SECONDMENT AT ESA/ESTEC

Dr. Simon Malej, *Head of Advanced Manufacturing Department*

Kidričeva 24A, 3000 Celje, Slovenia

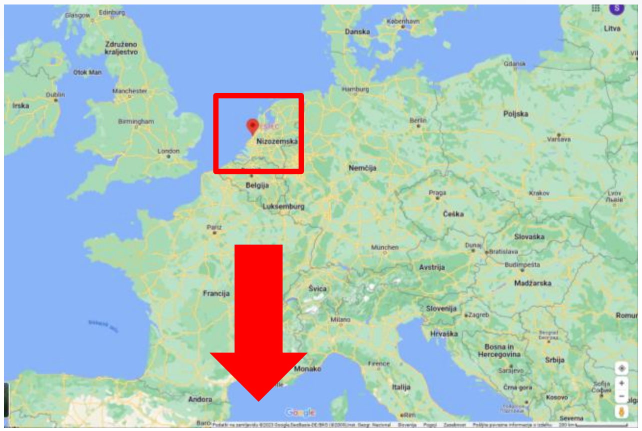
simon.malej@balmar.si *www.balmar.si*

BALMAR




Secondment of dr. Simon Malej

- Secondment duration: 01.03.2020-28.02.2023 (3 Years),
- Location: European Space Research and Technology Centre (ESTEC) in Noordwijk, the Netherlands



European Space Research and Technology Centre (ESTEC)

