.5281/zenodo.15404024

This study examines the influence of small compositional variations on the microstructure of 304L stainless steel produced by Laser Powder Bed Fusion (L-PBF). Despite identical processing parameters, N-atomized powder forms textured, columnar grains with elemental segregation, solidifying primarily as  $\gamma$ -austenite with secondary ferrite. In contrast, Ar-atomized powder produces equiaxed grains with uniform composition, following a primary ferrite to secondary  $\gamma$ -austenite mode. Operando synchrotron X-ray diffraction during L-PBF reveals that solidification mode critically shapes the final microstructure, underscoring the importance of solidification control for tailoring properties in austenitic stainless steels.

Authors: Sohrabi, Navid - Carreno-Morelli, Efrain

Title: Alloy design for additive manufacturing of a 6xxx aluminum alloy for ultra-high and medium strength applications

DOI: 10.5281/zenodo.15984469

6xxx alloys are widely used in different industries, such as automotive and aerospace industries. However, one of the main limitations for laser powder-bed fusion (LPBF) of this group of aluminum alloys is high hot cracking susceptibility. LPBF processing of 6xxx alloys parts without cracking is challenging. Often, hot cracking resistant LPBF alloys contain an extensive amount of Sc or Zr, which are expensive elements.

In this work, crack susceptibility models are used to develop a hot crack resistant Al-Si-Mg alloy with reduced Zr content. The observation of single laser tracks on plates machined from as-cast ingots, allows to optimize both laser power and scanning speed. Then, finite element modeling is used to simulate different processing parameter sets and extract the values of thermal gradient and solidification rate. These values are required to calculate the crack susceptibility index. Results showed that the thermal gradient is relatively independent of composition. However, for the solidification rate, the influence of composition is larger. For six alloys that did not have any cracks, a crack susceptibility index was calculated, and the alloy with the lowest CSI was selected for gas atomization and further processing. Printed parts with a density higher than 99.5% are obtained. No cracks are observed in samples printed with the optimized parameters. A proper choice of laser scan parameters results in an optimal bi-modal structure of melting pools consisting of columnar and equiaxed grains. Different heat treatments are used to adjust the required mechanical properties that can fit high and medium-strength applications.

Author: Soria, Sergio

Title: Characterization of hybrid lattice structures fabricated by laser powder bed fusion and casting processes by Bragg edge neutron imaging

DOI: 10.5281/zenodo.15312857

According to ISO/ASTM TR 52912, multimaterials are defined as parts or components fabricated using more than one material. Among the various multimaterial combinations investigated, those involving Cu-based or Al-based alloys with Ni-based superalloys or steels are particularly attractive. These combinations merge the high strength and corrosion resistance of Ni-based alloys or steels with the superior electrical and thermal conductivity of Cu and Al alloys. The development of hybrid lattice structures that combine laser powder bed fusion (LPBF) with casting techniques presents a promising strategy to tailor material properties for advanced applications. LPBF enables the fabrication of high-strength lattice frameworks using alloys optimized for mechanical performance, while casting allows the integration of materials with lower melting points and better thermal/electrical conductivity. This hybrid approach leverages the design flexibility of additive manufacturing with the bulk property benefits of cast metals, an ideal combination for aerospace, automotive, and energy applications.

In this study, hybrid lattice structures composed of Inconel 718/CuCrZr and AISI 316L/Al10SiMg were fabricated using this combined manufacturing approach. Inconel 718 and AISI 316L lattice frameworks were first produced by LPBF, and the grid structures were subsequently filled with CuCrZr or Al10SiMg powders melted using different casting processes. The present work focuses on the characterization of the microstructure and the residual strain associated with the manufacturing process in these multimaterial combinations. The analysis was performed using Bragg edge neutron imaging at POLDI (Pulse OverLap Diffractometer), the time-of-flight diffractometer at SINQ, Switzerland.

Author: Stoll, Thomas

Title: Laser Beam Shaping and Laser Beam Oscillations – Local and Temporal Modulation of the Energy Input as the Solution for Hard-to-weld Materials?

