Whitepaper: Balancing consolidation rate & minimum feature size for high-tech titanium serial parts

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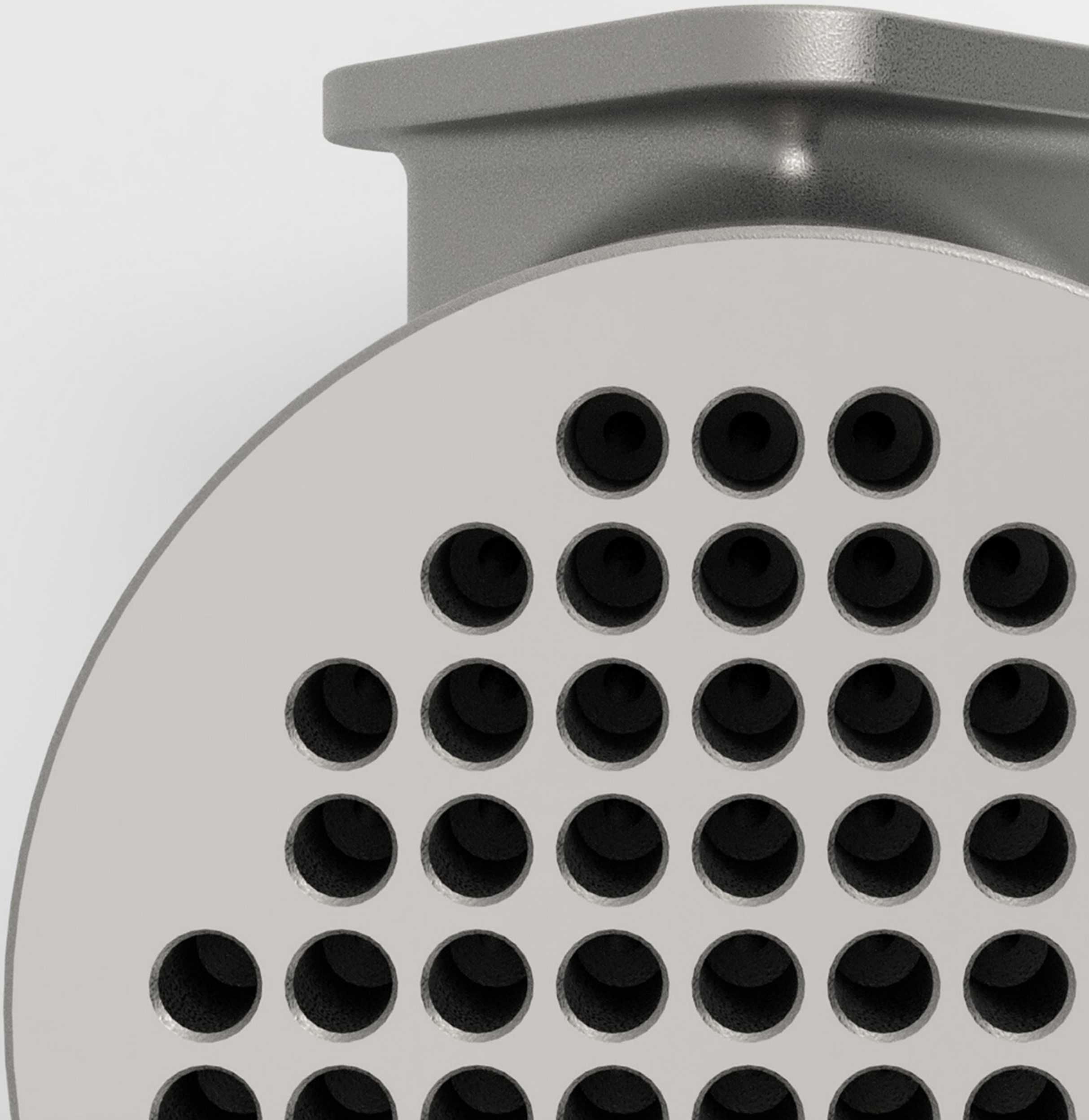

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Balancing consolidation rate & minimum feature size for titanium parts

This whitepaper demonstrates how Additive Industries are able to utilise the open architecture of the MetalFab system to support our customers in unlocking the potential of metal AM for serial production applications in the High-Tech sector. By developing parameters specific to a family of parts, our Additive Studios team were able deliver a Titanium Ti6Al4V process to customer NTS that balanced the consolidation rate needed to meet the requirements of their business case, whilst delivering high quality material properties and density for thin wall features on parts required to operate under strict conditions in a vacuum environment of semiconductor equipment.

