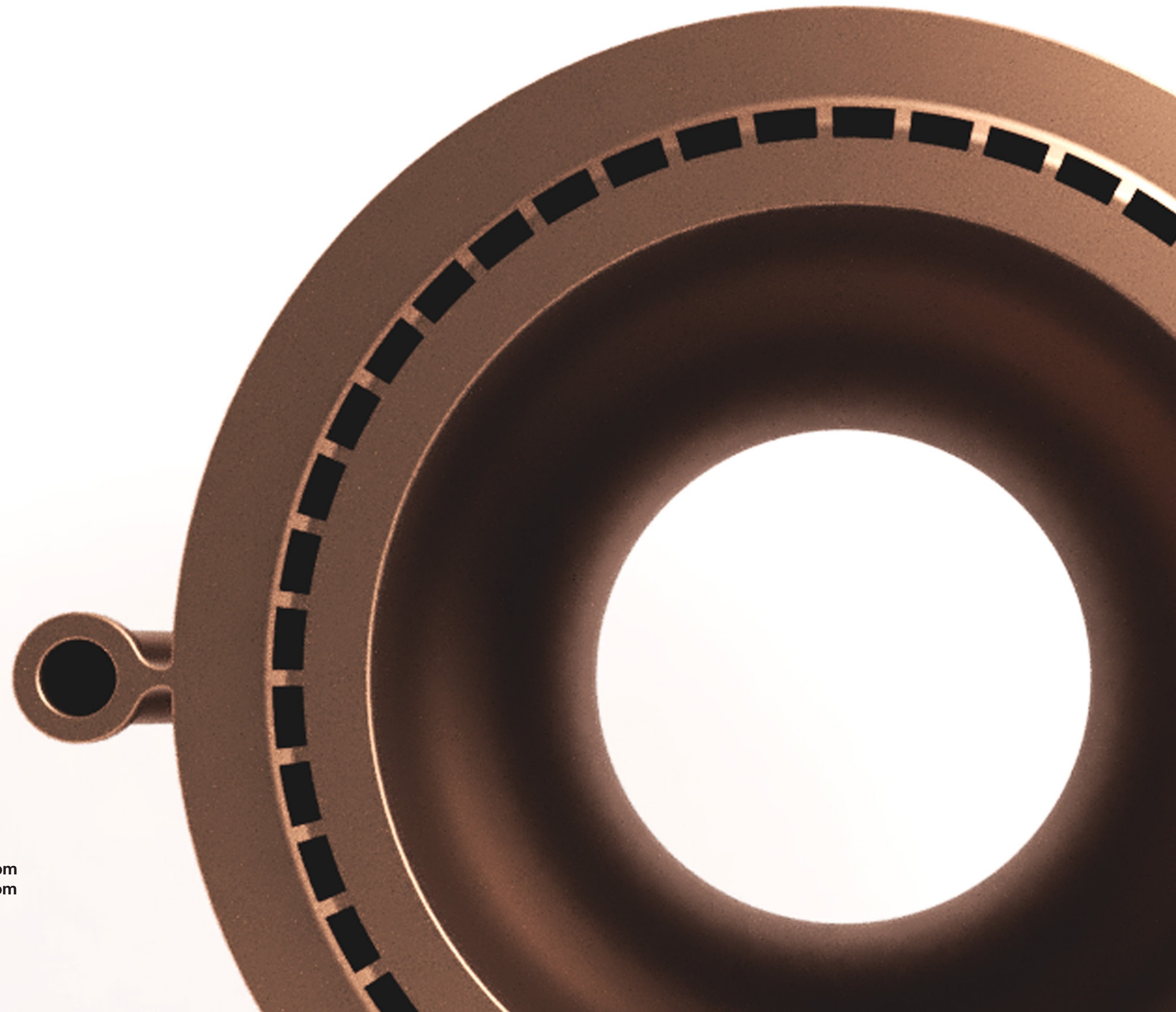
Whitepaper:
Production of high quality GRCop-42 copper alloy parts with MetalFab