DOI: 10.5281/zenodo.15425042

Additive manufacturing (AM), especially the process of Powder Bed Fusion using a laser-based system (PBF-LB/M), is nowadays a well-established technology that is already used for the manufacture of industrial parts, especially in the aerospace sector. As the processed materials mainly originate from the casting technology, severe process faults like hot cracking (solidification and liquation cracking), cold cracking, and, often still, residual porosity emerge during laser processing of the materials. Nevertheless, materials like highly alloyed aluminum (e.g., 2xxx, 6xxx, and 7xxx series), Ni-based superalloys, as well as refractory metals like tungsten, are of high interest for several industry sectors like aerospace, automotive, high-performance lightweight applications, plasma-facing environments (nuclear fusion), heat exchangers, and more. Especially for such high-end materials and applications, AM can play an essential role in manufacturing extremely complex and application-specific parts. This presentation provides an approach for the crack-free processing of hard-to-weld materials like highly alloyed aluminum and refractory metals like tungsten in process-based approaches, such as laser beam shaping and laser beam oscillations, that can be applied to every modern PBF-LB/M machinery. Such processing strategies tackle the root cause of hot or cold cracking - namely, the rapid cooling rate, with a locally and temporally adapted laser intensity distribution. With the application of both strategies - laser beam shaping and laser beam oscillations (with and without a combination) - severe crack reduction, up to a reproducible crack elimination at crack-prone materials like Al2024, Al6013, and tungsten, can be achieved. The experiments were conducted on bare metal sheets with a thickness of 2 mm, a laser wavelength of 1070 nm, and a variation of the laser power, scan speed, oscillation amplitude, oscillation frequency, laser beam profile, and spot diameter. An analysis of the top-view as well as the cross sections of the specimens gives detailed information about the cracking behavior and the microstructure depending on the adjusted parameter settings.

Author: Suresh, Sugirtha

Title: Development of Steel Powder for High-Strength and Damage-Tolerant AM parts

DOI: 10.5281/zenodo.15309151

Additive Manufacturing (AM) of metallic components has evolved from prototyping to industrial-scale production, enabling the fabrication of complex geometries for high-performance applications. Laser-Beam Powder Bed Fusion (LB-PBF) and Electron-Beam Powder Bed Fusion (EB-PBF) are among the most established AM techniques, which currently rely on conventional materials. However, limited knowledge exists on the additive manufacturing of advanced steels such as duplex, oxide dispersion-strengthened (ODS), and Transformation-/Twinning-Induced Plasticity (TRIP/TWIP) steels. This highlights the need for developing novel steel alloys specifically tailored for AM, as the final properties of printed parts are strongly influenced by the feedstock composition. This study focuses on optimizing X15CrMnNiN15-3-3-0.15, a high-strength, metastable austenitic TRIP/TWIP steel alloy, produced via the crucible-free Electrode Inert Gas Atomization (EIGA) process. The EIGA process minimizes manganese evaporation and de-nitriding, critical for preserving the powder's designed composition. Efforts to minimize energy and argon consumption during atomization further enhance process sustainability. Two critical process variables— electrode melting rate and atomization gas preheating— were varied to investigate their effects on powder characteristics, including particle size distribution (PSD), morphology, flowability, bulk density, magnetic saturation, and microstructure. Optimization of these parameters resulted in a refined PSD (lower D50) and highly spherical powders with minimal porosity and satellite formation, primarily consisting of the austenitic phase, enhancing suitability for both LB-PBF and EB-PBF applications. While this work focuses on powder development, future efforts will involve the use of these powders in AM to fabricate test components. These components will then be subjected to Quenching and Partitioning (Q&P) heat treatment, with the aim of achieving a tempered martensitic structure that enhances damage tolerance. The initial findings suggest promising potential for an alloy concept with improved processability, isotropic microstructures, and enhanced mechanical properties, which could contribute to the development of high-performance AM components with improved reliability, damage tolerance, and operational efficiency, for future industrial and medical applications.

