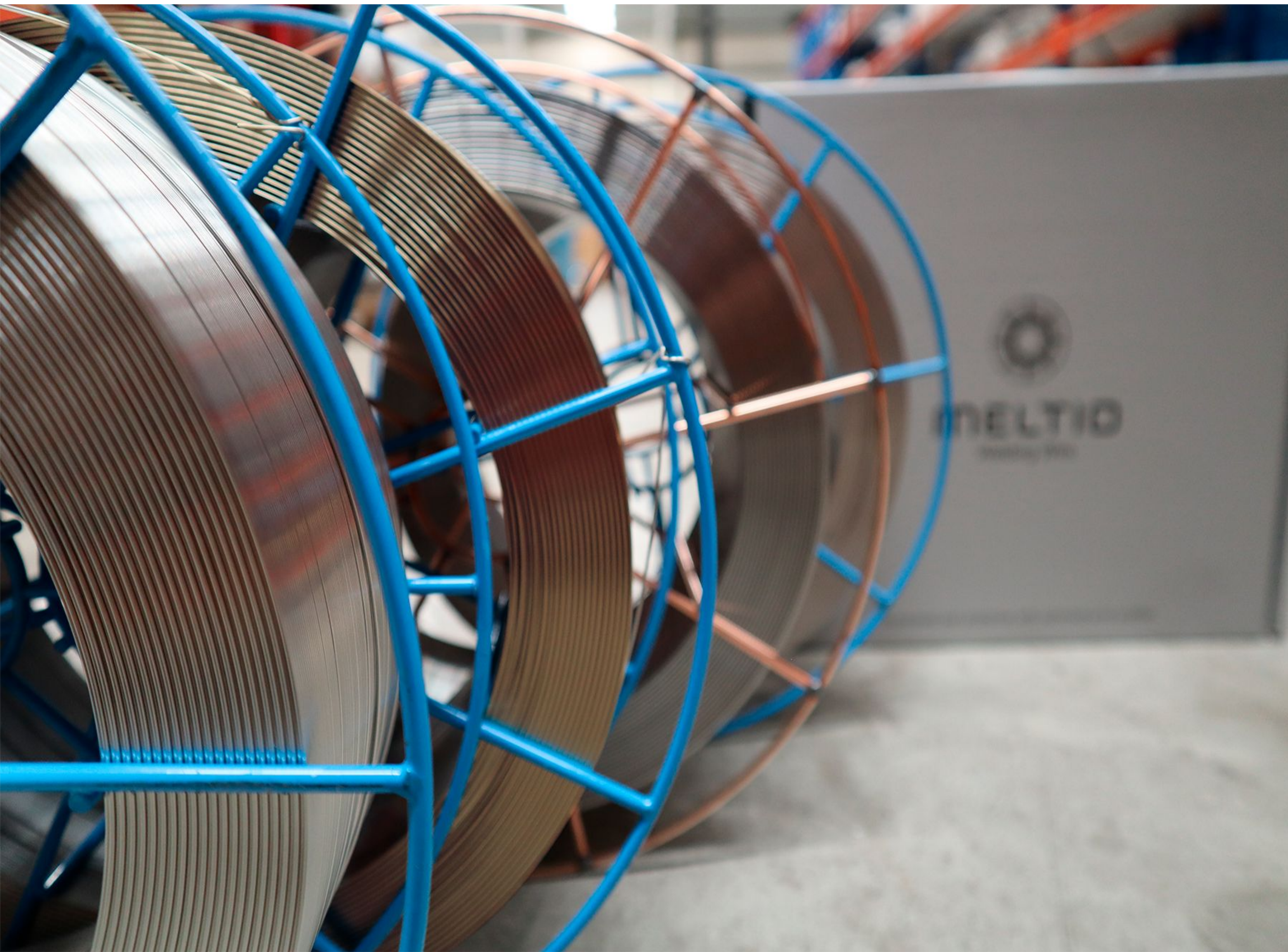
Meltio

Materials Characterisation Handbook

V6.0 / January 2026



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Introduction

In recent years, **additive manufacturing (AM)**, also known as **3D printing**, has emerged as an innovative technology revolutionizing the manufacturing industry. This disruptive technique enables the creation of complex geometries and intricate designs that were previously unattainable through conventional manufacturing processes. One of the areas that has experienced the most significant advancements in additive manufacturing is the **production of metallic materials**.

Meltio's use of **metal wire as feedstock** has led to substantial improvements in deposition control, material waste reduction, enhanced operational safety, and broader compatibility with a wide range of metallic material families. This wire-based approach ensures a stable and reliable material flow, resulting in smoother and more consistent additive manufacturing processes.

By leveraging these advantages, Meltio has not only optimized its processes but also expanded the scope of additive manufacturing applications. This ongoing commitment to innovation and material development continues to unlock new possibilities and extend the capabilities of Meltio's technology, offering users a wide array of material options and parameterization tools for their additive manufacturing needs.

In this document, Meltio has compiled all internal knowledge and information regarding materials with the aim of sharing it with the community. Here, you will find a detailed overview of all tested materials, including their characterization and parameterization for Meltio machines. The document also includes guidance on **creation of print profiles, material characterization**, **post-processing**, **heat treatments**, and **dual-material printing recommendations**, among other key topics.

Meltio Laser Head Specifications

	Infrared	Blue	Blue (High Power Option)
Available in:	M450, Meltio Engine v2 & v3	M600 & Meltio Engine Blue	Meltio Engine Blue
Laser power (Total / Per diode or Fiber)	1200W / 6 x 200W	1000W / 9 x 120W	1400W / 9 x 160W
Beam Shape	Matrix beam, Circular	Matrix Beam, rectangular	Matrix Beam, rectangular
Energy Distribution	Polar array of 6 beams approximating a top-hat energy distribution within the spot.	Polar array of 9 beams approximating a top-hat energy distribution within the spot.	Polar array of 9 beams approximating a top-hat energy distribution within the spot.

The Nature of Laser

Light **A**mplification by **S**timulated **E**mission of **R**adiation.

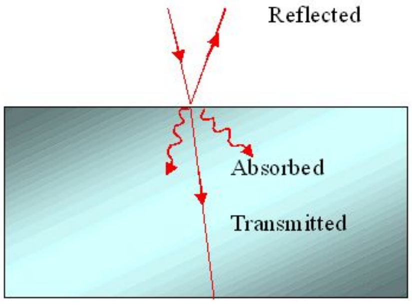
Meltio's blue **multi-laser approach is cost-effective**, outperforming expensive single high-power blue lasers, while **improving energy efficiency and sustainability** over infrared

Planck-Einstein Equation:

$$E = h \cdot f = \frac{h \cdot c}{\lambda}$$

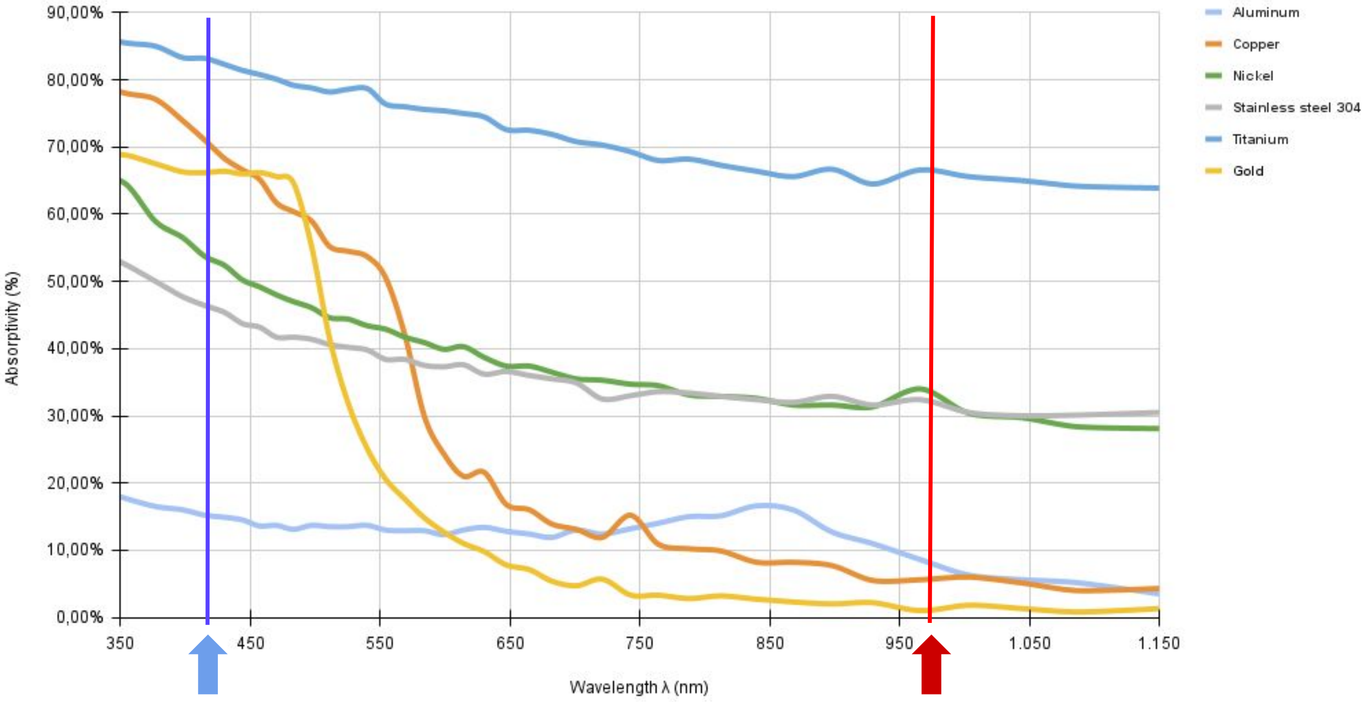
$$E_{976} = \frac{hc}{976 \times 10^{-9}} \approx 1.27\,\mathrm{eV}$$

$$E_{450} = \frac{hc}{450 \times 10^{-9}} \approx 2.76\,\mathrm{eV}$$



Blue wavelength offer higher photon energy which is **absorbed more efficiently by metals** compared to **Infrared.**

Materials Absorptivity to different wavelengths



Blue = 450 nm

IR = 976 nm

NASA TN D-5353, *Solar Absorptance and Spectral Reflectances of 12 Metals for Temperatures Ranging from 300 to 500 K*, E.W. Spisz, NASA Technical Note, Lewis Research Center, 1969. Available at: https://ntrs.nasa.gov/citations/19690024595

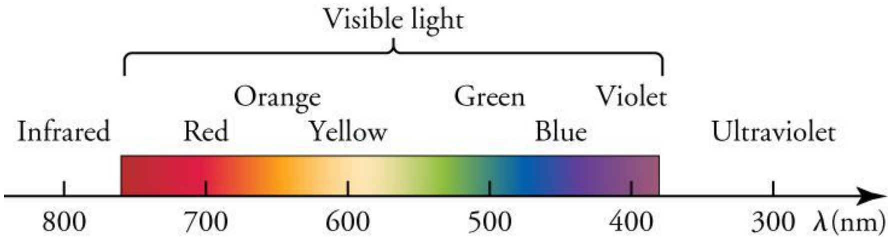
Material Parametrization

Keep in mind that every material is different. Therefore, the procedure for specific materials may vary. This guide is a basic introduction on how to parametrize a new material for the Meltio Engine Blue and may be used as an initial point of reference.

Considerations for Parameterization

There are a few things that should be considered about the new material to be parameterized.

- Will this material be able to absorb much energy from the laser beam of the Meltio Blue (450 nm wavelength)?
- Does it get oxidized really easily?
- What are the required mechanical properties?



Material Printability

After testing more than 50 different materials of all the material families, Meltio determine that in most of the cases, an alloy is hard to print if it has:

- High carbon content (steels)
- High reflectivity of laser wavelength (i.e. copper for IR)
- Ceramic phases inside final microstructure
- High melting temperature (refractories)
- Affinity for oxidation (titanium and aluminum)
- High thermal conductivity (copper & aluminum)

Apart from this poisonous elements like lead or arsenic between others make the printing process not safe for the operator, so should also be considered, all standard Meltio Materials does not contain any poisonous element.

Resuming, the chart below summarize all the main properties that are involved inside material printability and their expected behaviour:

Material	**Thermal Conductivity** Conducts heat away from the process, lower is better.	**Surface Reflectivity** Percentage of light reflected, lower is better.	**Electrical Conductivity** Relevant for hot wire, lower is better.	**Affinity to Oxidation** Affects shield gas consumption, lower is better.	**Affinity to Cracking*** Causes processing defects. Lower is better. Really depends on the alloy.	**Meltio Printability**
Stainless Steels	Low	Low	Very Low	Low	Low	Very Easy
Mild Steels	Low-Medium	Low-Medium	Low	Low-Medium	Very Low	Easy
Tool Steels	Low	Low-Medium	Low	Low-Medium	Medium-High	Medium
Nickel Alloys	Low	Low	Low	Very Low	Very Low	Very Easy
Titanium Alloys	Low	Low	Very Low	Very High	Medium	Medium
Copper Alloys	Very High	High	Very High	Medium	Low-Medium	Difficult
Aluminum Alloys	High	Very High	High	High	High	Difficult

* *Laser welding processes such as Meltio have lower heat input and hence are less prone to produce cracks and defects in the part.*

Material Wire Diameter Measurement

It is essential to measure the wire diameter with precision before any printing process.
Having in the additive program a wire diameter different than the measured value can result in a significant excess or lack of material input, which can cause excessive activation of the process control in an attempt to compensate for this deficiency or over extrusion that can cause loss of appropriate working distance and hence losing process stability and the final quality of the part.