Additive Industries b.v.
Achtseweg Zuid 155,
5651 GW Eindhoven,
The Netherlands
T: +31 (0)40 2180660



www.additiveindustries.com
info@additiveindustries.com

Production of high quality GRCop-42 copper alloy parts with MetalFab

Additive Manufacturing, and in particular Laser Powder Bed Fusion (LPBF), offers many benefits for the space and aerospace sector by unlocking novel design possibilities which are driving performance in the industry. This can be taken a step further when novel material alloys are also developed and tailored to the LPBF process.

This white paper shows the ability of the MetalFabG2 series hardware to additively manufacture parts made from GrCop-42 copper alloy. Through the process parameter development, Additive Industries have been able to achieve a high-quality process, showing good mechanical properties and high density of the material within the material specification published by NASA.

Introduction

GRCop42 is a copper-chromium-niobium alloy consisting of 4% Cr and 2% Nb. The material is part of the GRCop-alloy family developed by NASA, with potential applications for rocket engine components. The high interest from NASA, as well as other space flight companies in this copper alloy is due to the high thermal conductivity, combined with robust strength at higher temperatures, as well as the excellent creep resistance - all of which contributes to a highly beneficial material for aerospace and satellite applications.

NASA has extensively developed both the GRCop-84 and GRCop-42, first in the extruded wrought form, and now investing resources in developing the materials using additive manufacturing (AM), specifically the laser powder bed diffusion (LPBF). This modern technology offers significant advantages to reduce lead times and production costs, especially for manufacturing complex components such as liquid rocket combustion chambers.

The MetalFab system is well suited to processing this type of material, with its automated powder extraction and fully enclosed powder management and recirculation ensuring the quality of the powder is maintained throughout production cycles. Further to this, the 4 x full field lasers across a 420 × 420mm build area make it well suited to producing large circular parts with high efficiency of the lasers when assigned by the Dynamic Laser Assignment (DLA) software tool.

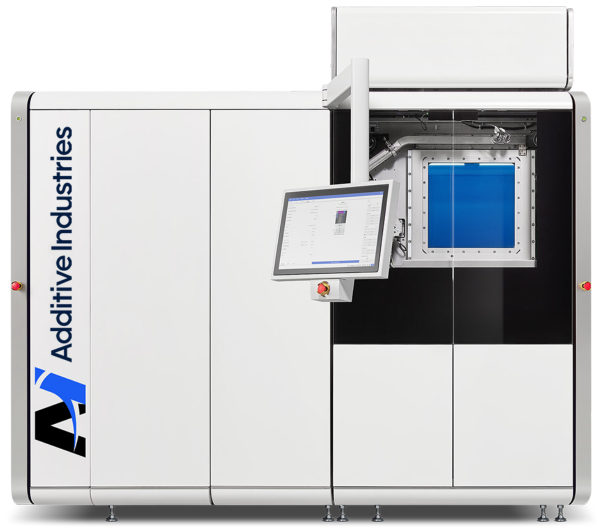


Fig 1 & 2: Rocket nozzle test part and MetalFab G2 Core system

Additive Industries
B.V. Headquarters,
Eindhoven,
The Netherlands
T: +31 (0)40 2180660

Additive Industries
North America, Inc.
Camarillo, United
States of America
T: +1 805 530 6080

Approach

Printing copper alloys with LPBF presents some challenges, especially with copper's high reflectivity and high thermal conductivity. Conventional lasers used in LPBF systems using near infrared light (around 1µm wavelength) commonly struggle to deliver enough energy to melt the powder, since a high amount of energy is reflected by the copper. And with enough energy to achieve melting, the high thermal conductivity of copper also causes large local thermal gradients in the melt zone, further causing poor melting, de-lamination, distortion and eventually build failure.