Author: T M, Nandakishor

Title: Interface engineering through TiC blending and interlayer approaches for defect mitigation in hybrid PBF-LB/M aluminium parts

DOI: 10.5281/zenodo.15310761

Modern industrial applications demand a combination of structural strength and design complexity in components. To achieve this, a hybrid in-situ multimaterial PBF-LB/M process was proposed, combining high-strength aluminium bulk parts produced through conventional manufacturing routes with complex AM-built regions made from AM-suitable alloys. However, the components manufactured combining AA 2017 as the conventional substrate and AlSi10Mg as the AM material resulted in defects including non-spherical porosity and hot cracking at the interface region due to epitaxial grain growth. In this study, material-based interventions to reduce defect formation to produce a high-integrity interface were investigated. Feedstock modifications to promote grain size reduction involved adding pure Ti, and introducing TiC nanoparticles through two methods: (i) blending 1 wt.% TiC with AlSi10Mg powder, and (ii) applying a pure TiC interlayer between AlSi10Mg and AA2017. The approach with TiC interlayer achieved over a 60% reduction in defect area, compared to just 13% for TiC blended powder. Furthermore, all TiC-modified samples exhibited a decrease of more than 70% in defect count, confirming the effectiveness of TiC modification in significantly reducing the number of defects. EBSD analysis revealed a 35% reduction in interface grain size with the TiC interlayer, versus 10% with the blended powder. The TiC interlayer promoted grain nucleation, thereby restricting epitaxial growth and inhibiting crack propagation at the interface through a uniform dispersion of unsintered TiC particles. Nonetheless, agglomerates and sintering of TiC particles were observed in all modified samples. The extent of TiC particle sintering was significantly higher in the samples printed with blended powder, likely due to direct laser exposure on TiC agglomerates. Additionally, TiC modification could have extended the melt pool lifetime, facilitating bubble degassing and reducing spherical porosity. Overall, the TiC interlayer approach demonstrated significantly superior performance compared to powder blending in enhancing the integrity of hybrid AM interfaces.

Author: Tarafder, Prithwish

Title: Effect of high oxygen content on unalloyed copper produced by electron beam powder bed fusion

DOI: 10.5281/zenodo.15311502

Pure copper with low oxygen content is known to produce wide columnar epitaxial grains when processed by raster scans with high scan rotation angles via electron beam powder bed fusion. However, oxygen, commonly found as non-passivating surface copper oxide in otherwise unalloyed precursor copper powder, can restrict the grain growth because of high grain growth restriction factor, and hence, can lead to a refined microstructure along build direction. Previous studies, although limited to LPBF, showed insignificant effect of the oxides on the electrical properties, while improved

strength properties are often reported for copper with high oxygen content. In this study, copper powder was furnace treated to increase its oxygen content and processed under similar conditions to the processing of pure copper, contrary to the previous LPBF studies that used different process settings. Oxidized copper shows refined grain structure with cellular solidification sub-grains evolved with ordered copper oxide particles at the sub-grain boundaries. Thermal stability of these oxide particles is tested by TG and conventional heat treatment (HT) at 400°C in argon, commonly used for copper. While HT led to a more preserved cellular sub-grain structure similar to as-fabricated condition, the TG experiment at 950°C under vacuum led to loss of mass due to the disassociation of copper oxide and more thermally activated agglomeration of the particles. Microstructural evolution is explained by lattice mismatch between oxide particles and the copper matrix, aided by simple thermal model data to approximate the temperature fields. With high oxygen content, a good combination of strength and electrical conductivity is found, caused by the interface properties and the strengthening effect from the harder phase of copper oxide. This approach demonstrates the feasibility of using oxidized copper powder in a favorable way instead of undergoing the recycling process for the need of high purity virgin powder.

Author: Thuillet, Rémi

Title: Study of the Wire Laser Additive Manufacturing (WLAM) Process Applied to a Low-Alloy Steel

DOI: 10.5281/zenodo.15422413

The Wire Laser Additive Manufacturing (WLAM) process enables the production of large-scale metal components. A thorough understanding of wire deposition regimes is crucial to minimizing internal and external defects, which are often responsible for the initiation of fatigue cracks. This work aims to identify the optimal parameters for printing medium- and large-scale structures using low-alloy steel. Using an instrumented WLAM experimental setup, an initial study is conducted to determine a stability window and to identify different bead geometries. A second study will focus on the quantification and analysis of internal defects observed during the printing of three-dimensional structures, by exploring various parameter sets within the stable deposition regime.