Percentage of lack of material when using 1.00 mm of wire diameter value in the additive program and the real measurement of the wire is:

- **0.99 mm** → 1.2% material loss
- **0.98 mm** → 3.9% material loss
- **0.97 mm** → 5.8% material loss
- **0.96 mm** → 7.7% material loss
- **0.95 mm** → 10.0% material loss
- **0.94 mm** → 11.5% material loss

For example, a **7.7%** loss of material is approximately equivalent to **0.077 mm per layer**. This represents a cumulative loss of **1 mm in height every 13 layers, losing 3mm of WD after 33 layers**, assuming that the width of the bead remains constant.

The measurements we took of Meltio Materials gave us the following values, this may vary depending on wire manufacturer as well as between production batches:

Meltio Materials	Average Measurements
ER70S-6	0.951
SS316L	0.952
SS308L	0.950
17-4Ph	0.957
Nickel 718	0.959
Nickel 625	0.955
H11	0.942
Titanium Grade 5	0.958
ErCuNiAl	0.949
CuCrZr	0.971
Al 4046	1.138

Which Wire Diameter should I use?

- Meltio measurement: 0.955 mm
- Meltio nominal: 1.00 mm
- Wire used: 0.98 mm

In this case, the value used (0.98 mm) is **0.025 mm greater than the measured diameter**, based on empirical testing. This practice is consistent with our experience, as parts tend to shrink in XY and expand in Z. Using the exact measured value can cause excessive growth in the Z dimension because of this phenomenon, hence adding extra 0.025 mm to any measurement offer reliable process.

According to our measurements, **all Meltio wires always have a diameter less than 1.00 mm,** so it is advisable to use an intermediate value between the measured and nominal values.

If the filament were larger than the nominal value, for example 1.02 mm, the approach would be the same: keep approximately 0.025 mm above the actual value, ensuring that the filament is measured before each print and adjusting the feeder if necessary.

Meltio print profile in Horizon and in Meltio Engine includes a predefined Wire diameter based on the Meltio Materials, update as necessary based on the wire you are using.

Wire measurement procedure

To measure the diameter of the wire, a representative section of the wire must be taken (1 meter). The equipment required for this procedure is a digital micrometer. Always follow the manufacturer measurement process as well as its maintenance and calibration methods.

1. Calibrate the micrometer to 0.000 mm before starting the measurement.
2. Separate the anvil and the spindle.
3. Insert the thread between both measuring surfaces.
4. Adjust the micrometer using the thimble and finish tightening with the ratchet stop to ensure constant pressure.
5. Take five measurements at different points along the wire.
6. Calculate the average value of the measurements obtained.

This average value will allow you to compare the actual diameter of the thread with its nominal diameter and evaluate any deviations that may affect the printing process.

Material Compatibility Chart

The following tables summarise the compatibility between the different alloys available in the system for use in both multi-wire configurations and substrate deposition applications.

Compatibility between Wire 1 and Wire 2

This table indicates the expected behaviour when combining two different materials during printing using Wire 1 and Wire 2.

- **Compatible (green):** the combination has good solubility and metallurgical stability.
- **Incompatible (red):** the mixture generates a high risk of cracking, segregation, or poor bonding.
- **Under development (blue):** combination with potential, but pending full validation or parameter adjustment.

🟩 Compatible
🟥 Imcompaible
🟦 In development

		Wire 1						
	Material	Stainlees steel	Mild Steel	Tool Steel	Titanium	Inconel	Copper	Aluminum
Wire 2	Stainlees steel	🟩	🟩	🟩	🟥	🟩	🟦	🟥
	Mild Steel	🟩	🟩	🟩	🟥	🟩	🟦	🟥
	Tool Steel	🟩	🟩	🟩	🟥	🟩	🟦	🟥
	Titanium	🟥	🟥	🟥	🟩	🟥	🟥	🟥
	Inconel	🟩	🟩	🟩	🟥	🟩	🟦	🟥
	Copper	🟩	🟩	🟩	🟥	🟩	🟦	🟥
	Aluminum	🟥	🟥	🟥	🟩	🟥	🟥	🟦

Compatibility between Wire 1 and Substrate

This table shows the compatibility between the material used as Wire 1 and the substrate material on which it is deposited.

- **Compatible (green):** stable metallurgical bonding is obtained during the first layers.
- **Incompatible (red):** the mixture generates a high risk of cracking, segregation, or poor bonding.
- **Under development (blue):** viable combination under specific conditions or under evaluation.

This information is essential for hybrid manufacturing, repair, and direct deposition applications on different types of base plates.

🟩 Compatible
🟥 Imcompaible
🟦 In development

		Wire 1						
	Material	Stainlees steel	Mild Steel	Tool Steel	Titanium	Inconel	Copper	Aluminum
Substrate	Stainlees steel	🟩	🟩	🟩	🟥	🟩	🟩	🟥
	Mild Steel	🟩	🟩	🟩	🟥	🟩	🟩	🟥
	Tool Steel	🟩	🟩	🟩	🟥	🟩	🟩	🟥
	Titanium	🟥	🟥	🟥	🟩	🟥	🟥	🟩
	Inconel	🟩	🟩	🟩	🟥	🟩	🟩	🟥
	Copper	🟦	🟦	🟦	🟥	🟦	🟦	🟥
	Aluminum	🟥	🟥	🟥	🟥	🟥	🟥	🟦

Open Platform and Meltio Materials

Meltio's **Laser Metal Deposition (LMD) technology** is built on an **open material platform**, allowing customers to use **readily available welding wire** to achieve outstanding mechanical performance. In any case Meltio can supply any material, ask for the **Official List of Available Materials** to your sales representative.

While **Meltio Materials** represent the **pre-validated and fully parameterized** alloys we offer, our **technology is not limited to them**. Customers and partners can **develop and optimize new materials** to gain a **competitive advantage** in their industries.

Our process delivers **high-density parts (>99.97%)** with **superior mechanical properties**, while ensuring **zero material waste—100% of the deposited material is used in the final part**.

Meltio Materials: Fully Validated & Optimized for LMD

Meltio offers a **portfolio of tested and validated materials**, available for purchase, **with ready-to-use parameters** in **Meltio Horizon** and **Meltio Space** slicing software.

Key Benefits of Meltio Materials

✔ **Turnkey Printing Experience** – Fully parameterized for **optimal print quality, efficiency, and reliability** on standard geometries.

✔ **High Material Efficiency** – **100% of extruded material is used in the part**, with **zero waste**.

✔ **Multi-Material Capabilities** – Print with **Single**, **Dual**, or **Quad-Wire** for advanced applications.

Meltio Materials and Their Value Proposition

Stainless Steels (AISI 316L, AISI 308L)

Stainless steel is a corrosion-resistant alloy composed mainly of iron, carbon, and chromium. It forms a protective chromium oxide layer that prevents rust and staining. With its durability and aesthetic appeal, stainless steel is widely used in various industries, including kitchenware, appliances, construction, and automotive components.

Tool/Carbon Steels (AISI H11)

The three general categories are low, medium, and high carbon steel. More carbon means harder and stronger. Less carbon means cheaper, softer, and easier to produce.
Carbon steel is most commonly found as a structural building material, in simple mechanical components, and in various tools.

Mild Steels (AWS ER70S-6)

It has low carbon content (<0.25% by wt.). It is ductile, machinable, and weldable. It is used in automobiles, furniture etc.

Nickel Alloys (Nickel 718, Nickel 625)

Nickel is a versatile element and will alloy with most metals. Nickel alloys are alloys with nickel as principal element. Its high versatility, combined with its outstanding heat and corrosion resistance has led to its use in a diverse range of applications; such as Aircraft gas turbines, steam turbines in power plants and its extensive use in the energy and nuclear power markets.

Titanium Alloys (Ti6Al4V)

It's really hard to refine. This is why this metal is so expensive. Its strength to weight ratio is higher than any other metal. This makes it extremely valuable for anything that flies. It's use where the weight requirements are critical and aluminum alloys cannot fit in.

Copper Alloys (AWS ERCuNiAl and CuCrZr)

Common applications include electronics, water pipes, and giant statues that represent liberty. Copper will form an oxidized layer, that will prevent further corrosion. Essentially, it'll turn green and stop corroding. This can make it last for centuries.

Aluminium Alloys (Al 4046)

Aluminum has amazing strength-to-weight ratio, this is the metal that's largely responsible for flight. It's easily formed (malleable)hile it doesn't rust, it will oxidize. Iron is the only metal that "rusts" by definition. Aluminum will corrode when it contacts salt. However, it will *not* corrode in contact with water.

Meltio TRL Classification System

Meltio can additive manufacture parts in metals such as copper and aluminum using its blue laser technology. However, for now, this technology works well only with thin-walled or small parts. When we try to print larger or solid parts, technical challenges arise—mainly due to how these materials behave during heating and cooling. We are actively developing and improving the process to make it more reliable with these metals in larger formats.

To determine the development stage of each material, we use an international scale called the Technology Readiness Level (TRL), which ranges from 1 to 9 (from experimental to fully ready for industrial production).

Meltio has adapted this scale into an internal classification with four levels:

- **Meltio Explore (TRL 1–3):** Initial exploration phase. For R&D only.

- **Meltio Develop (TRL 4–6):** Validation of initial concepts and prototype testing, ongoing parameter improvement, and profile standardization.

- **Meltio Qualified (TRL 7–8):** Materials ready for demanding applications. High reliability.

- **Meltio Proven (TRL 9):** Fully validated for production. Final industrial use.

Copper and aluminum are currently between TRL 3 and 5, meaning they are in validation and optimization phases. In contrast, steels, nickel alloys, and titanium are already between TRL 7 and 9, which means they are successfully used in real-world applications.

Meltio Materials	TRL
ER70S-6	Qualified - Proven
SS316L	Qualified - Proven
SS308L	Qualified - Proven
17-4Ph	Qualified - Proven
Nickel 718	Qualified - Proven
Nickel 625	Qualified - Proven
H11	Qualified - Proven
Titanium Grade 5	Qualified - Proven
ErCuNiAl	Qualified - Proven
CuCrZr	Develop
Al 4046	Develop

List of Tested Materials by Meltio

In the next section, Meltio has tried to summarize all the materials that were successful during the parametrization and characterization. All the materials are divided by material family, if the material is fully characterize or only tested with a few samples and if is available in Meltio material catalogue.

Meltio can supply any material, ask for the **Official List of Available Materials** .

Always request availability of said material through Meltio, we will provide the material in the shortest time or if it is not possible we will recommend the point of contact.