Additive Industries has been able to utilise its MetalFab technology to mitigate these common problems with copper and develop a process parameter to print GRCop-42 into fully dense parts, with optimal density and mechanical properties.

Specific strategies to work with GRCop-42's special properties include using a heated print bed, constantly held at 170°C, which decreases copper's reflectivity and with a high initial energy density, the melting process is significantly improved. The thermal conductivity is significantly reduced by higher contents of chromium (Cr) and niobium (Nb) in the alloy, which help in controlling the heat dissipation, hence, the Cr and Nb content in the powder should be precisely controlled.

Process development was carried out using the application of a Design of Experiment (DOE) approach, with the purpose of finding the most optimal settings of material parameters and machine configurations for printing the copper alloy. By conducting the DOE, important process parameters such as layer thickness, laser power, scan speed, gas flow setup and oxygen level have been developed. Additive Industries has developed a set of material parameters and machine configuration that is capable of manufacturing fully dense GRCop42 parts with a layer thickness of 40µm, printing with 4 full-field lasers with a built rate of 10,8 cm3/h per laser, achieving optical density of ≥99,8% across the build plate.

Transition from a traditional manufacturing method to additive manufacturing with laser powder bed fusion will require extensive material characterization, to ensure the technology can produce similar thermo-physical and mechanical properties. In the early stage of process parameter development for GRCop42, a standard qualification build was printed to analyse the density and mechanical properties achieved by the machine. Density cubes, thin section structures, surface roughness samples and vertical and horizontal tensile bars were built at 16 locations across the build plate, as shown in figure 3, 4 and 5.

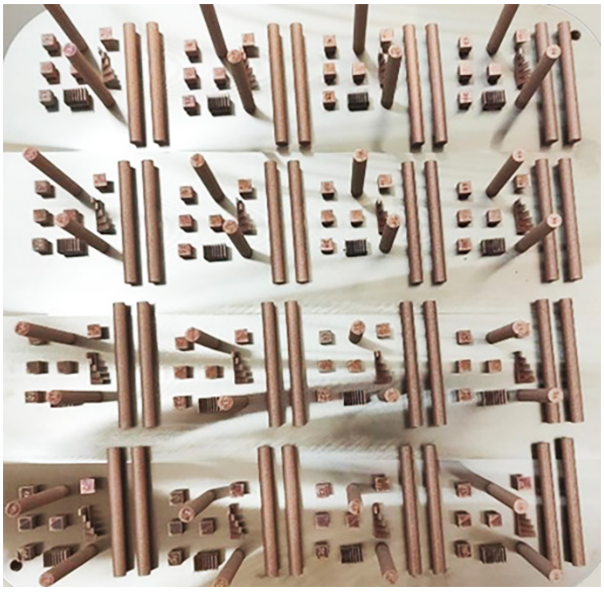


Fig 3: GRCop-42 parameter sign off build job overview


Fig 4: GRCop-42 parameter sign off build job

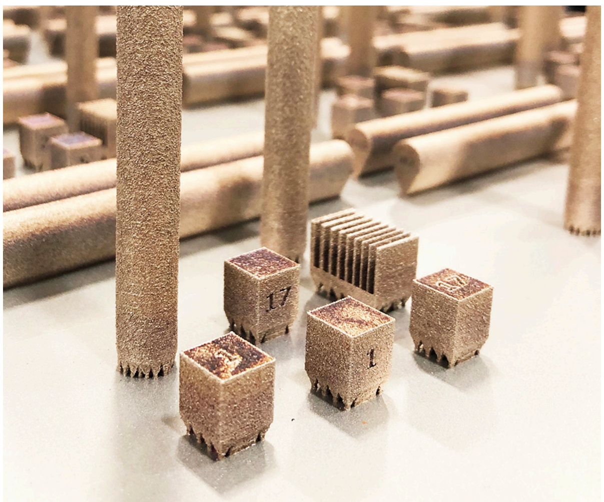


Fig 5: GRCop-42 parameter sign off build job - density & thin wall

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Results

Density cubes were measured by optical measurement method as per internal process. Figures 6 and 7 below show the optical density data on both XY and XZ plane, results consistently above 99,8% density across the build plate. There are no lack-of-fusion defects observed on any samples, indicating adequate melt pool depth which ensures the inter-layer overlap between layers.