EU »Space Shuttle«

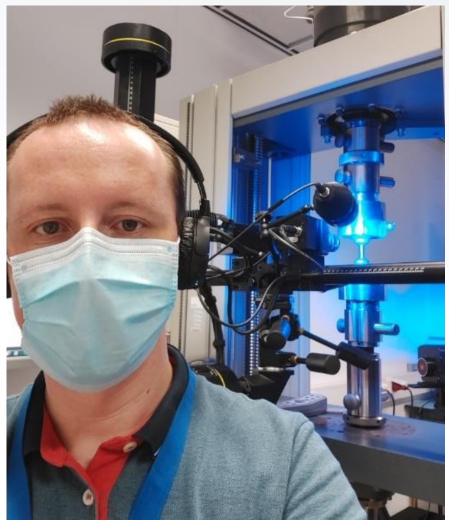
ESA organised Conferences

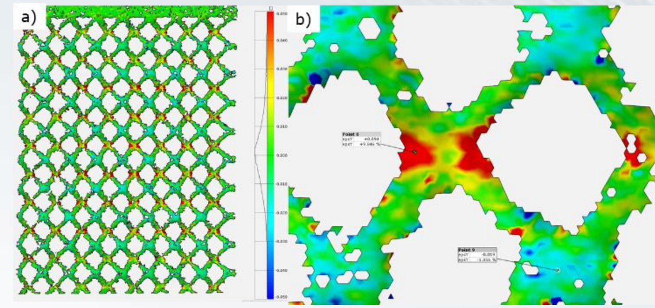
Clean Rooms for tests

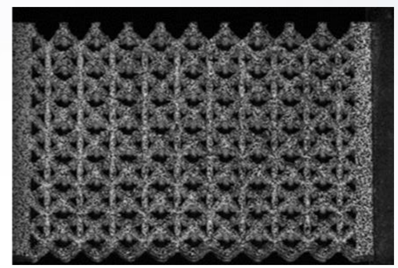
Mars Rover

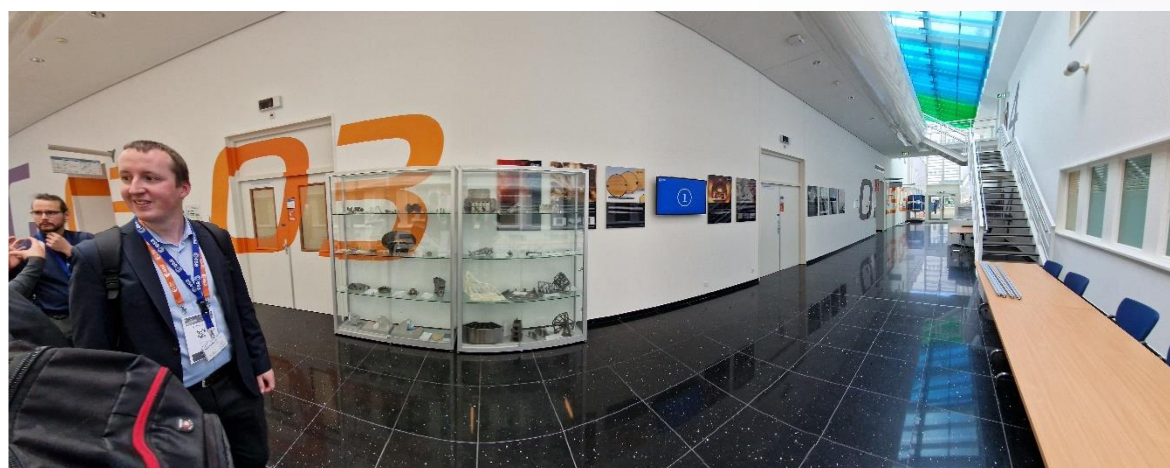
Secondment of dr. Simon Malej

- Department at ESTEC: Materials and Processes Section (TEC-MSP),
- Role in the department: Advanced Manufacturing Engineer.









Sent to the secondment by BALMAR

SPACE

Metal structural elements for space vehicles and metal propulsion elements.

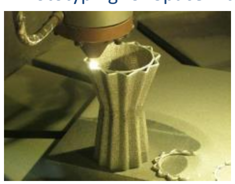
AVIATION

Airline, training in aviation and aviation consulting.

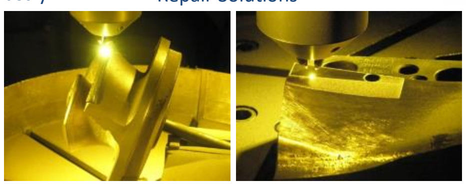
ADDITIVE MANUFACTURING

Direct Energy Deposition, Powder Bed Fusion, Hybrid Additive Manufacturing and LENS Technology.

Prototyping for Space Industry



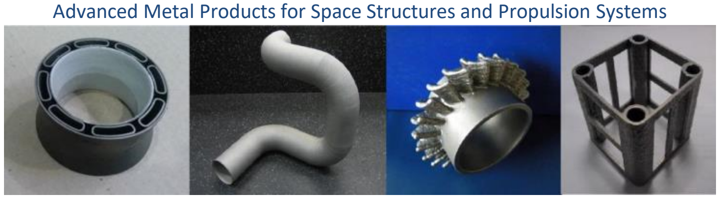
Repair Solutions



Hybrid Manufacturing of Space Components (Advanced Metal Fitting Design)

Airline Management, support Activities and Training (EASA AOC & ATO)

Advanced Metal Products for Space Structures and Propulsion Systems



Hybrid Manufacturing of Aerospace Components

Repair Solutions for Aerospace-Jet Engines

Major Partners and Customers:

esa European Space Agency · GE · Rolls-Royce · ITP In Service Support · Keppel Group · Kawasaki · ROBIN NEW AIRCRAFT · Mongolian Airways · IMT Inštitut za kovinske materiale in tehnologije

Activities during secondment:

- Active involvement on current ESA work activities (project evaluation, measurements, etc.)
- Mechanical/material test execution on ESA test equipment for BALMAR d.o.o. needs,
- Active work on ESA/BALMAR projects (GSTP) and presentation of other Slovenian projects,
- Mentorship to young trainees and researchers at TEC-MSP,
- Scientific and research papers preparation (with ESA as coauthor)*
- Support at organisation of ESA conferences and Workshops,
- Active involvement at Open Space Days at ESTEC,
- Organization of social events in the domain of Materials and Processes Section (TEC-MSP).

esa

ICAM22 International Conference on Advanced Manufacturing

Materials Science & Engineering A 878 (2023) 145229

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Hybrid additive manufacturing of Ti6Al4V with powder-bed fusion and direct-energy deposition