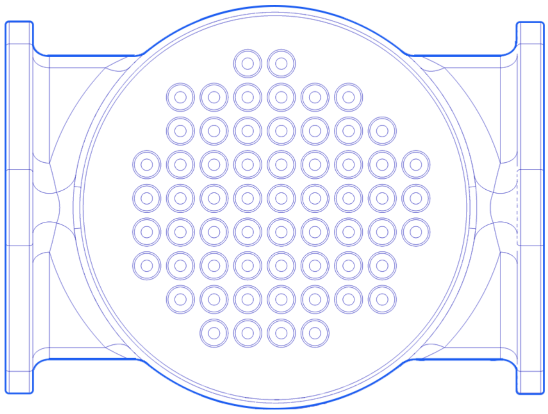
Introduction

As Metal additive manufacturing (AM) technologies become more mature and widespread for serial production applications, more industries are adopting this technology to provide a competitive advantage in their business. Laser Powder Bed Fusion (LPBF) is a technology that is beginning to offer opportunities within the High-Tech sector, where companies such as NTS Group at their Hengelo facility in the Netherlands are using Additive Industries MetalFab equipment to manufacture serial production parts for the semiconductor industry. Whilst NTS have been successfully delivering many production parts using the technology, certain applications require more development to meet the engineering requirements for demanding operating conditions, such as tight dimensional tolerances, thin wall structures or surface finish requirements.

This Whitepaper looks at a specific case where the Additive Industries' Additive Studios' consulting team were asked to develop a process parameter set for Titanium Ti6Al4V which achieved fully dense thin walls for a serial production application which would be operating under high vacuum conditions, and shows the steps taken to develop such a set of parameters based on a customer requirement.

In the semicon industry AM is gaining popularity in applications where internal channel structures are integrated in a part - here AM offers advantages over the traditional approach as it allows production as a single piece with complex channels flowing in multiple directions. Conventionally, you would see parts constructed of multiple parts which are bonded, welded or brazed together to make a leak or pressure tight construction. With AM, the manufacturing process is simplified resulting in shorter lead times and lower cost.

Typical applications in the High-Tech sector are cooling housings, vacuum grippers and manifolds. For these applications, the channels are critical in the performance of the part and must be as close as possible to the outer surface for cooling performance, or within a tight volume or as light as possible.



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Optimisation of parameters - approach

Optimising process parameters for high build rate and thin wall features is a challenging task. where it is necessary to find the right balance between two requirements which often require different process parameters. More often than not, it is required to split the part geometry into bulk and thin wall regions to enable the respective parameters to be applied where they are needed. Therefore, it is important to carefully evaluate and adjust the process parameters such as laser power, scan speed, hatch spacing, and gas flow to achieve the desired build rate and wall thickness without compromising the part quality.

In this project, the Additive Studios team was tasked by NTS with developing a set of parameters for the MetalFab to print leak-tight Ti6Al4V thin-wall parts of 0.4mm with density of 99.8% or higher to meet the demands of a vacuum application in the Hi-Tech sector. The challenge was to create a parameter set that would not only be able print the thin-wall geometries consistently of this density but also ensure the production of bulk parts were without discrepancy in mechanical properties. The general purpose set of Ti6Al4V parameters — developed targeting a relatively high build rate of 33 cm^3/h to manufacture bulk components with 60µm layer thickness — was found to be too aggressive for printing these specific thin-wall geometries. As a general purpose, balanced parameter set it is designed to cover a broad base of applications from small to large, but this broad scope means that the parameter is not validated below wall thicknesses of 1mm. When applied to much thinner walls an issue arose due to excessive energy density in very short hatch vectors, leading to the appearance of keyhole defects at 0.4 and 0.5mm thickness, as shown in the figure below. Therefore it was clear that further refinement of the parameters was necessary to meet the project requirements, which would be carried out using the application of a Design of Experiments (DOE) approach.