Fig 6: Density cubes cut at XY and XZ planes

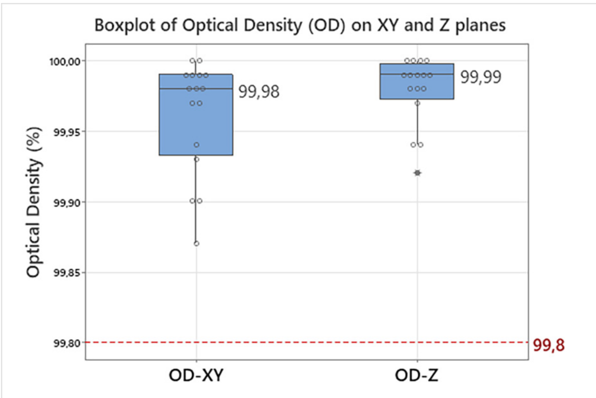

Fig 7: Optical density in XY and XZ planes achieving consistent results above 99,8%

Thin section samples were also produced, with different wall thickness sizes next to each other. With the optical microscopy it was determined that the parameter set could achieve dense and controlled thin walls of <0,5 mm.

Fig 8: Thin wall samples - thickness range 0.15 - 1mm

Tensile bars were tested according to the ASTM E8 standard in its as-built condition with vertical and horizontal orientations. Consistent mechanical properties were achieved across the full build plate with multi-lasers, showing an average of 528 MPa ultimate tensile strength (UTS), 296 MPa yield strength, and 27% elongation at break for the vertical bars. For the horizontal bars, higher UTS (545 MPa) and yield strength (334 MPa) average were achieved, with a slightly lower elongation value at 25%. The test results are shown in the box plot charts in figure 9 below.