Simon Malej [a,b,e,*], Matjaž Godec [a], Črtomir Donik [a], Matej Balazic [b], René Zettler [c], Thomas Lienert [d], Laurent Pambaguian [e]

[a] Institute of Metals and Technology, Lepi Pot 11, 1000, Ljubljana, Slovenia
[b] Balmar D.o.o., Kidričeva Ulica 24A, 3000, Celje, Slovenia
[c] DIStech Disruptive Technologies GmbH, High-Tech-Park 24, A-8605, Kapfenberg, Austria
[d] Optomec, 3911 Singer N.E, Albuquerque, NM, 87109, USA
[e] European Space Research and Technology Center, Keplerlaan 1, 2201 AZ, Noordwijk, Netherlands

ARTICLE INFO

Keywords:
Hybrid additive manufacturing
Ti6Al4V
Tensile properties
Defects
Microstructure

ABSTRACT

A single component can often benefit from being built using more than a single processing technique. Here, we investigated the hybrid additive manufacturing (HAM) of Ti6Al4V using a combination of powder-bed fusion (PBF) and direct-energy deposition (DED). The aim was to identify critical areas and assess the performance of the hybrid process relative to the individual processes. The PBF sub-parts were built first, and then completed by DED. The builds were in the horizontal and vertical directions, so we could observe the mechanical anisotropy relative to the build direction. X-ray computed tomography, microstructural examinations, and tensile testing coupled with digital image correlation were employed to assess the parts. The as-built PBF surface can be used to build HAM Ti6Al4V samples with DED, thus eliminating steps like machining. The HAM samples built in horizontally had intermediate tensile strengths of about 1050 MPa, and in the vertical direction, about 860 MPa, i.e., lower than the DED samples. Strength-wise, horizontally built parts exceeded the requirements. However, a reduction in deposition size (especially $<10^2$ mm^2) promoted a different temperature evolution and, in the worst-case scenario, heat accumulation, which led to the formation of an undesirable microstructure and local plastic deformation in the DED part.

1. Introduction

Hybrid additive manufacturing (HAM) combines the advantages of two technologies to give a product properties, capabilities, complexities, designs and repairs unavailable with a single technique [1]. It is usually a combination of additive manufacturing (AM) technology and conventional processes, like machining [2]. In some cases, 2 a.m. technologies [3] or a secondary process, like metal forming along with the AM process [3], are combined in a process chain. Many combinations have been researched. These include wrought + powder-bed fusion (PBF) [4], forged + wire-arc AM (WAAM)/metal forming (in-situ) [3], and PBF + WAAM [5].

The authors have previously combined PBF and direct-energy deposition (DED) [6–8] in a process chain to produce net-shape parts, such as the structural parts for space satellites. PBF can produce geometrically complex parts with good accuracy (0.01–0.5 mm) and surface roughness (Ra = 7.8–11.1 μm [9] or higher [10]), good-to-excellent mechanical properties, and it has little need for post-processing (some machining of the functional surfaces, removing the dust from the surface and surface treatment are usually necessary) [11–14]. However, PBF is a relatively slow process (2–180 cm^3/h), while the size of the parts is limited by the size of the chamber where the part is built [13]. On the other hand, DED can produce semi-complex parts (without a support structure), achieve a high deposition rate of 125–500 cm^3/h, and involve larger chambers or no chamber at all (work volume limited by manipulation systems) [12,15–17]. The components built with DED tend to have poorer mechanical properties, a medium or lower accuracy (0.1–1 mm), and a higher surface roughness (Ra = 20–50+ μm) compared to components built with PBF [14,18]. The mechanical properties of DED tend to be lower than PBF due to larger average grain size, cell or dendrite spacing, more extensive segregation, and larger volume fractions of terminal solidification constituents

* Corresponding author. Institute of Metals and Technology, Lepi Pot 11, 1000, Ljubljana, Slovenia.
E-mail address: simon.malej@imt.si (S. Malej).

https://doi.org/10.1016/j.msea.2023.145229
Received 10 March 2023; Received in revised form 18 May 2023; Accepted 30 May 2023
Available online 1 June 2023