Author: Turani, Matteo

Title: Balancing processability, high strength, and work hardenability in an AlMgScFe alloy processed by PBF-LB

DOI: 10.5281/zenodo.15395727

In response to the growing demand for additive-manufactured components in aerospace, aviation, and motorsport applications, many aluminum alloys suitable for laser powder bed fusion (PBF-LB) have been developed, with a primary focus on achieving high strength. A common strategy to balance both processability and strength is to produce a very fine and equiaxed microstructure, with grain sizes smaller than a few micrometers. However, this approach often compromises other critical mechanical properties, such as work hardenability and uniform plasticity, which are essential for industrial applications and damage-tolerant structures.

In this study, an Al alloy is designed for PBF-LB processability while maintaining a coarse grain structure and solidification cracking mitigated through the addition of Fe with a close- to-eutectic content. The inclusion of Fe - typically regarded as an impurity in Al alloys - enhances the material's sustainability without negatively impacting its mechanical properties. In combination with the presence of elements, such as Sc, that can form strengthening precipitates upon heat treatment, iron contributes to a tensile strength exceeding 450 MPa. Experimental results also demonstrate improved work hardenability, enhanced thermal stability, superior high-temperature performance, good heat conductivity, and excellent resistance to intergranular corrosion.

These achievements offer a promising approach for optimizing aluminum alloy design tailored for PBF-LB applications and for meeting industrial requirements for both strength and applicability in demanding sectors.

Author: Turnali, Ahmet

Title: Exploiting additive manufacturing-induced cellular structures for the design of precipitation-strengthened alloys

DOI: 10.5281/zenodo.15234868

One of the key characteristics of additively manufactured (AM) alloys is the emergence of cellular structures, in which cell boundaries predominantly manifest as a combination of solute segregation and dislocation walls. Consequently, cell structures encompass regions exhibiting compositional and structural gradients when moving from cell cores to cell boundaries. This provides a distinctive window into the local variations in phase stability, which significantly influences the material's phase transformation behavior and can be actively leveraged during post-AM heat treatments to facilitate the site-specific formation of precipitates at cell boundaries.

Inspired by these insights, we computationally designed an Al10.5Co25Fe39.5Ni25 multi-principal element alloy to utilize this phenomenon. The alloy's composition was chosen to segregate Al, a fast-diffusing, precipitate-forming element, into the interdendritic regions during the AM process and aligned solute segregation with dislocation walls at the cell boundaries. This created a "pre-conditioned" state with an enhanced local chemical driving force and a reduced

nucleation barrier for precipitate formation before aging. Comprehensive multi-scale characterization, including in situ synchrotron X-ray diffraction (SYXRD), was performed to evaluate the influence of cellular structures on precipitation kinetics, precipitate size and volume fraction, and the evolution of mechanical properties after aging treatment relative to a reference condition in which cellular structures were removed via solution annealing before aging. The results are critically discussed to reveal the interplay between cellular structures and phase transformation behavior, offering key insights into engineering the microstructures of AM alloys via post-AM heat treatments.

Author: Varghese, Tony

Title: Microstructure and Deformation Behavior of Metastable Ti-Mo Alloys Fabricated by Powder Feeding Strategies in Laser Additive Manufacturing

DOI: 10.5281/zenodo.15303574

Additive manufacturing (AM) of binary alloys with dissimilar powder characteristics poses significant challenges in achieving compositional homogeneity and microstructural uniformity. These challenges are particularly critical in the fabrication of metastable  $\beta$ -Ti alloys, where compositional deviations at macro- and microstructural scales directly influence phase stability and deformation mechanisms. This study systematically evaluates the impact of powder feeding methodologies- mechanical powder mixing (PM) and double-hopper (DH) delivery-on the microstructure, mechanical properties, and deformation behaviour of Ti-15Mo (wt.%) alloys fabricated via directed energy deposition (DED) at a laser power of 800 W.