Material	Material Family	Fully Characterized / Tested - IR Laser	Fully Characterized / Tested - Blue Laser	Availability
ER70S-6	Mild Steel	Characterized	Fully Characterized	Meltio material
SS316	Austenitic Stainless Steel	Fully Characterized	Fully Characterized	Meltio material
SS307	Austenitic Stainless Steel	Tested	Tested	Compatible
SS308	Austenitic Stainless Steel	Tested	Fully Characterized	Meltio material
1.4343 (SS309)	Austenitic Stainless Steel	Tested	Tested	Compatible
17-4PH	Precipitation Hardening Stainless Steel	Fully Characterized	Fully Characterized	Meltio material
Super Duplex	Austenitic - Ferritic Stainless Steel	Tested	Tested	Compatible
SS410	Martensitic Stainless Steel	Tested	Tested	Compatible
SS410NiMo	Martensitic Stainless Steel	Tested	Tested	Compatible
SS420	Martensitic Stainless Steel	Tested	Tested	Compatible
35N	Alloy Structural Steels	Tested	Tested	Compatible
Invar	Nickel Alloy	Fully Characterized	Tested	Compatible
Nitinol	Nickel Alloy	Tested	Tested	Compatible
Inconel 718	Nickel Alloy	Fully Characterized	Fully Characterized	Meltio material
Inconel 625	Nickel Alloy	Fully Characterized	Fully Characterized	Meltio material
Monel K500	Nickel Alloy	Tested	Tested	Compatible
Hastelloy X	Nickel Alloy	Tested	Tested	Compatible
H11	Tool Steel	Fully Characterized	Fully Characterized	Meltio material
H12	Tool Steel	Tested	Tested	Compatible
H13	Tool Steel	Tested	Tested	Compatible
P20	Tool Steel	Tested	Tested	Compatible
M7	Tool Steel	Tested	Tested	Compatible
Ti 553	Titanium Alloy	Tested	Tested	Compatible
Titanium Grade 5	Titanium Alloy	Fully Characterized	Fully Characterized	Meltio material
Titanium Grade 23	Titanium Alloy	Tested	Tested	Compatible

List of Tested Materials by Meltio (Continuation)

Material	**Material Family**	**Fully Characterized / Tested - IR Laser**	**Fully Characterized / Tested - Blue Laser**	**Availability**
ERCuSi-A	Bronze	Tested	Tested	Compatible
Bronze Bearing	Bronze	Tested	Tested	Compatible
Bronze Marine (ErCuNiAl)	Bronze	Fully Characterized	Fully Characterized	Meltio material
CuCrZr	Copper	Tested	Tested	Meltio material
CuNi7	Cupronickel	Tested	Tested	Compatible
CuNi30	Cupronickel	Tested	Tested	Compatible
CuNi9Sn6	Cupronickel	Tested	Tested	Compatible
Babbit (Tin)	White Metal	Tested	Tested	Compatible
Platinum	Noble Metal	—--	Tested	Compatible
Pure Gold	Noble Metal	Tested	Tested	Compatible
White Gold	Noble Metal	Tested	Tested	Compatible
Red Gold	Noble Metal	Tested	Tested	Compatible
Silver	Noble Metal	Tested	Tested	Compatible
4046	Aluminum Alloy	Tested	Tested	Meltio material
AlMg4,5Mn (5083)	Aluminum Alloy	Tested	Tested	Under Development
5183	Aluminum Alloy	Tested	Tested	Under Development
AlMg4,5Mn (5083)	Aluminum Alloy	Tested	Tested	Under Development
6061-Ram 2	Aluminum Alloy	Tested	Tested	Under Development
7075-Ram2	Aluminum Alloy	—--	Tested	Under Development
Scalmalloy	Aluminum Alloy	Tested	Tested	Under Development
Al7Si	Aluminum Alloy	Tested	Tested	Compatible
NICARW (Ni-CW composite)	Specialty	Tested	Tested	Compatible
Haynes 25	Cobalt alloy	Tested	Tested	Compatible
Stellite	Cobalt Alloy	Tested	Tested	Compatible
Niobium	Refractory Metal	—--	Tested	Compatible

Introduction to Meltio Material Datasheets

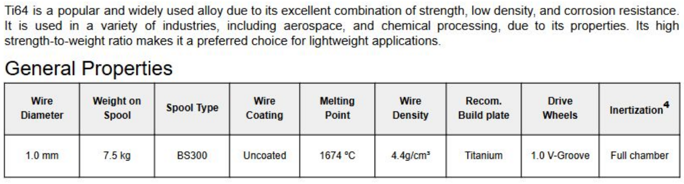
Material datasheets (https://meltio3d.com/materials/) are technical documents that provide detailed information on the properties, characteristics, and specifications of a particular material. These documents are an essential tool for engineers, designers, and manufacturers as they allow them to select the appropriate material for a specific application, evaluate its performance, and predict its behavior under different conditions of use.

Inside a datasheet, a customer should find detailed information about properties, characteristics and different specifications of the material. This datasheets will lead to a better understanding and better material selection for a specific application.

Contents of Meltio Material Datasheets

General Properties

Including general information on the material and the printing machinery, such as: wire diameter, spool weight, spool type, coating presence, melting point, material density, recommended build plate, recommended drive wheels, and the type of inertization required.



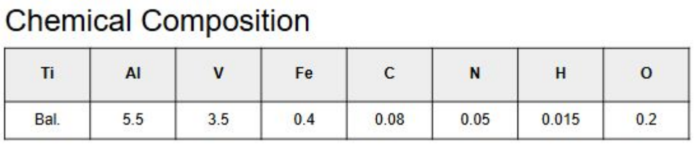
Ti64 is a popular and widely used alloy due to its excellent combination of strength, low density, and corrosion resistance. It is used in a variety of industries, including aerospace, and chemical processing, due to its properties. Its high strength-to-weight ratio makes it a preferred choice for lightweight applications.

General Properties

Wire Diameter	Weight on Spool	Spool Type	Wire Coating	Melting Point	Wire Density	Recom. Build plate	Drive Wheels	Inertization[4]
1.0 mm	7.5 kg	BS300	Uncoated	1674 ºC	4.4g/cm³	Titanium	1.0 V-Groove	Full chamber

Chemical Properties

Consists of the chemical composition of the material. It lists all its alloys and their proportion. In addition to the chemical composition.

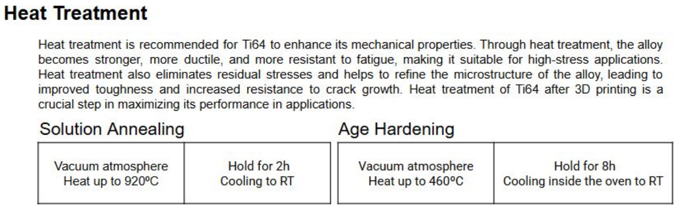


Chemical Composition

Ti	Al	V	Fe	C	N	H	O
Bal.	5.5	3.5	0.4	0.08	0.05	0.015	0.2

Heat Treatment

It can be found a small text about the mandatory nature of the heat treatment followed by the main recommended steps to carry it out.



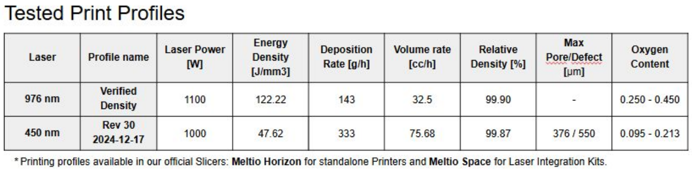
Heat Treatment

Heat treatment is recommended for Ti64 to enhance its mechanical properties. Through heat treatment, the alloy becomes stronger, more ductile, and more resistant to fatigue, making it suitable for high-stress applications. Heat treatment also eliminates residual stresses and helps to refine the microstructure of the alloy, leading to improved toughness and increased resistance to crack growth. Heat treatment of Ti64 after 3D printing is a crucial step in maximizing its performance in applications.

Solution Annealing		Age Hardening	
Vacuum atmosphere Heat up to 920ºC	Hold for 2h Cooling to RT	Vacuum atmosphere Heat up to 460ºC	Hold for 8h Cooling inside the oven to RT

Tested Print Profiles

A table of basic printing parameters that have demonstrated good performance on Meltio machines. It includes the material deposition rate, volume rate, relative density achieved with Meltio systems, and general data such as maximum pore size and observed defects.



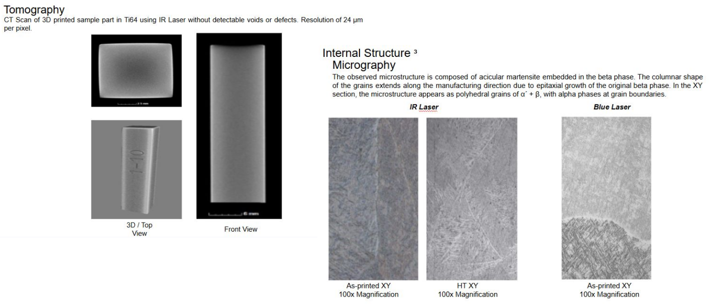
Tested Print Profiles

Laser	Profile name	Laser Power [W]	Energy Density [J/mm3]	Deposition Rate [g/h]	Volume rate [cc/h]	Relative Density [%]	Max Pore/Defect [µm]	Oxygen Content
976 nm	Verified Density	1100	122.22	143	32.5	99.90	-	0.250 - 0.450
450 nm	Rev 30 2024-12-17	1000	47.62	333	75.68	99.87	376 / 550	0.095 - 0.213

* Printing profiles available in our official Slicers: **Meltio Horizon** for standalone Printers and **Meltio Space** for Laser Integration Kits.

Internal Structure

Ensure that the material meets industry requirements for density, microstructure, and absence of defects, all of which are critical for achieving optimal mechanical properties.



Tomography

CT Scan of 3D printed sample part in Ti64 using IR Laser without detectable voids or defects. Resolution of 24 µm per pixel.

3D / Top View

Front View

Internal Structure [3]

Micrography

The observed microstructure is composed of acicular martensite embedded in the beta phase. The columnar shape of the grains extends along the manufacturing direction due to epitaxial growth of the original beta phase. In the XY section, the microstructure appears as polyhedral grains of $\alpha' + \beta$, with alpha phases at grain boundaries.

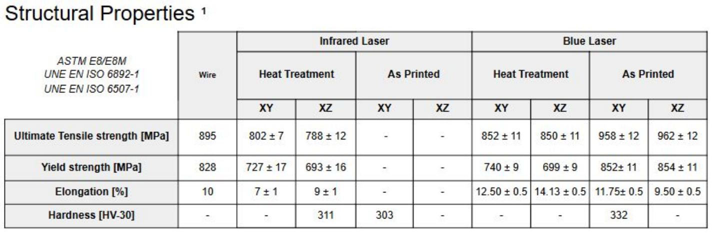
As-printed XY 100x Magnification

HT XY 100x Magnification

As-printed XY 100x Magnification

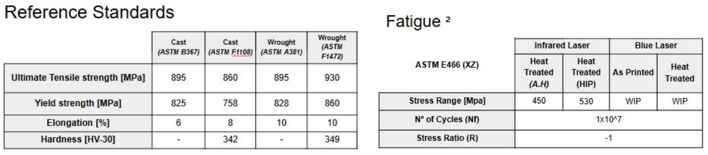
Structural Properties and Reference Standards

It shows all the values of mechanical properties obtained from the material, with a table to be able to make the **comparison with some casting and forging standards**. The aim is that the material approaches or even exceeds the standards of the sector.



Structural Properties [1]

ASTM E8/E8M *UNE EN ISO 6892-1* *UNE EN ISO 6507-1*	Wire	Infrared Laser				Blue Laser			
		Heat Treatment		As Printed		Heat Treatment		As Printed	
		XY	XZ	XY	XZ	XY	XZ	XY	XZ
Ultimate Tensile strength [MPa]	895	802 ± 7	788 ± 12	-	-	852 ± 11	850 ± 11	958 ± 12	962 ± 12
Yield strength [MPa]	828	727 ± 17	693 ± 16	-	-	740 ± 9	699 ± 9	852± 11	854 ± 11
Elongation [%]	10	7 ± 1	9 ± 1	-	-	12.50 ± 0.5	14.13 ± 0.5	11.75± 0.5	9.50 ± 0.5
Hardness [HV-30]	-	-	311	303	-	-	-	332	-



Reference Standards

	Cast *(ASTM B367)*	Cast *(ASTM F1108)*	Wrought *(ASTM A381)*	Wrought *(ASTM F1472)*
Ultimate Tensile strength [MPa]	895	860	895	930
Yield strength [MPa]	825	758	828	860
Elongation [%]	6	8	10	10
Hardness [HV-30]	-	342	-	349

Fatigue [2]

ASTM E466 (XZ)	Infrared Laser		Blue Laser	
	Heat Treated *(A.H)*	Heat Treated (HIP)	As Printed	Heat Treated
Stress Range [Mpa]	450	530	WIP	WIP
Nº of Cycles (Nf)	1x10^7			
Stress Ratio (R)	-1			

Key Takeaways from Material Datasheets

“Real” Materials

With Meltio the material composition used for additive manufacturing is close to the commodity material used in the welding industry, not a special blend for AM.

Density

All our material test are targeted to find showcases with densities above 99.75%, up to **99.87%** for Titanium or **99.97%** for 316LSi.

This is as good as it gets in Metal AM, no other technology can beat us.

Near Isotropy

The Compact heat affected zone, high cooling rate and excellent densification lead to a uniform microstructure and high levels of isotropy.

Parts typically show less than 10% anisotropy in Ultimate tensile strength placing Meltios printing process at the leading edge of what is achievable in direct metal 3D Printing.

Rivaling Traditional Mfg

All of our tested material results in terms of mechanical properties are compared to casting and wrought.

All results are superior to casting and most of them are up to par with wrought, in accordance with the available base standard.

Deposition Parameters

Meltio provides a set of developed and validated process profiles, integrated into its own Slicers, which allow reproducible and high quality results to be obtained.

In addition all testing data comes referenced with the third party lab responsible for the analysis of the samples.

Current Meltio Material Datasheets

Meltio Stainless Steel 316L

Highly corrosion-resistant grade of austenitic stainless steel with great mechanical properties. Ideal for marine and chemical applications.

Meltio Titanium 64

High strength Alpha+Beta alloy with excellent fracture toughness, corrosion resistance and biocompatibility. Widely used in aerospace, marine, chemical and biomedical industries.

Meltio Stainless Steel 17-4PH

A martensitic precipitation hardened stainless steel capable of achieving high hardness while offering excellent corrosion resistance. Typical applications include pump impellers, pipes, and valves.

Meltio Nickel 718

High strength nickel-super alloy with large working temperature range. Highly resistant against cracking while protecting well against corrosion.

Meltio Mild Steel ER70S

Mild steel with adequate mechanical properties and high ductility. Easily welded and machined.