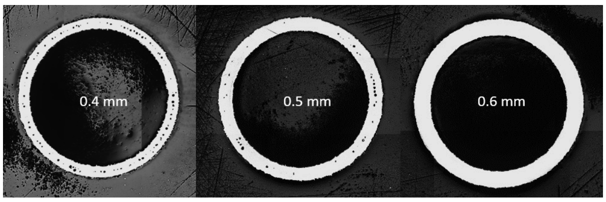


Fig. 1 - Keyhole defects at 0.4 & 0.5mm wall thickness

DOE can be simply explained as a statistical technique used to design experiments that can efficiently determine the relationship between input variables and output responses. In the context of LPBF, DOE can be used to identify the key process parameters that affect the part quality and determine the optimal settings for these parameters in a very simple stepwise methodology as shown in Figure 2. The experimental design can include any process parameters such as laser power, scan speed, powder characteristics, and gas flow rate, and their interactions can be evaluated using statistical tools such as analysis of variance (ANOVA). By conducting a DOE, it is possible to obtain a comprehensive understanding of the process, which can help in developing a robust and reliable process for LPBF for any applications.

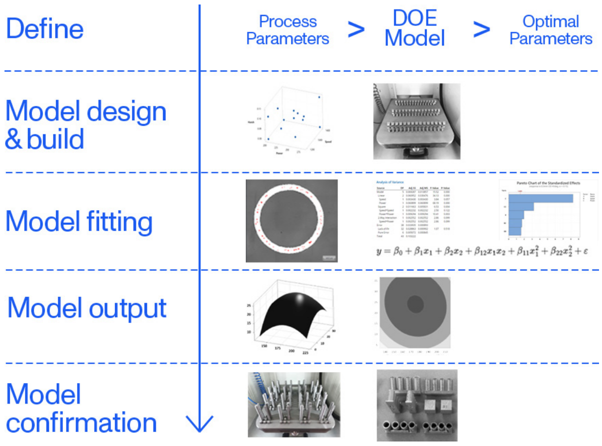
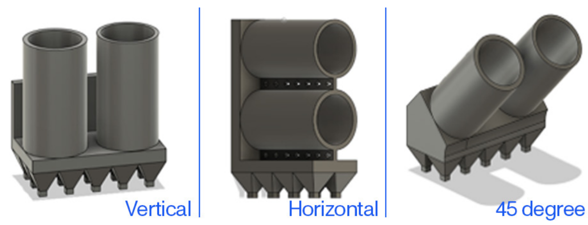


Fig. 2 - Stepwise DOE method to optimise parameters

The first stage of the development is to determine a baseline using the existing parameter set, with a range of representative geometries, in various orientations. To enable this various thin wall specimens are designed which can be built, mounted and polished to determine the key areas to focus the optimisation.



From this point the first set of experiments are designed and executed with the samples analysed optically with size key responses - two thicknesses in three orientations.

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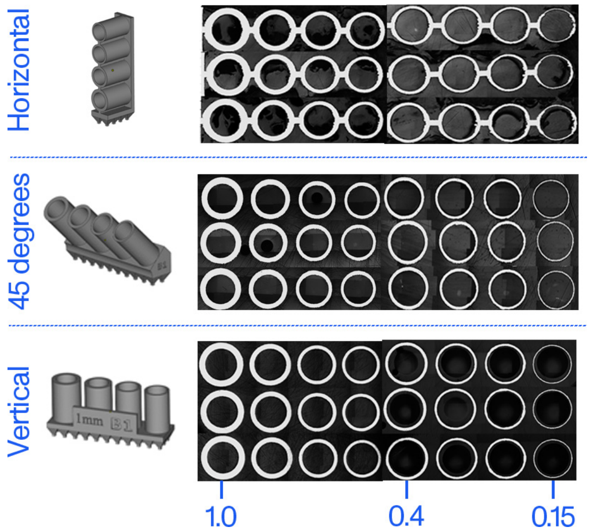
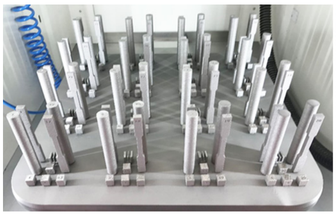
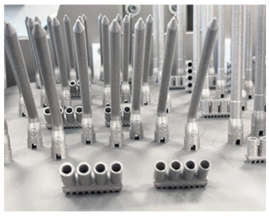
The result of this experiment leads to the down selection of four parameters which are compiled into a build and produced for validation, analysis and ultimately final selection. The results of this job showed an optimal parameter was easily achieving the density requirements of 99.8% and wall thickness of 0.4mm - in fact it is possible to achieve densities of >99.95% at this thickness with the optimal parameter set. Further to this, it was shown that wall thicknesses as low as 0.15mm were possible with densities >99.8%.