Microstructural analysis revealed that the PM approach, utilizing mechanically blended Ti and Mo powders, resulted in heterogeneous phase distribution along the build direction, with localized  $\alpha$ -phase precipitation due to Mo segregation with higher hardness ( $470 \pm 30$  HV) variation along the print direction. Conversely, the DH method, employing controlled, separate powder feed rates, facilitated uniform elemental dispersion, yielding a predominantly  $\beta$ -phase microstructure with minimal compositional fluctuations which resulted in limited hardness variation of  $325 \pm 25$  HV. Mechanical characterization under compressive loading demonstrated that PM specimens exhibited higher yield strength (850 MPa) compared to DH specimens (450 MPa), attributed to  $\alpha$ -phase-induced precipitation strengthening. However, alloys processed via the double hopper (DH) method displayed a 30% enhancement in work-hardening capacity, attributed to the retention of metastability achieved through precise compositional control. Deformation analysis confirmed twinning-induced plasticity (TWIP) as the dominant mechanism in both conditions, with  $\{332\} \langle 113 \rangle$  as the predominant twin system but the twin distribution was more uniform in DH samples. The DH approach is particularly suited for systems where parent powders differ significantly in density, as it effectively mitigates elemental segregation. This enables precise microstructural control and predictable mechanical behavior, supporting the use of multi-hopper systems in DED to ensure compositional fidelity and reproducibility in high-performance alloy fabrication.

Author: Vaddamanu, Satya Chaitanya

Title: Understanding Precipitation Kinetics in an Additively Manufactured Hot Work Tool Steel

DOI: 10.5281/zenodo.15425976

Additive manufacturing (AM) of tool steels often produces complex microstructures. Conventional alloys such as H13 present significant challenges in laser powder bed fusion (PBF-LB) due to their high carbon content, which leads to elevated residual stresses and an increased risk of cold cracking in the as-printed state. As a result, tool steels typically require modification or complete redesign to achieve optimal processability in PBF-LB.

Osprey HWTS 50 is a newly developed hot-work tool steel alloy specifically engineered for AM, featuring a reduced carbon content compared to traditional grades like H13. This adjustment, along with tailored levels of chromium, molybdenum, and vanadium, not only improves printability but also enhances tempering resistance and reduces susceptibility to cold cracking. The alloy's composition promotes the formation of temper-resistant vanadium- and molybdenum-rich carbides, rather than the chromium-rich carbides typically observed in H13, which is crucial for controlling the precipitation sequence and optimizing mechanical properties.

Heat treatment remains essential for tailoring the mechanical response of AM tool steels. However, the unique microstructures and presence of nanoscale precipitates in these materials mean that conventional interpretations of precipitation behaviour may not apply. This study investigates the precipitation mechanisms and sequences that arise from the modified alloying strategy in Osprey HWTS 50.

Both as-built and as-quenched samples underwent isothermal double tempering at 350, 575, and 650 °C. Atom Probe Tomography (APT) was used to analyse the size, morphology, and composition of the resulting precipitates. Directly tempered specimens exhibited higher concentrations of nitrogen than those subjected to quenching and tempering. In over-aged (650 °C) condition, vanadium-rich MC and molybdenum-rich M<sub>2</sub>C carbides could be distinguished. The evolution and chemical makeup of these precipitates allowed for the identification of phase transformations at various temperatures, defining the precipitation sequence in this alloy system.

Author: Van Petegem, Steven

Title: Microstructure and stress evolution in LPBF revealed by in situ X-ray and neutron Diffraction

DOI: 10.5281/zenodo.15426009

The development of microstructure and residual stress during laser powder bed fusion (LPBF) is governed by complex thermal histories involving rapid cooling and repeated reheating. To investigate these effects in real time, we applied complementary operando techniques to track phase transformations, strain evolution, and crystallographic texture formation during LPBF.

In the first study, high-speed in situ X-ray diffraction was used to examine phase evolution in hypo-eutectoid carbon steel. The measurements revealed a transition in the primary solidification mode from  $\delta$  - ferrite to austenite under rapid cooling, followed by the formation of martensite once the cooling rate exceeded the transformation threshold. Post-mortem analysis confirmed the presence of a lath martensitic microstructure with high hardness. In addition, both diffraction and simulation data indicated that cementite was the dominant carbide phase formed during intrinsic heat treatment (IHT). These results demonstrate how operando diffraction can resolve the timing and nature of solid-to-solid transformations, including tempering and carbide precipitation, under the unique thermal conditions of LPBF.