Meltio Nickel 625

Ni625 excels for its weldability, making it an ideal choice for cladding or repair of components working at high temperatures or requiring increased corrosion protection.

Meltio Tool Steel H11

One of the most commonly used tool steels, thanks to its outstanding impact toughness. Widely used for hot tooling applications, in the manufacturing of dies, and in aerospace applications.

Meltio Invar

This alloy gets its name thanks to its extremely low coefficient of thermal expansion, from -250°C up to about 200° C. Ideal for measuring equipment, cryogenic applications and molds for composite components.

Meltio CuCrZr

High-performance copper alloy with excellent thermal and electrical conductivity, combined with enhanced mechanical strength thanks to chromium and zirconium additions. Ideal for heat exchangers, electrical components, and welding electrodes.

Meltio Aluminun 4046

Aluminum-silicon alloy with good corrosion resistance and excellent weldability. Commonly used as a filler metal or for components requiring thermal management and good surface finish.

Meltio Marine Bronze (ERCuNiAl)

Copper-nickel-aluminum alloy designed for high-strength applications in marine environments. Combines excellent corrosion resistance with good mechanical performance, making it suitable for shipbuilding, offshore components, and desalination equipment.

Parametrization Steps for High Density Parts With A Reliable Process

In order to achieve high density parts there are a few key requirements. The single most important requirement leads to the energy input per unit volume of material. Insufficient energy input will lead to pores and lack of fusion, which results in poor material performance, on the other hand excessive energy input will lead to unstable process and process control activations

The most relevant parameters for this study are: **Deposition Speed**, **Layer Height, Layer Width**, **Laser Power and Rotation angles and Process Control**. The energy density is not an input parameter, but rather a result between the extrusion width, layer height, print speed and laser power. **Recommendation:** Always ensure the **wire feeder is properly tightened** to prevent deposition issues.

Relevant Additive Manufacturing Parameters Configuration for Solid Profiles

Laser Power

For all materials and configurations, the **laser power should be set to the maximum available** on the machine to achieve the **highest possible deposition rate**. The rest of the parameters will be optimized to ensure a reliable process.

Layer Parameters for Solid Profiles

For printing solid profiles with the Meltio system, it is recommended to use the following layer parameter ranges to ensure optimum density and stability in the printing process:

- **Layer Height (LH):** 1.0 – 1.2 mm. Larger Layer Heights will make the material be out of the Machine Working Distance. Larger laser power allow larger layer heights.
- **Layer Width (LW):** 1.0 – 1.4 mm. Based on our experiments the layer width is always slightly larger than the LH, this will offer good adhesion between passes, using way larger LW can cause porosity between passes.

Print Speed

Our focus is to reach the maximum energy density (Laser Power/ LH*LW*Print Speed) that allows a stable process, **a stable process means no Process Control Activations**. Usually lower Printing Speed and larger lh and LW allows higher concentrations of heat allowing higher deposition rates when compared to moving faster and smaller LH and LW. Different sets of Print Speeds are tested, after this cut with wire EDM and then evaluated through penetrant liquid test, the result with the highest deposition rate and less porosity is selected.

Rotation angles

In the infrared system, tests were performed at +45° and -45°, with the infill alternating between these two single directions. In contrast, the blue system uses a continuously rotating pattern of +45° applied to each successive layer in order to ensure homogeneous distribution of heat as well as offering more angles to much better more geometries or to have a more agnostic perspective and not be part topology dependent or the part being affected by it.

Process Control

Process Control monitors the continuity between the deposition head and the substrate. When continuity is lost, the system **automatically increases material flow** to restore contact. Combining **accurate Process Control** with Meltio design guidelines ensures **reliable, high-quality prints** and fully leverages the potential of wire-based DED.

Common Activation Scenarios

- Excessively **high energy density** (wire melts before reaching the melt pool)
- Incorrect or increasing **working distance** (wire melts before reaching the melt pool)
- **Excessive overhangs** in the print geometry

Solutions

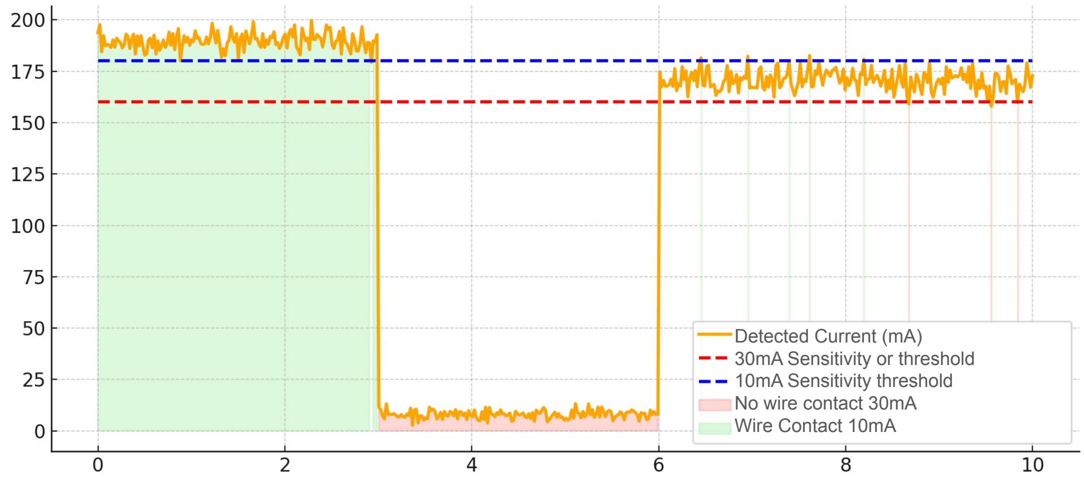
- Reduce energy density: lower laser power (decrease deposition rate) or **increase Print Speed (increase deposition rate)**
- Use the **Working Distance Wizard** and adjust **Material Flow Rate**
- Evaluate and adapt the **design for Meltio AM** capabilities

Testing Without Process Control

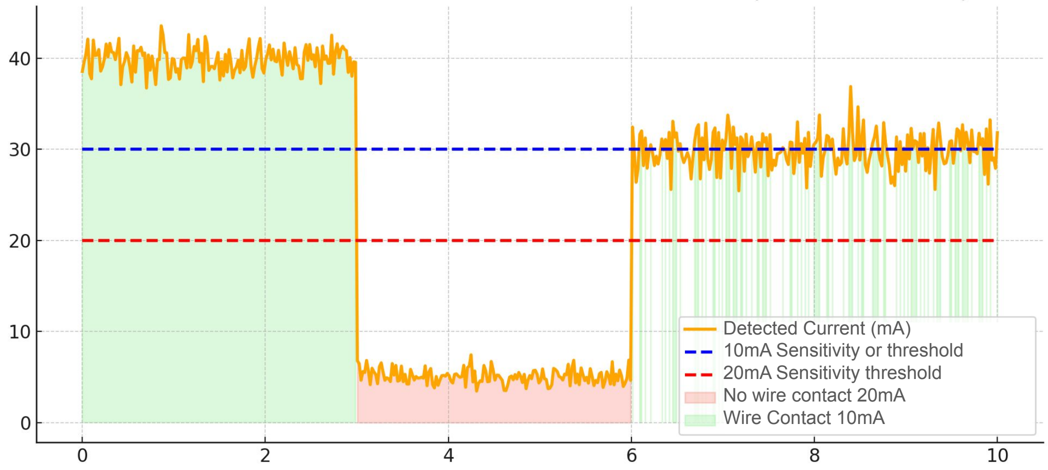
During the first phase of material optimization, we recommend **deactivating Process Control** to confirm process reliability. If the energy density is too high, the print will fail due to lack of wire continuity—this ensures that the process itself is stable without relying on correction mechanisms and allows to find the top of the process window, focusing on reducing porosity adjusting the energy density (lower part of the process window). Once stability is achieved, Process Control can be re-enabled to help with overhangs or non-standard geometries.

Process Control Mode and Parametrization

1. **Without Hotwire:**
    a. **Engine Blue**
        - **Process Control Mode:** Automatic Current Mode
            - **PC Voltage:** 12V
            - **PC Max Current:** 190mA
            - **Default PC Sensitivity:** 30mA (190-30 = 160mA)
            - System can be calibrated through Expert Mode, this will define reference current to what the sensibility or threshold value will be applied.



    b. **Meltio M600**
        - **Process Control Mode:** Automatic Current Mode
            - **PC Voltage:** 5V
            - **PC Max Current:** 40mA
            - **Default PC Sensibility:** 15mA most of the materials, Ti requires higher values
            - System can be calibrated through Expert Mode sending CAN codes, this will define reference current to what the sensibility or threshold value will be applied, the ideal values should be between 380 and 420mA. Contact Meltio Tech Support if you want to recalibrate process control value. Firmware versions prior to Mastercontroller_10_19062025 were autocalibrated at the beginning of every additive process.



    c. **Engine IR v3**
        - **Process Control Mode:** Fixed Current
    d. **Engine v2 and M450**
        - **Process Control Mode:** Voltage

Hotwire Integration on M600(Advanced)

Once the initial print parameters are optimized, **Hotwire** can be introduced for further improvements. It is not recommended to use Hotwire from the beginning due to process unpredictability.

Electrical Settings (Based on Joule Effect)

The effect varies by material conductivity, greater resistance greater effect (e.g., greater in stainless steels like 316L, minimal in copper).

- **Hotwire Current Range (M600):** 0–75 A
  - Minimum noticeable: 20 A
  - High values may overheat the wire, leading to instability and unwanted Process Control Activations. In these cases it is recommended to increase the volume of material to obtain a lower energy density.

- **Hotwire Voltage Range (M600):** 3500–6000 mV
  - **Recommended:** 5000 mV
  - <3500 mV may prevent current ramp-up.
  - 6000 mV or more may destabilize the system and interfere with Process Control (which operates around 5000 mV).

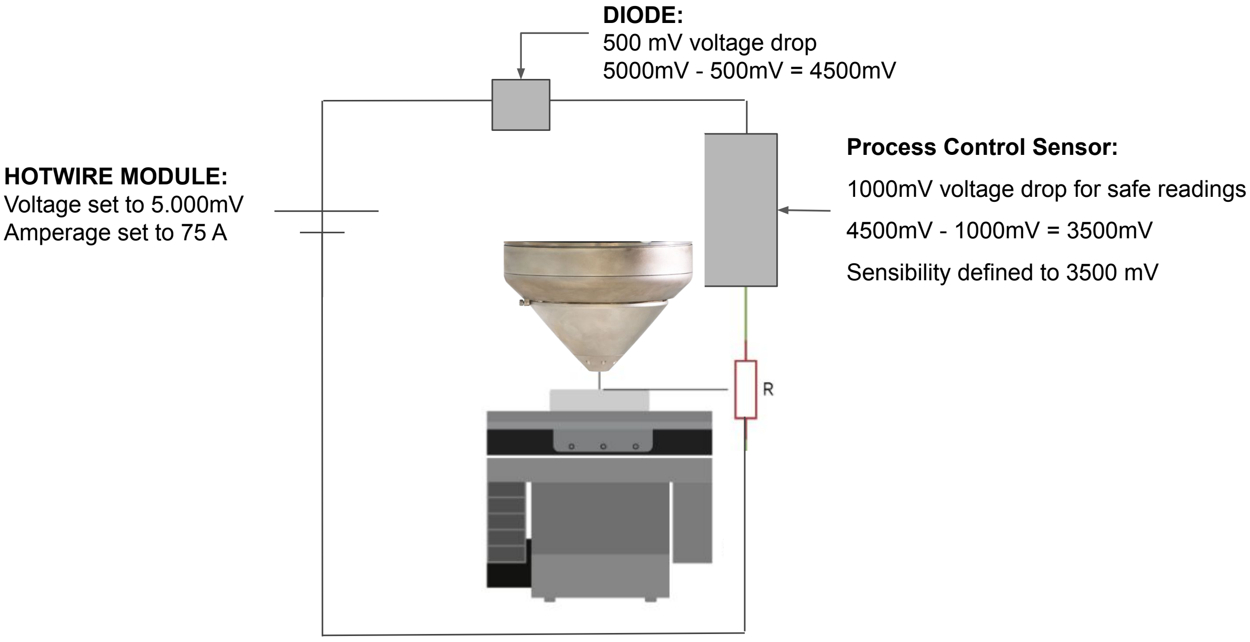
1. **Process Control configuration when using Hotwire on M600:**
   a. **Process Control Voltage Mode**
      - **Default sensitivity: Must be calculated** depending on material and stability following the above guidelines.

        When the wire is touching the substrate, voltage is close to 0 mV, the total power generated can be certainly calculated through Joules effect formula, but is difficult to determine how much it is applied in the melt pool or along a larger distance of the wire.

        They electrical system includes a diode in order for the the current to flow only in one direction, to the part and not back to the hotwire power supply, this diode has an average consumption of 5000 mV, so from the initial 5000 mV we could have 4500mV.

        When the wire is not in contact with the substrate, the process control voltage sensor would be reading 4500 mV and 0 amperage, in order for the process control to activate, its sensibility should be lower than 4500 mV.