The final stage of the process is to produce a series of final material qualification builds utilising the new parameter set to ensure they are robust and repeatable in a production scenario. These jobs include standard material test specimens including vertical and horizontal tensile test specimens, standard density cubes, thin section structures and surface roughness samples produced at 16 locations across the baseplate. Density cubes, thin sections and surface roughness specimens are analysed through Additive Industries internal procedures and a total of 64 tensile test bars are tested following the ASTM E8 standard through an approved external test house. Further to this, a series of net shape, flat dog bone type bars are produced across the build plate and tested in as-built condition.





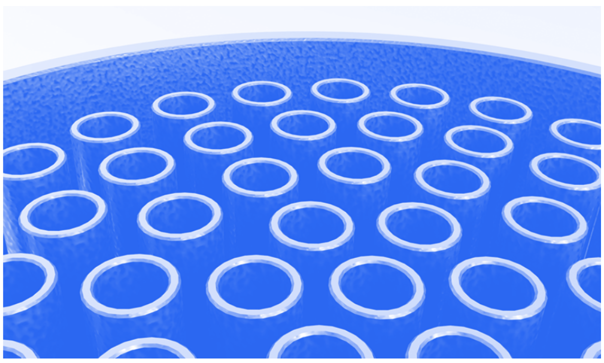
It is confirmed through this procedue that the parameter meets the requirements, notably:

- Acceptable productivity rate for business case - 100cm^3/h (4 lasers)
- Mechanical properties exceed ASTM standard
- Surface roughness 8.5µm Ra for all surfaces
- Density >99.95% @ 0.4mm wall thickness
- Density >99.8% @ 0.15mm wall thickness

Conclusion

By scientifically applying DOE approach using an AM-customised response surface model, it is demonstrated that one set of optimized parameters can achieve a relatively high consolidation rate of 25 cm^3/h per laser, which still significantly reduces the cost per part, while achieving the minimum feature size down to 150 µm with a typical tolerance of 15 µm. The part quality is certainly not compromised: >99.8% density is achieved across the build plate for both thin-wall and bulk samples, regardless of build orientation. The absence of near-border porosity or any interconnected porosity in the part ensures leak tightness in thin wall features which was confirmed by the customer during physical testing. Additionally, the consistent surface roughness across the full build plate with Ra values under 10 µm ensures high precision and quality of the printed parts.

Furthermore, the optimized process parameters also ensure consistent mechanical properties across the full build, which exceed the minimum requirements for Ti64, making the final products more durable and high-performing. Different sets of tensile bars were fabricated at 16 different locations across the full build plate using four lasers. These bars were subsequently machined and tested by a NADCAP-approved supplier in accordance with ASTM E8 standards. The recorded median values for the Ultimate Tensile Strength, 0.2% Proof Strength, and Elongation at break were 1278 MPa, 1136 MPa, and 10.5%, respectively. These consistent mechanical property results demonstrate the robustness of the process which has significant implications for the production of high-performance complex components with one parameter set.



White paper:

At Additive Industries, our objective is the success of our customers in achieving the lowest cost per part at market leading quality.

We pride ourselves on our flexibility to work with our MetalFab users in achieving their industrial goals.

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