The second study focused on 2205 duplex stainless steel and employed operando neutron diffraction and Bragg-edge imaging to investigate residual stress and texture formation. Neutron diffraction enabled layer-by-layer tracking of strain evolution during LPBF, showing that stress redistribution occurs primarily within the first few layers beneath the heat-affected zone. Texture analysis revealed strong crystallographic alignment, which significantly influenced stress determination and highlighted the importance of accounting for orientation-dependent elastic constants. Bragg-edge imaging further mapped spatial variations in strain and texture throughout the bulk of the build.

Together, these studies demonstrate how real-time X-ray and neutron diffraction provide access to complementary length and time scales, offering a comprehensive view of the processes driving microstructure evolution and residual stress development in metal additive manufacturing.

Author: Vedani, Maurizio

Title: Fe-Cu multi-materials manufactured via laser directed energy deposition by in-situ alloying

DOI: 10.5281/zenodo.15309656

Copper-steel multi-materials and functionally graded materials combine the excellent electrical and thermal conductivity of copper with the high mechanical strength of steel. Although Fe and Cu are substantially insoluble at the solid stage, their combination can create a sort of composite material at the microstructural scale which can potentially provide special features to properly designed multi-material systems.

This study examines the microstructural, mechanical, and thermophysical properties of constitutive layers of commercially-pure Cu - 4130 steel structures fabricated via laser directed energy deposition using an in-situ alloying strategy. Four intermediate compositions were investigated: 100% 4130, 75% 4130 - 25% Cu, 50% 4130 - 50% Cu, and 25% 4130 - 75% Cu. The composition with lowest amount of Cu experienced solidification cracking due to large thermal stresses and insufficient liquid replenishment, while more abundant Cu-rich terminal liquid in other compositions could successfully backfill microcracks formed during early solidification stages. In general, Fe-Cu liquid phase separation and Marangoni convection generated a recursive macrostructure in samples, with copper and steel alternating as matrix and dispersed phase. Measurements of the thermal properties showed that interconnected Cu-rich regions in Fe50Cu50 and Fe25Cu75 could increase the diffusivity by ~50% and ~200%, respectively, compared to full steel samples. In situ tensile tests carried out inside a FEG-SEM allowed investigating the crack growth mechanisms of the different samples. These findings provide insights into the critical factors governing laser directed energy deposition of copper-steel multi-materials, contributing to process optimization and highlighting new design opportunities for multi-materials produced by additive manufacturing.

Author: Vela, Brent

Title: Bayesian Active Learning of Microstructure Transition in Rapid solidification Using Phase-Field Simulations

DOI: 10.5281/zenodo.15310079

This study investigates the mechanisms governing microstructure selection during rapid solidification, with a focus on the transition from cellular and dendritic to planar interface morphologies under conditions relevant to additive manufacturing. We employ a phase-field model that quantitatively captures solute trapping, kinetic undercooling, and morphological instabilities across a wide range of growth velocities ( $V$ ) and thermal gradients ( $G$ ), applying it to a binary Fe-Cr alloy as a surrogate for 316L stainless steel. By combining high-fidelity phase-field simulations with a Gaussian Process-based Bayesian active learning approach, we efficiently map microstructural transitions across the multidimensional space of composition, growth velocity, and temperature gradient.

Our phase-field results are compared to classical theories of rapid solidification. In particular, the classical KGT model accurately predicts the critical value of  $G$  above which the interface remains planar at any growth velocity. We observe that microstructures evolve from dendritic to cellular as the temperature gradient approaches this critical  $G$  value. Additionally, we identify unstable "intermediate" microstructures near the dendrite-planar boundary at low  $G$ , even in the absence of banding instabilities in the Fe-Cr system. Such "intermediate" microstructures are difficult to identify with conventional design of experiments, however using Bayesian active learning methods, we have successfully identified this "transient" solidification regime.

Overall, our results demonstrate the effectiveness of Bayesian-guided phase-field modeling in efficiently exploring complex microstructural transitions within high-dimensional parameter spaces, offering a powerful computational tool for tailoring process conditions to achieve desired microstructures and properties in rapidly solidified metallic alloys.