        A safe way to ensure the process control will activate properly it is including an extra offset of 1000mV, with this we can ensure we have a clear reading, in the next page illustration a diagram can be seen.



   b. **Process Control Current Mode (WIP):** Max current depend on hotwire values and this fluctuates continuously, using this process control must be avoided.
      - **Default sensitivity: 15mA for** Hotwire values: **75 A 5000 mV**

Energy Density Formules

As previously mentioned, the energy density is a parameter that relates the volume of material deposited to a defined energy input. The unit for energy density is Jules / mm^3.Please note that energy density values are not extrapolable within different materials as they have different laser absorption and behavior. Also the formula does not consider all the physical properties of the material being printed but offer an approachable way of characterizing the materials.

Meltio M450 and M600:

Due to the Volumetric Material Calculation that happens directly in the slicing software, we need to recalculate the material volume. Use the following formula to calculate the energy density:

$$\frac{\text{Laser Power (W)}}{\text{Layer Height (mm)} \times \text{Deposition Width (mm)} \times \frac{\text{Print Speed (mm/min)}}{60}} = \text{Energy Density (J/mm}^3\text{)}$$

Meltio Engine:

Calculating the energy density for the Meltio Engine is easier as the wire feed-rate is a direct input parameter. Here the material volume is calculated using wire feed-rate and the wire diameter.

$$\frac{\text{Laser Power (W)}}{\text{Wire Feedrate (mm/s)} \times \pi \times \text{Wire Radius (mm)}^2} = \text{Energy Density (J/mm}^3\text{)}$$

Process Bands

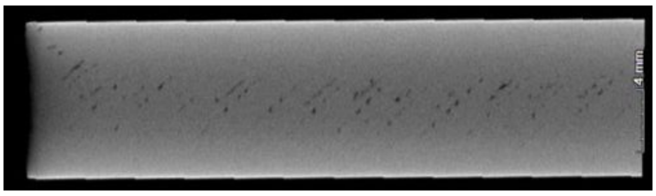
Interpretation of Results

When Interpreting the results of the aforementioned study we find that we can group our parts into three different Process Bands based on the energy density they were produced with: Lack of Fusion, Minor Defects and Fully Dense Parts.

1: High Speed & Lack of Fusion

Low Energy Density

Parts printed within this range of energy densities can be produced at the highest speed but with serious defects, often containing multiple long linear indications of lack of fusion. Use parameters within this band for printing parts quickly when mechanical properties are not of importance. Beware that due to the large sizes, defects may appear visible to the naked eye after machining.

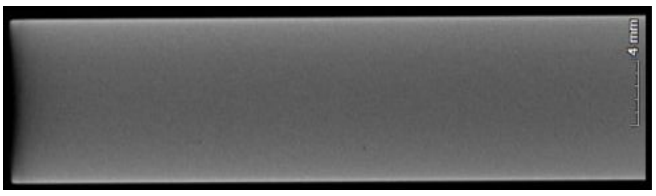


Typical Defect Pattern for parts that show “Lack of Fusion”.

2: Medium Speed & Minor Defects

Medium Energy Density

Parts printed in this range generally do not show defects that are visible to the naked eye and perform well mechanically. Defect size is generally smaller than 250 microns but may affect fatigue life of the component adversely.

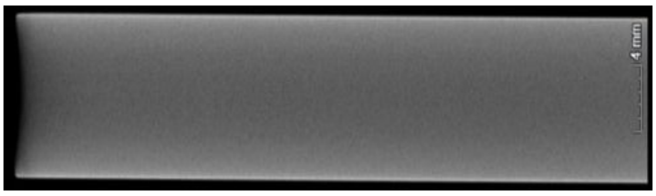


Parts printed in this range show minor defects.

3: Fully Dense Parts

High Energy Density

Parts printed in this region do not show any defects that can be detected using CT Scanning. Density measurements beyond this point must be performed using metallography. We find that parts in this region typically show densifications greater than 99.99%. This however comes at the price of print speed which is typically much lower.



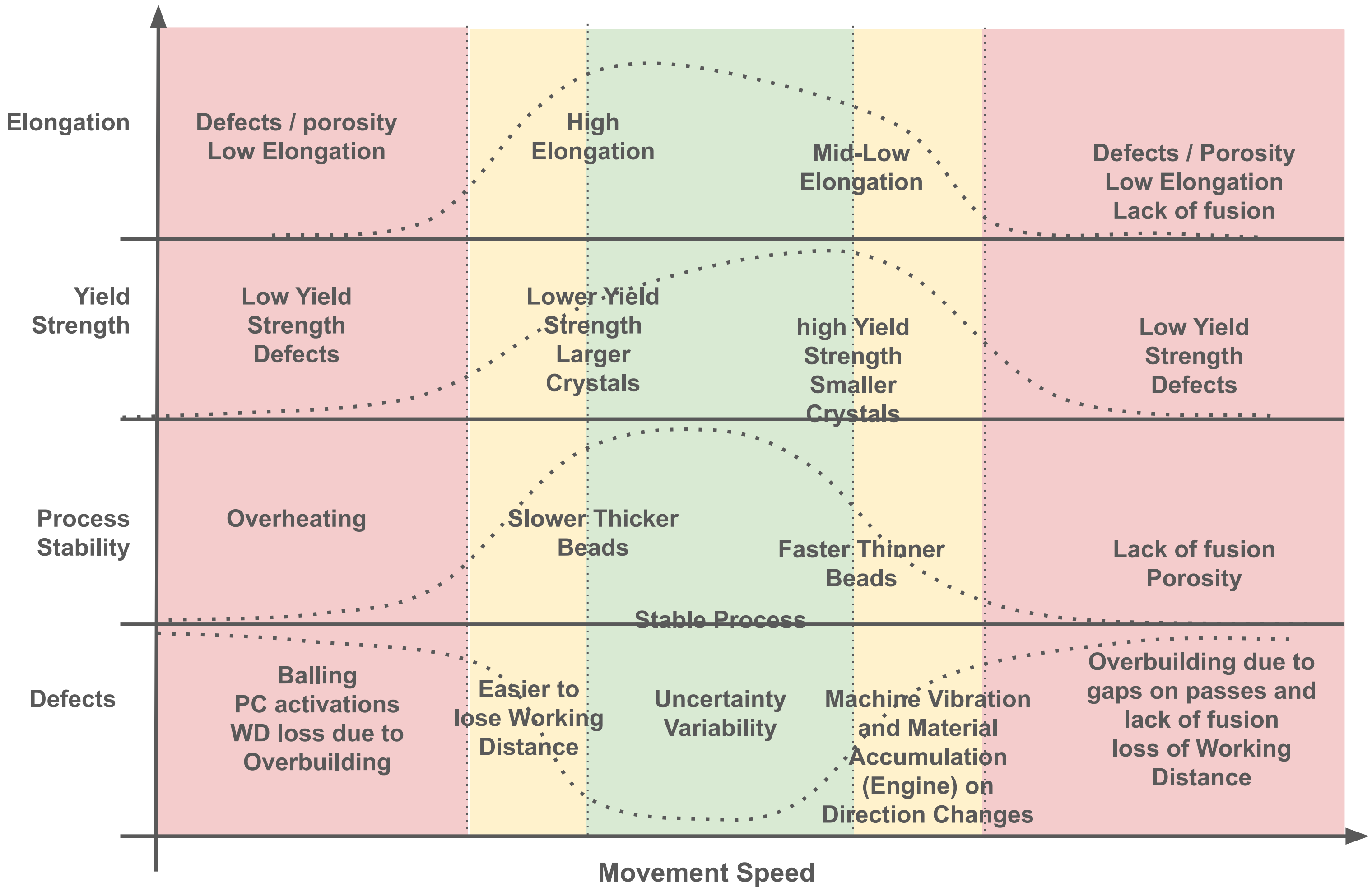
Defect-Free Build using High Energy Density.

Note: *The results and classification of process bands are based purely on the described methodology and only serve as guidance for the easy selection of applications dependent process parameters.*

Influence of Movement Speed on Structural Properties in Laser Metal Deposition

The relationship between movement speed and structural properties in laser metal deposition, under constant laser power and deposition volume rate, is primarily governed by thermal dynamics and solidification behavior. As the movement speed increases, the heat input per unit length decreases, resulting in a faster cooling rate. This leads to finer and more equiaxed grain structures, increased hardness, and higher residual stresses, though it may also cause incomplete melting or weak interlayer bonding if the energy input becomes insufficient. Conversely, slower movement speeds provide higher heat input, promoting coarser, columnar grains and improved bonding between layers, but at the expense of potential distortion and lower hardness due to slower cooling. Maintaining a balance between these extremes is crucial, as it ensures consistent bead geometry, stable deposition, and optimal mechanical performance. Therefore, selecting an appropriate movement speed is essential to achieve the desired microstructure and mechanical properties in the final component.

Constants:
- Laser Power
- Volume Rate



Microstructural Evolution with Movement Speed

Movement speed directly influences the linear energy input and, consequently, the solidification behavior of the material.

- At **low speeds**, the high energy input generates a **high thermal gradient** and **slow cooling rate**, favoring the growth of **coarse columnar grains** and increasing the likelihood of segregation and porosity.
- At **intermediate speeds**, a **balanced thermal gradient** and **moderate cooling rate** promote a **fine and homogeneous microstructure**, typically composed of mixed columnar and equiaxed grains, resulting in optimized mechanical properties.
- At **high speeds**, the **low thermal gradient** and **fast cooling rate** caused by low energy input lead to **incomplete fusion** and **heterogeneous fine-grained structures**, reducing interlayer cohesion and overall mechanical performance.

Meltio Materials Characterization Methodology

Characterization Development Phases for Solid parts

Blue System

Meltio qualifies materials through a structured, step-by-step process divided into four phases, designed to identify optimal printing parameters and validate the material's performance for industrial applications **using the Meltio Blue system**.

Phase 0 serves as a **preliminary stage** in which the general **printability of the material** is evaluated. This includes verifying the stability of the melt pool, assessing arc behavior, and ensuring the wire feedability and compatibility with Meltio's system. If the material proves printable under basic conditions, it proceeds to the qualification workflow.

Phase 1 is divided into **two stages: Test A and Test B**. In this phase, a wide range of parameter sets is tested using **CT scanning** and **hardness measurements** to evaluate **bulk density**. The primary goal is to identify parameter sets that meet the requirements of the **NASA-STD-6030** standard. Any parameters that fail to deliver macroscopically dense builds are discarded.

Phase 2 uses the selected parameter from the previous phase to fabricate **larger preforms** intended for the extraction of **tensile** and **metallographic samples**. During this phase, **heat treatments** are applied to optimize the **mechanical properties** of the material. The goal is to assess and refine the material's mechanical performance under standardized conditions. At the end of this phase, comprehensive data is collected, allowing for the creation of a detailed **material datasheet**.

Phase 3 involves validating the chosen parameter through **impact or fatigue testing** on large preforms. Additional analyses, such as **chemical composition checks**, are carried out to confirm the material's consistency and reliability.

Below are the main steps required to successfully complete each phase of the qualification process.

Verification Process for Optimal Parameter Selection and Material Density

This section describes the process verification system, both the Meltio infrared and the Meltio Blue systems, for parameter selection, in order to identify the ones that provide the best relative density.

Samples are built using simple geometries (Phases 1), from which by-products are extracted to perform defect analysis and classify the different energy density bands. For the acceptance of these samples, they must demonstrate high densification in the printed parts.

This information allows users of the Meltio systems to select the most efficient process to achieve the target material quality.

Verification Process

The verification system depends on the Meltio system being used:

Blue System:

The process verification consists of two steps: the first is an analysis using penetrant liquids to detect surface defects in the samples, and the second involves performing micrography on the samples to assess defect size and material density (based on NASA-STD-6030 standards).

The sample dimensions are **250mm*250mm*30mm (X*Y*Z)**, and we extract 6 specimens of **30mm*60mm*30mm (X*Y*Z)** for penetrant liquid testing and micrography.

According to the standard, the porosity should be less than 0.25% of the volume in 6cm², with pore sizes under 100 microns. The full results of the material testing process can be found in the material data sheets for each of the Meltio materials.

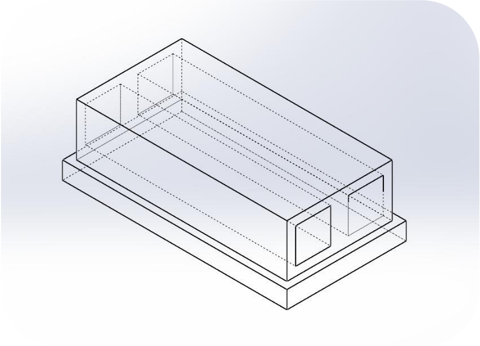
Characterization Phases - Blue System

Phase 0 - Printability

A large range of parameters are tested to define the process window.