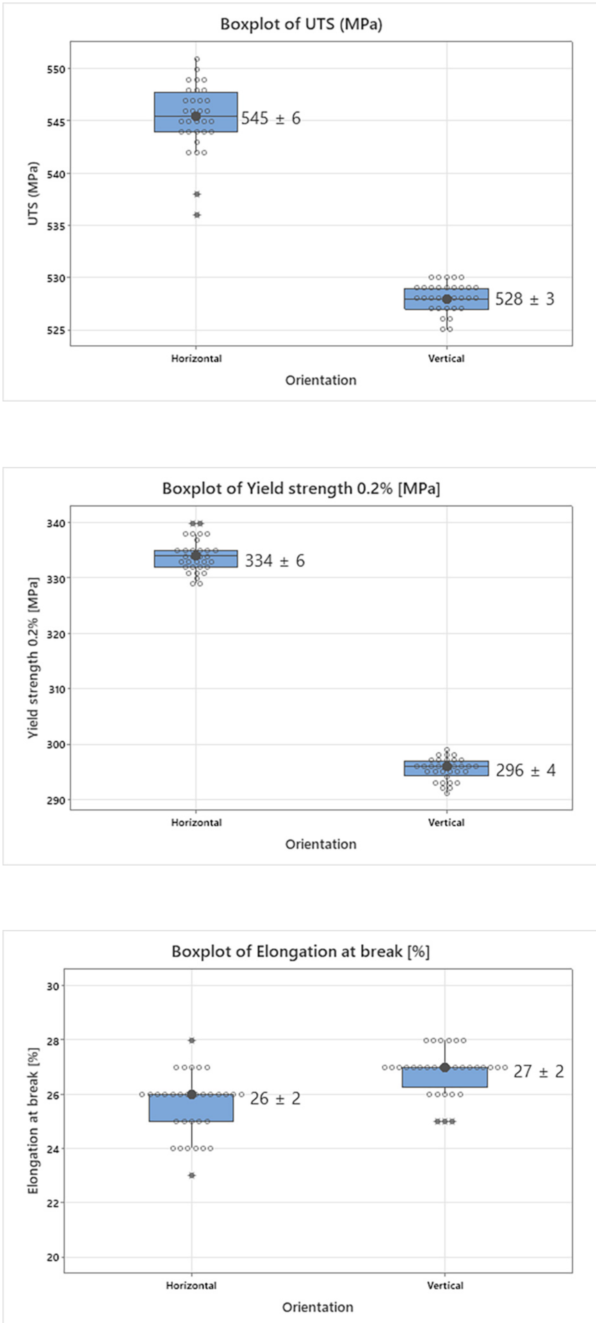

Fig 9: Mechanical properties of tensile bars

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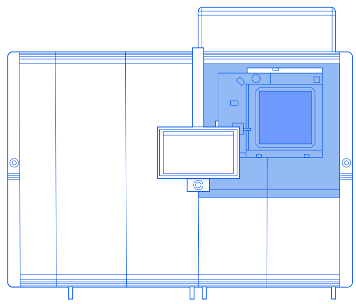
Conclusion

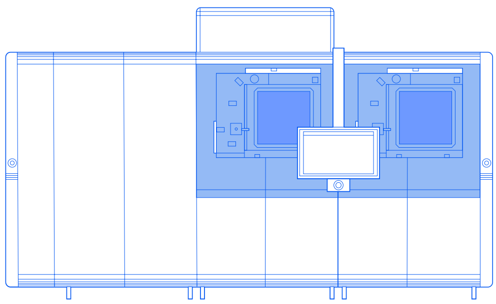
Additive Industries have successfully developed a process parameter set to produce high quality parts in the copper alloy GRCop-42, developed by NASA, in the MetalFab G2 system. Further to this, the ability to cycle and run this material in a highly controlled and enclosed environment to ensure material consistency and quality over time is demonstrated, with the powder batch used as per the NASA specification with a 10-53µm particle size distribution.

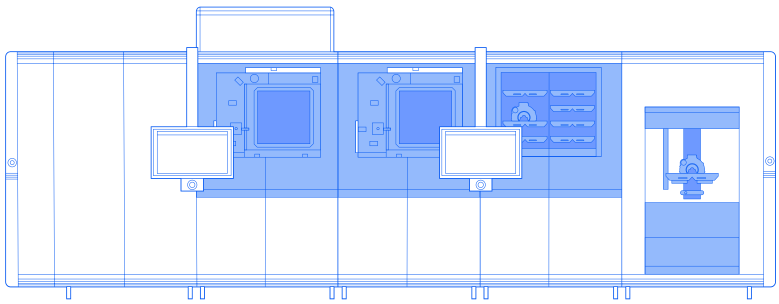
Demonstration parts have been produced to show the capability of this material within the MetalFab system, as shown in figure 10, and a Material Datasheet is available to download on the Additive Industries website (https://www.additiveindustries.com/copper-based-alloys).

A high level of consistency of material quality across the bed has been proven with a range of features from thin walls through to bulk material tested, which shows robustness in the combination of material, parameter set and machine for producing a wide range of geometries, targeting applications in the space sector.

Fig 10: Rocket nozzle demonstration part produced on MetalFab system with the GRCop-42 alloy







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.

To find out more, contact us at:
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Contact details

Additive Industries b.v.
Achtseweg Zuid 155, 5651 GW Eindhoven,
The Netherlands
P.O. Box 30160, 5600 GA Eindhoven,
The Netherlands
T: +31 (0)40 2180660

Additive Industries North America, Inc.
Process and Applicati ons Development Center
1250 Avenida Acaso, Unit H, Camarillo, CA 93012,
United States of America
T: +1 805 530 6080