Author: Weidinger, Julius

Title: Accelerated Alloy Development for AM by Mimicking AM Process Conditions

DOI: 10.5281/zenodo.15295525

Nickel-based superalloys are extensively utilized in demanding environments characterized by elevated temperatures and corrosive atmospheres. In recent years, the application of additive manufacturing (AM) techniques, especially electron-beam powder bed fusion (PBF-EB), has gained significant attention due to their potential to enable design freedom, weight reduction, and advanced geometries. However, a major limitation of some nickel-based superalloys, particularly the highly  $\gamma'$  strengthened ones, lies in their pronounced crack susceptibility when transitioning from casting to additive manufacturing processes. The development of nickel-based superalloys with reduced cracking tendencies, tailored for AM, remains a time-intensive and costly challenge. The large number of constituents and their complex interactions impedes identifying simple cause-effect relationships regarding processability as well as mechanical properties and makes alloy development very challenging. Experimental alloy development is further complicated by the fact that atomizing powder of each potential alloy composition would be extremely time-consuming, expensive and, hence, impractical.

This contribution introduces Successive Electron Beam Remelting (SEBR) as a novel and cost-effective approach for alloy development for additive manufacturing with the PBF-EB process. The SEBR process involves iterative remelting of bulk alloy samples, wherein the melt pool depth is progressively reduced during successive remelting steps. The intention is to mimic the layer-wise solidification and microstructural evolution characteristic of PBF-EB processes, including the occurrence of AM-relevant cracking phenomena. Initial experiments have demonstrated the formation of cracks within and adjacent to the remelted zone produced by the SEBR process. The morphology of these cracks as well as the crack density exhibit a strong correlation with those observed in actual PBF-EB builds. Hence, the evaluation of crack susceptibility through SEBR appears feasible and may offer a rapid and cost-efficient pathway to assess the processability of novel nickel-based alloys for additive manufacturing without the need for powder.

Author: Yan, Wentao

Title: High-fidelity Modeling of Multi-Material Additive Manufacturing: Process, Microstructure, and Property

DOI: 10.5281/zenodo.15211277

Multi-material additive manufacturing opens a new avenue for materials design and synthesis, but also increases the complexity in the process-structure-property relationships. To this end, we have developed and seamlessly integrated a series of high-fidelity multi-physics models for multi-material additive manufacturing. Specifically, multiphase flow models using the coupled computational fluid dynamics (CFD) and discrete element method (DEM) simulate the motions of unmelted powder particles in the melting procedure of nano- and micro-particle reinforced composites. For the cases where different powders are melted for in-situ alloying, the model incorporates the major physical factors, e.g., the composition evolution due to evaporation and convection, the varying thermo-physical material properties dependent on the local chemical compositions, and the heat release/absorption due to alloying/chemical reactions. The microstructure evolutions at both the grain- and dendrite- scales are modelled using the phase field and cellular automaton methods. The mechanical properties and thermal stresses are simulated using the crystal plasticity finite element (FE) model, which incorporates the realistic geometry (rough surfaces and voids), temperature profiles and microstructures including the interactions between reinforcing particles and dislocations. These models have proven to be useful in revealing the physical mechanisms and guiding manufacturing process optimization, which have been validated against experiments.

Author: Zinoviev, Aleksandr

Title: Simulation-driven microstructure engineering: linking process, structure, and performance

DOI: 10.5281/zenodo.15310122

Tailoring microstructure for enhanced performance is a central objective in the advancement of metal additive manufacturing (AM). Achieving this goal requires a predictive understanding of how process parameters influence grain morphology, texture, and local heterogeneities, the key features that govern material behaviour. To support microstructure design in AM, we have developed an integrated computational framework that links process conditions to microstructural outcomes and mechanical properties across multiple length scales.

This framework combines melt-pool-scale thermal simulations based on the finite difference method, cellular automata-based simulations for microstructure evolution, and micromechanical simulations using crystal plasticity finite element method. An analytical method is also included for rapid estimation of effective elastic properties at the mesoscale. These tools have been validated experimentally for laser powder bed fusion systems and extended to accommodate directed energy deposition.