Preform Size: 15mm x 30mm x 60mm

Varied Parameters: Layer Height, Laser Power, Print Speed, Flow Rate



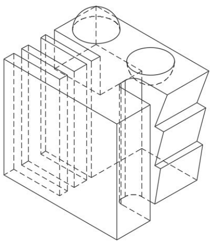
Phase 1 - Bulk Density

Subselection of best results from phase 0 we build sufficient samples for statistically significant testing for each of parameter set.

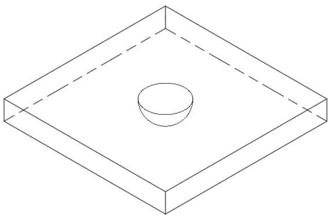
TestA
Preform Size: 67mm x 50mm x 70mm
Tested Attributes:
- Liquid penetrant test

Test B
Preform Size: 250mm x 250mm x 30mm
Number of samples: 6

Tested Attributes:
- Density
- Micrography
- Metallography



Test A



Test B

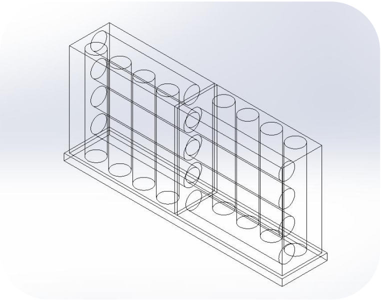
Phase 2 - Structural Properties

Once the phase 1 parameters were accepted, we constructed sufficient samples to perform statistically significant tests for each set of parameters.

Preform Size: 95mm x 155mm x 55mm
Preform Cut Size: 30mm x 155mm x 55mm
Sample Size: M4 cylindrical (UNE EN ISO 6892-1)
Number of samples: 16 samples in two directions, 8 horizontal and 8 vertical per block.
Printing Direction: XY

Tested Attributes:
- Density
- Hardness post Heat Treatment
- Tensile Strength
- Metallography

Preform Size



Preform Cut Size

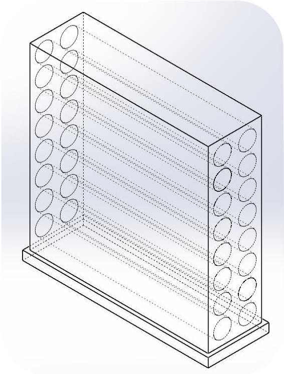
Phase 3 - Advanced Properties

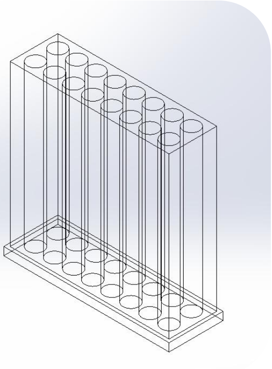
Selection of best parameter set from phase 2. Advanced tests are carried out based on the material.

Preform Size: 30 mm x 100mm x 100mm
Sample Size: Depending on the test (ASTM)
Number of samples: From 16 to 40.
Printing Direction: XY and XZ

Tested Attributes:

- Fatigue Testing
- Impact Testing
- Chemical Analysis
- RDX testing





Meltio Materials Characterization Methodology

Characterization Development Phases for Solid parts

Infrared System (Legacy)

Meltio qualifies materials through a step-by-step approach, **exclusively designed for the Meltio Infrared Printing System**, divided into three phases with the goal of identifying the optimal printing parameters.

Phase 1: In this initial phase, a wide range of parameter sets is tested using computed tomography (CT) and hardness measurements to estimate bulk density. All parameter sets that do not result in macroscopically dense builds are discarded.

Phase 2: The top three parameter sets from Phase 1 are selected to produce larger preforms. These preforms are used to extract samples for tensile testing and metallographic analysis. Heat treatments are applied during this phase as required. By the end of Phase 2, sufficient data is gathered to generate a preliminary material datasheet.

Phase 3: The best parameter set identified in Phase 2 is used to produce large preforms for impact or fatigue testing. Additional evaluations, such as chemical composition analysis, are conducted to verify the final properties of the material.

Verification Process for Optimal Parameter Selection and Material Density

This section describes the process verification system, both the Meltio infrared and the Meltio Blue systems, for parameter selection, in order to identify the ones that provide the best relative density.

Samples are built using simple geometries (Phases 1), from which by-products are extracted to perform defect analysis and classify the different energy density bands. For the acceptance of these samples, they must demonstrate high densification in the printed parts.

This information allows users of the Meltio systems to select the most efficient process to achieve the target material quality.

Verification Process

The verification system depends on the Meltio system being used:

Infrared System:

The verification of the printing process involves CT scan analysis of a large number of samples to ensure good part density.

The printed samples have dimensions of **60mm*30mm*15mm (X*Y*Z)**, from which two specimens of **10mm*50mm*10mm (X*Y*Z)** are extracted for CT scan analysis.

CT scans are performed at a resolution of 24 microns per pixel by an external laboratory. The full results of the material testing process can be found in the material data sheets for each of the Meltio materials.

Characterization Phases - Infrared System

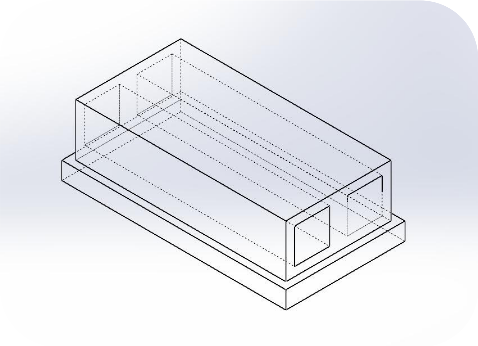
Phase 1 - Bulk Density

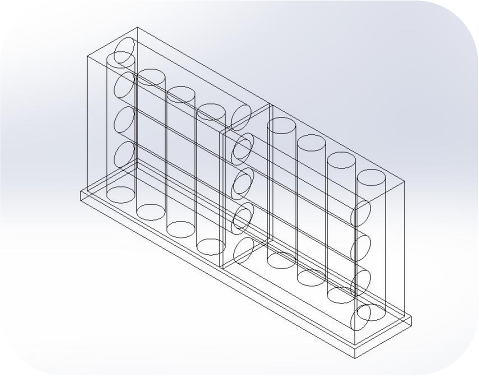
A large range of parameters are tested to define the process window.

Preform Size: 15mm x 30mm x 60mm
Sample Size: 10mm x 10 mm x 60mm
Number of samples: 10

Varied Parameters: Layer Height, Laser Power, Print Speed, Flow Rate

Tested Attributes:
- Density
- Hardness





Phase 2 - Basic Properties

Subselection of best results from phase 1 we build sufficient samples for statistically significant testing for each of parameter set.

Preform Size: 30mm x 160mm x 70mm
Sample Size: M10 cylindrical (UNE EN ISO 6892-1)
Number of samples: 48
Printing Direction: XY and XZ

Tested Attributes:
- Density
- Hardness post Heat Treatment
- Tensile Strength
- Metallography

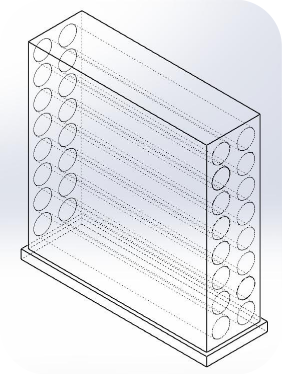
Phase 3 - Advanced Properties

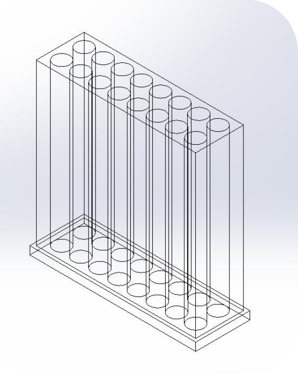
Selection of best parameter set from phase 2. Advanced tests are carried out based on the material.

Preform Size: 30 mm x 100mm x 100mm
Sample Size: Depending on the test (ASTM)
Number of samples: From 16 to 40.
Printing Direction: XY and XZ

Tested Attributes:

- Fatigue Testing
- Impact Testing
- Chemical Analysis
- RDX testing





Meltio Materials Characterization Methodology

Characterization Development Phases for Hollow parts

Blue System

Meltio characterizes hollow profiles using a cylindrical geometry with a **diameter of 80 mm and a height of 150 mm**. This geometry was specifically selected to determine the optimal printing parameters.

This approach ensures that the geometry of the hollow cylinder, which presents specific challenges such as **thermal gradients and wall stability**, can be reliably manufactured with consistent material quality and dimensional accuracy using the Meltio system.

- The profile of **a single perimeter** profile is optimized for single thin-walled cylinders and validated for cylinders with 80 mm diameter and larger diameter geometries. In smaller parts—where the enclosed area or perimeter length is reduced—thermal accumulation may to happen. To prevent overheating, a minimum cooling time per layer is applied. For example, if the layer is completed in 20 seconds, but the minimum time defined per layer is 25 seconds, a 5-second pause is automatically inserted to adjust the time to the minimum layer time and prevent overheating in smaller areas. If the layer time is longer than the minimum layer time, no pause is applied.
- The **double perimeter** profile has also been developed to meet the requirements of applications that require greater wall thickness. It is optimized to improve the bond between passes and increase structural strength, while maintaining control over roundness and internal diameter.
- Geometries that use **three or more perimeters** are considered **solid profiles**, as they allow the use of infill between perimeters. These profiles follow a different parameterization strategy focused on controlling material deposition and internal structure..

At Meltio, hollow profiles are printed using maximum laser power, as they are optimized for high deposition rate, ensuring complete fusion of the material. The parameters are defined based on the thermal and geometric behavior of each material, paying special attention to the aspect ratio (AR), that is., the ratio between the height and width of the deposition.

The parameterization strategy is based on the following key considerations:

- **Deposition height and width:** The height and width of the deposited bead depend directly on the fluidity and thermal conductivity of the material. Increased energy input increases both the height and width of the bead, altering the resulting Aspect ratio. For example, stainless steel produces thick lines and requires slower printing speeds to maintain stability.
    - **Lines of height and width** are typically formed in materials with high viscosity or low thermal conductivity.
    - **Aspect ratio (AR) (Height / Width)** values typically range from 0.20 to 0.36, depending on the material and energy input. To obtain these values, the layer height is divided by the layer width. For example, the profile of a single wall of 316LSi has an aspect ratio of 0.2424, with a deposition height of 1.2 mm and a deposition width of 4.95 mm.
- **Base Print Speed**: Base print speed: The base print speed is selected together with the line dimensions to ensure stable and uniform deposition. The speed must be adjusted according to the observed quality of the part:
    - If you can observe material hanging, also known as "hairs," on the print surface, it means that not enough energy is being transferred to the material; the profile speed should be reduced to match the material's needs.
    - If a wave pattern appears on the surface, which does not look completely horizontal to the layers, it indicates excess energy; the speed should be increased.

  In addition, using slower speeds with higher bead heights and widths allows for increased deposition rates, as the heat retained in the printed part promotes better fusion and flow of the material.
- **Cooldown Time per Layer**: Cooldown time is critical for materials sensitive to thermal accumulation. For example, titanium for hollow 1 perimeter profile may require up to 60 seconds of cooling between layers to prevent overheating and ensure geometric fidelity.

  This strategy also considers part size. The hollow cylinder profile is designed for geometries of 80 mm in diameter or greater. When printing smaller hollow profiles—either in enclosed area or length—the risk of heat accumulation increases. To mitigate this, a **minimum cooldown per layer** is applied:

    - For instance, if a geometry is set with a 25-second cooldown per layer but the actual layer time is only 20 seconds, an additional 5-second pause is added.
    - Conversely, if a geometry takes 35 seconds to complete, no cooldown is applied, as sufficient time has already elapsed during printing.
    - When the geometry has two perimeters or more, waiting times are reduced because performing the two perimeters maintains greater process stability.

Characterization Development Phases for Hollow parts for Blue Laser 1.4kW

The following table shows the parameters of the official profiles for one perimeter and for two perimeters available in our official Slicers Meltio Horizon and Meltio Space. These profiles are continuously developed and improved, so they may be subject to change in the future.