Materials Characterization 172 (2021) 110842

Contents lists available at ScienceDirect

Materials Characterization

journal homepage: www.elsevier.com/locate/matchar

Hybrid additive manufacturing of Inconel 718 for future space applications

M. Godec [a,*], S. Malej [a], D. Feizpour [a], Č. Donik [a], M. Balažic [b], D. Klobčar [c], L. Pambaguian [d], M. Conradi [a], A. Kocijan [a]

[a] Institute of Metals and Technology, Lepi pot 11, 1000 Ljubljana, Slovenia
[b] Balmar, Kidričeva ulica 24a, 3000 Celje, Slovenia
[c] Faculty for Mechanical Engineering, University of Ljubljana, Aškerčeva cesta 6, 1000 Ljubljana, Slovenia
[d] ESA European Space Research and Technology Centre, Postbus 299, 2200, AG, Noordwijk, the Netherlands

ARTICLE INFO

Keywords:
Hybrid additive manufacturing
Inconel 718
SLM-DED
Precipitates
Heat treatment

ABSTRACT

We present a detailed analysis of the hybrid fabrication of test parts made from Inconel 718 using two additive-manufacturing (AM) technologies: selective laser melting (SLM) and directed-energy deposition (DED). This combination should allow the manufacturing of larger parts with geometrically complex structures that no other technologies could achieve. However, it is necessary to ensure the consistency of the mechanical properties of such parts. The hybrid SLM/DED parts, as well as the individual SLM and DED processed parts, were evaluated in terms of microstructures and mechanical properties, to understand the mechanisms that control the properties. We introduced a custom solution treatment and aging to dissolve the Laves phase, which was present in the DED part, where it reduced the mechanical properties. For a hybrid part with excellent properties, there must be good bonding between the SLM and DED parts, while the DED process must be adapted to prevent δ-phase precipitation. This new technology has the potential to produce high-added-value metallic products for space applications, that benefit from the properties developed through hybrid AM.

1. Introduction

The space industry strives to combine high performance and reliability with reducing the weight of components. In the past few years, additive manufacturing (AM) has become an attractive tool in space applications as it enables near-final-shape products with only minor surface machining and reduced buy-to-fly ratios. Two popular forms of AM, selective laser melting (SLM) and directed-energy deposition (DED), are already being increasingly used for metallic materials [1]. SLM can produce parts with a high dimensional accuracy and excellent mechanical properties; however, it is time consuming and the chamber size of SLM machines limits the size of the parts that can be produced. DED is much quicker and does not have a maximum size limitation, but at the expense of less dimensional accuracy of the final parts and poorer mechanical properties. Therefore, a novel hybrid approach with a combination of the two techniques could lead to a broad range of products, aiming at maximizing the benefits offered by each technique. The main drivers for hybrid technology are manufacturing flexibility, cost savings and a faster production-to-market time.

Most publications mentioning hybrid technology refer to the combination of conventional and additive manufacturing [2,3] or to combining different materials with an AM process [2,4–6]. To the best of our knowledge, there are no reports of combining SLM and DED technologies. The closest attempt would be combining 2 AM approaches, which was recently reported for SLM and laser-metal-deposition manufactured AISI 316 L individual parts joined by laser metal deposition [7]. Hybrid printing could be a critical step towards the AM of large-scale components. AM, with its rapid melting, cooling and subsequent re-heating, typically leads to a microstructure with high residual stresses, and leads to the formation of a dislocation substructure and segregations [8,9]. The characteristics of AM technologies are many macro defects, particularly porosity and regions of un-melted powder. In addition, undesirable phases can form during AM [10], which are, together with the defects, detrimental to the mechanical properties [10,11]. This makes microstructure control the key challenge for AM, in particular for complex alloy systems.

Inconel 718 is a Ni-Cr-based superalloy used in high-temperature applications, like aviation and aerospace, because of its superior thermal and strength properties under extreme temperature and mechanical conditions [12,13]. The AM of Inconel 718 has been well reported

* Corresponding author.
E-mail address: matjaz.godec@imt.si (M. Godec).

https://doi.org/10.1016/j.matchar.2020.110842
Received 7 August 2020; Received in revised form 5 December 2020; Accepted 19 December 2020
Available online 26 December 2020