A distinguishing aspect of this work is its capacity to simulate grain structure evolution not only at the multi-layer, but also at the part scale. Using high-performance computing resources we achieved efficient cellular automata simulations of parts exceeding 1,000 mm<sup>3</sup> in volume. This capability enables targeted exploration of processing routes to design grain size, shape, and crystallographic orientation distributions aligned with desired performance outcomes.

By enabling direct links between AM process parameters, evolving microstructures, and resultant properties, this computational approach provides a foundation for the digital design of microstructure. It advances beyond descriptive modelling to support rational, simulation-driven microstructural engineering in AM.

Author: Kang, Hoseong

Title: Post-heat treatment effect on the microstructure and mechanical properties of directed energy deposited IN738LC alloy

DOI: 10.5281/zenodo.15172237

IN738LC alloy is one of the representative Nickel-based superalloys for high-temperature components, including gas turbine systems. As the lifetime of gas turbine systems getting longer, maintenance, repair and overhaul of Ni-based superalloy components becomes important issues. However, a conventional welding process has a limitation to apply high-grade Ni-based superalloys due to their high crack susceptibility. To overcome this problem, laser-based additive manufacturing (AM) has been developed but the application of high-grade Ni-based superalloy remains one of challenging issues. Because the biggest obstacles for depositing crack-free high-grade Ni-based superalloy are liquation cracking during solidification, a small laser-beam sized directed energy deposition (DED) was applied in this study. To explore the optimal processing window, response surface methodology was conducted to find the highest dimensional accuracy - relative density - hardness combinations. Based on the optimal DED parameters, crack-free IN738LC components were successfully built by laser-based DED. To control the microstructure and mechanical properties of DED IN738LC components, various post-heat treatments were conducted. Although the solution treatment was conducted at 1190 °C, homogenization was not completed in the DED IN738LC due to the solute drag resistance and pinning force from fine MC carbides in the as-built state. Also, the heat treatment step increment causes microstructural changes, including  $\gamma'$  phase growth and MC carbide decomposition in the IN738LC samples, and such microstructural changes affect both tensile and creep properties. This result represents that crack-free IN738LC components can be achieved by reducing heat affected zone during laser-based AM, and appropriate post-heat treatment required for AM components due to their different microstructure with the conventional IN738LC alloy.

Author: van der Linde, Carina

Title: Efficient Model-Based Framework for Microstructure Design in LPBF of Ti-6Al-4V

DOI: 10.5281/zenodo.15427555

The microstructure of Ti-6Al-4V plays a pivotal role in determining its mechanical and fatigue properties. However, the microstructure evolution during the Laser Powder Bed Fusion (LPBF) process depends critically on the thermal history of the process, which is inherently complex and cyclic in nature. Traditionally, favorable  $\alpha+\beta$  microstructures are achieved by decomposing the as-built  $\alpha'$ -martensite through post-process heat treatments, or through more recently investigated in-situ heat treatments. While both of these methods introduce additional process steps and complexity, this work focuses on leveraging LPBF process parameter tuning to directly tailor the microstructure.

The key challenge lies in navigating the vast and multidimensional design space of process parameters in LPBF, compounded by the scarcity of operando synchrotron data and hence reliance on mostly post-mortem microstructural analysis. To address this, we present a model-based framework that couples a computationally efficient thermal model with a microstructure evolution model including stable  $\alpha$ s-phase, martensitic  $\alpha$ m-phase and  $\beta$  -phase. This framework predicts microstructure evolutions across various parameter combinations, validated against experimental data.

Our approach enables rapid screening of thousands of parameter combinations– including volumetric energy density, layer thickness, interlayer time, and build plate temperature– at  $\sim 1000$  x faster than the scan-resolved models used in literature, yet with sufficient accuracy. This allows us to map attainable microstructures, identify optimal parameters, and solve practical challenges like preserving a favorable  $\alpha$ s+ $\beta$  structure under varying interlayer times or spatially tailoring microstructures while controlling  $\alpha$ s lath thickness. Since traditional forward exploration becomes increasingly tedious and computationally expensive when varying process parameters layer-wise, we also explore gradient-based inverse design to determine layer-specific parameters for targeted microstructures.

This work marks a step toward fully utilizing the LPBF process window for microstructure design by thermal-microstructural modeling and optimization, thereby minimizing trial-and-error and enabling accelerated development of engineered microstructures.