1 Perimeters

Material	Revision	Deposition Height (mm)	Deposition Width (mm)	Base Print Speed (mm/s)	Cooldown (sec)	Aspect ratio (Height / Width)
316LSi	**Rev13 2025/06/13**	1,2	4,95	5	20	0.2424
308LSi	**Rev1 2025/06/13**	1,2	4,95	5	20	0.2424
17-4 PH	**Rev1 2025/06/13**	1,2	4,95	5	20	0.2424
ER70S-6	**Rev1 2025/06/13**	1,2	4,95	5	20	0.2424
H-11	**α Rev24 2025/07/08**	0,85	3,2	10	20	0.2656
Titanium 64	**Rev4 2025/06/26**	1,5	4,65	5	60	0.3226
Nickel-718	**Rev17 2025/06/23**	0,8	3,5	10	20	0.2286
Nickel-625	**Rev17 2025/07/07**	0,75	3,6	9	20	0.2083
CuCrZr	**Rev2 2025/06/27**	0,9	2,5	7,5	0	0.36
ERCuNiAl	**Rev4 2025/06/27**	0,8	3	12,5	20	0.2667
Al-4046	**Rev1 2025/06/24**	0,8	4	18,9	0	0.2

2 Perimeters

Material	Revision	Deposition Height (mm)	Deposition Width (mm)	Base Print Speed (mm/s)	Cooldown (sec)	Aspect ratio (Height / Width)
316LSi	**Rev12 2025/06/16**	1	2	9	10	0.5
ER70S-6	**Rev1 2025/06/16**	1	2	9	10	0.5
H-11	**Rev1 2025/07/01**	1	2	9	10	0.5
Titanium 64	**Rev3 2025/07/02**	1,4	1,7	14,5	10	0.8235
Nickel-718	**Rev1 2025/06/30**	1,2	2	10,5	10	0.6
Nickel-625	**Rev1 2025/06/30**	1,2	2	10,5	10	0.6
308LSi	**Rev1 2025/06/16**	1	2	9	10	0.5
17-4 PH	**Rev1 2025/06/16**	1	2	9	10	0.5
CuCrZr	**Rev6 2025/07/07**	0,8	1,8	7	0	0.4444
Al-4046	**Rev13 2025/07/11**	0,8	3	12,5	10	0.2667
ERCuNiAl	**Rev3 2025/07/02**	1	2,2	12	10	0.4545

Deposition rates of Meltio materials

In the next section, Meltio has summarized the deposition rates for the IR system and the Blue systems of 1.0 kW and 1.4 KW

The values correspond to the current revision of the profiles in Meltio Horizon and Meltio Space. It is recommended to check future updates in the slicers, as the deposition rates may change in upcoming versions due to profile improvements or process optimizations.

The table include **solid and hollow profiles**, with deposition rates expressed in **Kg/h** and **cc/h**, providing a mass-based reference and volumetric equivalence. This dual representation facilities process planning, material comparison, and manufacturing time estimation.

Material	**Infrared 1.2 kW**				**Blue 1.0 kW**				**Blue 1.4 kW**			
	Profile	**Rev**	**Kg/h**	**cc/h**	**Profile**	**Rev**	**Kg/h**	**cc/h**	**Profile**	**Rev**	**Kg/h**	**cc/h**
Titanium 64	**Solid**	**VD IR**	**0,14**	**32**	**Solid**	**Rev 30**	**0,36**	**81**	**Solid**	**Rev 10**	**0,46**	**104**
Density: 4,43g/cm3	Hollow 1P	Utility	0,19	43	Hollow 1P	Rev 2	0,29	65	Hollow 1P	Rev 4	0,56	126
	Hollow 2P	Utility	0,19	43	Hollow 2P	Rev 2	0,28	63	Hollow 2P	Rev 3	0,55	124
Nickel 625	**Solid**	**VD IR**	**0,22**	**26**	**Solid**	**Rev 13**	**0,50**	**60**	**Solid**	**Rev 5**	**0,64**	**76**
Density: 8,2g/cm3	Hollow 1P	Utility	0,35	43	Hollow 1P	Rev 2	0,54	66	Hollow 1P	Rev 17	0,74	90
	Hollow 2P	Utility	0,35	43	Hollow 2P	Rev 2	0,53	65	Hollow 2P	Rev 1	0,77	94
Nickel 718	**Solid**	**VD IR**	**0,20**	**25**	**Solid**	**Rev 9**	**0,37**	**45**	**Solid**	**Rev 3**	**0,62**	**76**
Density: 8,2g/cm3	Hollow 1P	Utility	0,35	43	Hollow 1P	Rev 2	0,53	65	Hollow 1P	Rev 17	0,83	101
	Hollow 2P	Utility	0,35	43	Hollow 2P	Rev 2	0,51	62	Hollow 2P	Rev 1	0,74	90
308	**Solid**	**VD IR**	**0,26**	**33**	**Solid**	**Rev 7**	**0,31**	**39**	**Solid**	**Rev 3**	**0,48**	**61**
Density: 7,9g/cm3	Hollow 1P	Utility	0,34	43	Hollow 1P	Rev 2	0,51	65	Hollow 1P	Rev 1	0,85	108
	Hollow 2P	Utility	0,34	43	Hollow 2P	Rev 2	0,49	62	Hollow 2P	Rev 1	0,51	65
316L	**Solid**	**VD IR**	**0,26**	**33**	**Solid**	**Rev 10**	**0,36**	**46**	**Solid**	**Rev 3**	**0,48**	**61**
Density: 7,9g/cm3	Hollow 1P	Utility	0,34	43	Hollow 1P	Rev 2	0,49	62	Hollow 1P	Rev 13	0,85	108
	Hollow 2P	Utility	0,34	43	Hollow 2P	Rev 2	0,47	59	Hollow 2P	Rev 12	0,52	66
17-4PH	**Solid**	**VD IR**	**0,17**	**22**	**Solid**	**Rev 25**	**0,26**	**34**	**Solid**	**Rev 5**	**0,33**	**43**
Density: 7,75g/cm3	-	-	-	-	Hollow 1P	Rev 2	0,5	65	Hollow 1P	Rev 1	0,83	107
	-	-	-	-	Hollow 2P	Rev 2	0,49	65	Hollow 2P	Rev 1	0,51	107
ER70-S	**Solid**	**VD IR**	**0,17**	**22**	**Solid**	**Rev 41**	**0,33**	**42**	**Solid**	**Rev 1**	**0,42**	**54**
Density: 7,8g/cm3	Hollow 1P	Utility	0,33	42	Hollow 1P	Rev 2	0,52	67	Hollow 1P	Rev 1	0,84	108
	Hollow 2P	Utility	0,33	42	Hollow 2P	Rev 2	0,5	64	Hollow 2P	Rev 1	0,51	65
H11	**Solid**	**VD IR**	**0,14**	**18**	**Solid**	**Rev 27**	**0,24**	**31**	**Solid**	**Rev 3**	**0,31**	**40**
Density: 7,81g/cm3	Hollow 1P	Utility	0,33	42	Hollow 1P	Rev 2	0,5	64	Hollow 1P	α Rev 27	0,76	97
	Hollow 2P	Utility	0,33	42	-	-	-	-	Hollow 2P	Rev 1	0,51	65
ERCuNiAl	-	-	-	-	**Solid**	**Rev 35**	**0,35**	**44**	**Solid**	**Rev 3**	**0,88**	**110**
Density: 8 g/cm3	-	-	-	-	-	-	-	-	Hollow 1P	Rev 4	0,96	120
	-	-	-	-	-	-	-	-	Hollow 2P	Rev 3	0,85	106
CuCrZr	-	-	-	-	-	-	-	-	**Solid**	**Rev 6***	**0,65**	**73**
Density: 8,94g/cm3	-	-	-	-	Hollow 1P	Rev 8	0,4	45	Hollow 1P	Rev 2	0,54	60
	-	-	-	-	Hollow 1P	Rev 9	0,4	45	-	-	-	-
	-	-	-	-	-	-	-	-	Hollow 2P	Rev 6	0,32	36
Al 4046	-	-	-	-	-	-	-	-	**Solid**	**Rev 11**	**0,18**	**67**
Density: 2,67 g/cm3	-	-	-	-	Hollow 1P	Rev 10	0,42	157	Hollow 1P	Rev 1	0,41	153,56
	-	-	-	-	-	-	-	-	Hollow 2P	Rev 12	0,16	59,93

* refractory platform

Meltio has summarized the **average mass deposition rate** when comparing different laser configurations: 1.4 kW Blue vs. 1.2 kW IR, 1.0 kW Blue vs. 1.2 kW IR, and 1.4 kW Blue vs. 1.0 kW Blue. The results are divided into **solid profiles** and **hollow profiles** (1P and 2P), providing a clear reference of the relative increase in deposition performance between systems. These values allow a direct comparison of efficiency depending on the laser power and profile type, supporting process selection and production planning.

Mass deposition rate average	**1,4 kW Blue vs 1,2 kW IR**	**1,0 kW Blue vs 1.2 kW IR**	**1,4 kW Blue vs 1,0 kW Blue**
Solid Average	239,28%	174,66%	137,00%
Hollow 1P Average	245,63%	152,24%	161,34%
Hollow 2P Average	181,28%	146,64%	123,62%

Mechanical Properties Reference Standards

The mechanical properties of parts manufactured with Meltio technology compare favourably with the values set out in ASTM standards for cast and forged components. A comparative guide based on ASTM standards is provided in this document.

Stainless Steel 316L	**Cast** *(ASTM A743)*	**Cast** *(ASTM A403)*	**Wrought** *(ASTM A473-24)*	**Wrought** *(ASTM A351)*
Tensile Strength (MPa)	485	515	450	550
Yield Strength (MPa)	205	208	170	260
Elongation (%)	30	40	40	35
Hardness (HV30)	-	215	-	225

Titanium 64	**Cast** *(ASTM B367)*	**Cast** *(ASTM F1108)*	**Wrought** *(ASTM A381)*	**Wrought** *(ASTM F1472)*
Tensile Strength (MPa)	895	860	895	930
Yield Strength (MPa)	825	758	828	860
Elongation (%)	6	8	10	10
Hardness (HV30)	-	342	-	349

Nickel 718	**Cast** *(AMS 5383)*	**Casting (ASTM A494)**	**Wrought** *(ASTM B5383)*	**Wrought** *(ASTM B637)*
Tensile Strength (MPa)	345	802	1275	1241
Yield Strength (MPa)	125	758	1034	1034
Elongation (%)	10	5	12	10
Hardness (HV30)	342	-	350	-

Nickel 625	**Casting (ASTM A494)**	**Wrought** *(ASTM B564-22)*	**Wrought** *(ASTM B446)*
Tensile Strength (MPa)	485	690	827
Yield Strength (MPa)	275	276	414
Elongation (%)	25	30	30
Hardness (HV30)	-	-	220

17-4PH	**Casting (ASTM A747)**	**Wrought** *(ASTM A7058/A7058M)*
Tensile Strength (MPa)	1205	1310
Yield Strength (MPa)	1035	1035
Elongation (%)	5	5
Hardness (HV30)	-	-

ER70S-6	**Casting (ASTM A494)**	**Wrought** *(ASTM A.3)*
Tensile Strength (MPa)	585	550
Yield Strength (MPa)	205	250
Elongation (%)	24	23
Hardness (HV30)	160	127

Tool Steel H11	**Wrought (ASTM 1472)**
Tensile Strength (MPa)	1990
Yield Strength (MPa)	1650
Elongation (%)	10
Hardness (HRC)	53

ERCuNiAl	**Wrought (ASTM B283/B283M -24)**
Tensile Strength (MPa)	565
Yield Strength (MPa)	255
Elongation (%)	32
Hardness (HRC)	152

Invar	**Wrought (ASTM A658)**
Tensile Strength (MPa)	500
Yield Strength (MPa)	241
Elongation (%)	31
Hardness (HV-30)	127

CuCrZr	**Wrought** *(ASTM B740)*
Tensile Strength (MPa)	450
Yield Strength (MPa)	350
Elongation (%)	20
Hardness (HRC)	-

Al 4046	**Casting** *(ISO R2147)*
Tensile Strength (MPa)	300
Yield Strength (MPa)	170
Elongation (%)	2.5
Hardness (HRC)	115

Mechanical Properties Blue System

Mechanical Properties of Meltio parts compare favourably to properties of conventionally manufactured components. We provide a comparative guide comparing the properties of Meltio parts with ASTM standard properties. In most cases the properties of our printed parts exceed the values of castings and rival those of forgings.
More detailed information can be found in the individual datasheets.

Stainless Steel 316L	**HT XZ**	**As Printed XZ**
Tensile Strength (MPa)	641 ± 47	586 ± 77
Yield Strength (MPa)	332 ± 50	474 ± 22
Elongation (%)	46 ± 14	17.7 ± 15
Hardness (HV30)		173

Titanium 64	**HT XZ**	**As-Built XZ**
Tensile Strength (MPa)	850 ± 11	962 ± 12
Yield Strength (MPa)	699 ± 9	854 ± 11
Elongation (%)	14.13 ± 0.5	9.50 ± 0.5
Hardness (HV30)		332

Nickel 718	**HT-1 XZ**	**As Printed XZ**
Tensile Strength (MPa)	1290 ± 26	874 ± 9
Yield Strength (MPa)	1026 ± 19	520 ± 5
Elongation (%)	11 ± 2	31 ± 2
Hardness (HV30)		247

Nickel 625	**HT-2 XY**	**HT-1 XY**	**As-Built XY**
Tensile Strength (MPa)	903.6 ± 8.4	848 ± 14.1	834 ± 17.1
Yield Strength (MPa)	509.3 ± 42	405 ± 24	540 ± 29.8
Elongation (%)	40.2 ± 2.7	51.4 ± 4.8	46 ± 6.4
Hardness (HV30)			222

17-4PH	**HT XZ**	**As Printed XZ**
Tensile Strength (MPa)	1200 ± 59	1088 ± 28
Yield Strength (MPa)	1135 ± 43	866 ± 17
Elongation (%)	4 ± 1	5 ± 2
Hardness (HV30)		324

ER70S-6	**HT XZ**	**As Printed XZ**
Tensile Strength (MPa)	463 ± 7	600 ± 63
Yield Strength (MPa)	300 ± 5	550 ± 34
Elongation (%)	26 ± 8	11 ± 5
Hardness (HV30)		136

Tool Steel H11	**HT XZ**	**As Printed XZ**
Tensile Strength (MPa)		
Yield Strength (MPa)		
Elongation (%)		
Hardness (HRC)		

ERCuNiAl	**HT XZ**	**As Printed XZ**
Tensile Strength (MPa)	691 ± 7	725 ± 80
Yield Strength (MPa)	291 ± 4	435 ± 20
Elongation (%)	26 ± 1	22 ± 13
Hardness (HRC)		191

308	**As Printed XZ**	**As Printed XZ**
Tensile Strength (MPa)	580 ± 41	605 ± 10.2
Yield Strength (MPa)	291 ± 23	416 ± 23.3
Elongation (%)	50.8 ±5	27 ±6.72
Hardness (HV-30)		213

CuCrZr	**As Printed XZ**
Tensile Strength (MPa)	
Yield Strength (MPa)	
Elongation (%)	
Hardness (HRC)	

Al 4046	**As Printed XZ**
Tensile Strength (MPa)	
Yield Strength (MPa)	
Elongation (%)	
Hardness (HRC)	

Mechanical Properties Infrared System

Mechanical Properties of Meltio parts compare favourably to properties of conventionally manufactured components. We provide a comparative guide comparing the properties of Meltio parts with ASTM standard properties. In most cases the properties of our printed parts exceed the values of castings and rival those of forgings.

More detailed information can be found in the individual datasheets.

Stainless Steel 316L	**HT XZ**	**As Printed XZ**
Tensile Strength (MPa)	547 ± 8	655 ± 11
Yield Strength (MPa)	253 ± 17	347 ± 28
Elongation (%)	62 ± 2	41 ± 4
Hardness (HV30)	192	-

Titanium 64	**HT XZ**
Tensile Strength (MPa)	788 ± 12
Yield Strength (MPa)	693 ± 16
Elongation (%)	9 ± 1
Hardness (HV30)	311

Nickel 718	**HT XZ (S.A. + A.H.)**	**HT XZ (S.A.)**	**As Printed XZ**
Tensile Strength (MPa)	1208 ± 49	925 ± 86	833 ± 50
Yield Strength (MPa)	980 ± 2	631 ± 10	537 ± 32
Elongation (%)	10 ± 5	15 ± 2	25 ± 3
Hardness (HV30)	332	285	245

Nickel 625	**HT XZ**
Tensile Strength (MPa)	739 ± 19
Yield Strength (MPa)	323 ± 15
Elongation (%)	58.4 ± 3.9
Hardness (HV30)	160 ± 3

17-4PH	**HT XZ**	**As Printed XZ**
Tensile Strength (MPa)	1391 ± 7	1017 ± 15
Yield Strength (MPa)	1243 ± 8	815 ± 17
Elongation (%)	10 ± 3	14 ± 0.1
Hardness (HV30)	393	258

ER70S-6	**As Printed XZ**
Tensile Strength (MPa)	525 ± 12
Yield Strength (MPa)	402 ± 37
Elongation (%)	15 ± 9
Hardness (HV30)	175

Tool Steel H11	**HT XZ**	**As Printed XZ**
Tensile Strength (MPa)	2087 ± 2	1830 ± 105
Yield Strength (MPa)	1735 ± 101	1170 ± 90
Elongation (%)	12.18±0.19	3.46 ± 0.36
Hardness (HRC)	51	52

Invar	**As Printed XZ**
Tensile Strength (MPa)	522 ± 14
Yield Strength (MPa)	337 ± 22
Elongation (%)	24 ± 2
Hardness (HV-30)	147

ERCuNiAl	**As Printed XZ**	**ERCuNiAl**
Tensile Strength (MPa)		
Yield Strength (MPa)		
Elongation (%)		
Hardness (HV-30)		

CuCrZr	
Tensile Strength (MPa)	
Yield Strength (MPa)	
Elongation (%)	
Hardness (HRC)	

Introduction to Post-Processing and Heat-Treatment

Introduction

Heat treatment is a process of heating and cooling metals or alloys to alter their physical and mechanical properties without changing their shape. The objective of heat treatment is to improve the material's performance, durability, and strength.
There are various types of heat treatment processes, including annealing, normalizing, tempering, quenching, etc. Each process involves heating the metal to a specific temperature, holding it at that temperature for a specific time, and then cooling it at a controlled rate.

Heat treatment applications

Heat treatment is not always mandatory, but it can be essential to achieve the desired properties and performance of a metal or alloy. In many cases, heat treatment is required to meet specific design or performance requirements.
For example, some metal alloys used in high-stress applications, such as aircraft parts or critical machine components, require heat treatment to improve their strength and durability. Similarly, some manufacturing processes may require heat treatment to relieve stresses, reduce distortion, or improve machinability.
However, there may be cases where heat treatment is not necessary or may even be detrimental to the metal's properties. Therefore, the decision to perform heat treatment depends on the specific material, its intended use, and the desired properties.

Process order of heat treatments

The heat treatment is carried out depending on its purpose. If the heat treatment is required in order to machine the material (stress relieve), it will always be carried out after the printing process and before removing the piece from the base plate, this is the case of hard steels (H11 tool steel) to avoid cracking during machining. On the other hand, if the heat treatment serves to improve the mechanical properties of the material, it will generally be carried out after removing the piece from the base plate and before the final machining process, this is the case of Ti64 or Inconel 718.

Materials with a high tendency to cracking *(i.e. Tool Steels)*

Annealing
Plate Removal
Machining
Quenching + Tempering

Materials with a low to Medium tendency to cracking *(i.e. Ti64 or 316L)*

Plate Removal
Machining
HT if needed

Note: Machining and Plate Removal may be interchanged for optimized workholding

Equipment

The equipment used for heat treatment depends on the type of heat treatment process and the size and shape of the material being treated. Usually, the most common are a furnace to heat the material to a certain temperature and a quenching tank for cooling the material rapidly. More complex heat treatments are typically outsourced to service providers.

Cost of heat treatments

The cost of heat treatment depends on various factors, including the type of heat treatment, the size and shape of the part, the material being treated and the quantity of parts being treated.
Generally, the larger the part size, the higher the cost of heat treatment. This is because larger parts require more time and energy to heat and cool, which increases the operating costs of the equipment. Also, larger parts require bigger facilities and ovens which are less common, driving up the cost.

Moreover, the cost of heat treatment can also vary depending on the type of heat treatment process being used. For example, annealing and normalizing are typically less expensive than quenching and tempering, which require more specialized equipment and materials.
In addition, the material being treated can also affect the cost of heat treatment. Some materials may require longer heating and cooling times or more specialized equipment, which can increase the cost.
Therefore, it is important to consider all these factors when estimating the cost of heat treatment for a specific part or batch of parts.

** Please note that the following chart is intended to provide a simplified overview of the heat treatment process. While the information presented is generally accurate, it is important to recognize that actual heat treatment processes can vary depending on a range of factors, including the specific materials involved, the equipment used, and the desired outcomes. As such, the information presented should be used for educational purposes only and should not be relied upon as a definitive guide to the heat treatment process in all cases. It is recommended that you consult with a qualified professional or refer to more detailed technical resources for specific information on heat treatment processes applicable to your situation.*

Study of thermal cycles effect for CNC post-processing

This study evaluates the influence of three different cooling conditions — Room temperature (reference), air cooled, and water cooled (quenching with cutting fluid) — of an additive manufactured part on its hardness and derived mechanical properties.

The following study uses 17-4PH stainless steel as a representative metal, as it is a precipitation hardening alloy of the martensitic family. In additive manufacturing (AM) processes, especially those involving high thermal gradients and rapid solidification, the properties as printed are greatly influenced by the cooling conditions that occur immediately after deposition. The cooling method applied plays a fundamental role in determining the final microstructure, hardness and mechanical performance of the material.

Sample Dimensions:

This experiment was carried out using 3 samples of 30 × 30 × 90 mm prints, a single type of cooling was applied to each sample throughout its manufacture.
Each sample is produced in 3 steps of 30x30x30, after each step cooled down is applied, then a face of the cube is machined to allow the hardness test to be performed on said face. More information on the effect of the different cooling methods on the next page or section.

Cooling Conditions:

1- Controlled cooling, cooled down naturally at room temperature, (reference condition) yielded the **highest hardness (398 HV)**. This is attributed to a more complete martensitic transformation and a homogeneous distribution of fine precipitates. Under this condition, the material exhibited **high yield strength and tensile strength**, but **low ductility**. The dense microstructure with minimal retained austenite favors load-bearing capacity and structural rigidity.

2- Air cooling with compressed air on a CNC machine during 7 minutes, producing an **intermediate hardness (387 HV)** and mechanical behavior that balances strength and ductility. The slower cooling rate can lead to the presence of retained austenite or coarser precipitates, slightly lowering the resistance to plastic deformation. However, it improves **elongation** and **impact resistance**.

3- Quenching with cutting fluid on a CNC machine during 30 seconds on a CNC machine resulted in the **lowest hardness (365 HV)**, due to less efficient martensitic transformation and potential formation of soft phases such as retained austenite. The material displayed **medium-low strength** but **increased ductility**, offering improved deformation capacity under cyclic or dynamic loads.

The cooling method directly affects not only hardness but also the internal stress state, phase distribution, and mechanical reliability of the printed or heat-treated part. The data confirms the following relationship between cooling rate and mechanical behavior:

- **Controlled Cooling (398 HV)**: High strength, low ductility → Recommended for rigid, load-bearing parts.
- **Air Cooling (387 HV)**: Balanced strength and toughness → Recommended for components requiring both resistance and flexibility.
- **Cutting Fluid Cooling (365 HV)**: Lower strength, high ductility → Recommended for flexible, fatigue-tolerant applications.

In conclusion, the **selection of the cooling strategy** for 17-4PH stainless steel should be aligned with the specific functional requirements of the component. **Controlled cooling** is optimal for applications requiring high hardness and structural integrity, while **air or fluid quenching** offers viable alternatives where **ductility, energy absorption, or resistance to cyclic loading** are more critical. Proper control of the cooling phase is essential to tailor the final properties of 17-4PH and ensure its performance in demanding industrial environments.

Study of thermal cycles effect for CNC post-processing

How this affects printing on a hybrid system?

In hybrid systems that combine additive and subtractive processes in the same configuration, the type of cooling can significantly influence material performance. Inadequate cooling management could lead to unexpected contraction or high levels of residual stress, which in turn can cause the printed part to become more fragile.

How it affects tool wear?

Cooling conditions during printing influence surface hardness and residual stress distribution, which in turn affect tool wear in the subtractive phase:

- Higher hardness surfaces (as in controlled cooling) are more resistant to cutting, increasing tool load and wear rate, especially for high-speed or dry machining.
- Lower hardness surfaces (as in cutting fluid-cooled parts) are easier to machine and reduce tool wear, but may also produce gummy or ductile chips, potentially affecting chip evacuation and surface finish.

What Meltio recommends?

The cooling strategy applied during metal additive manufacturing has a direct impact on the microstructure, mechanical properties and reliability of the final component. It also influences process efficiency and tool wear in hybrid systems. Based on operational experience and thermal studies, Meltio recommends:

- Avoid using liquid refrigerants during printing. Abrupt and uncontrolled cooling can cause incomplete microstructural transformations, soft phases, internal stresses, and negatively affect material quality. This is not the most recommended option when seeking the best mechanical properties, but it is the one that allows for the fastest cooling of the material for subsequent machining and reduces tool wear..
- Cooling to room temperature between layers or sections. This strategy allows for gradual heat dissipation, promoting controlled and uniform solidification. It usually results in components with greater hardness, structural strength and less deformation, making it particularly suitable for parts subjected to static or structural loads.
- The use of compressed air or fan as an intermediate option. This solution is particularly useful in hybrid systems where more active thermal dissipation is required to protect tools or reduce cycle time. Air-assisted cooling provides a balance between mechanical strength and ductility, making it suitable for parts that must absorb impacts or load cycles

Maintain a consistent and controlled thermal strategy throughout the process, especially in step or segmented printing. Proper thermal management improves material reproducibility, reduces the risk of distortion, and optimises tool life in hybrid systems.

How to Evaluate Titanium Printed Parts Visually?

In Meltio's wire deposition additive manufacturing technology, titanium is generally processed under an inert gas atmosphere, using argon as a shielding gas. This gas is supplied by a laminar flow from the deposition head and, additionally, it is possible to inert the manufacturing chamber until residual oxygen concentrations of approximately 50 ppm are reached.

Due to the high reactivity of titanium at elevated temperatures, gases such as nitrogen, oxygen, or hydrogen are not used as shielding gases, as these can be absorbed interstitially by the material, negatively affecting its properties. In addition, titanium has a high chemical affinity for oxygen, which promotes the formation of titanium oxides in the presence of this element.

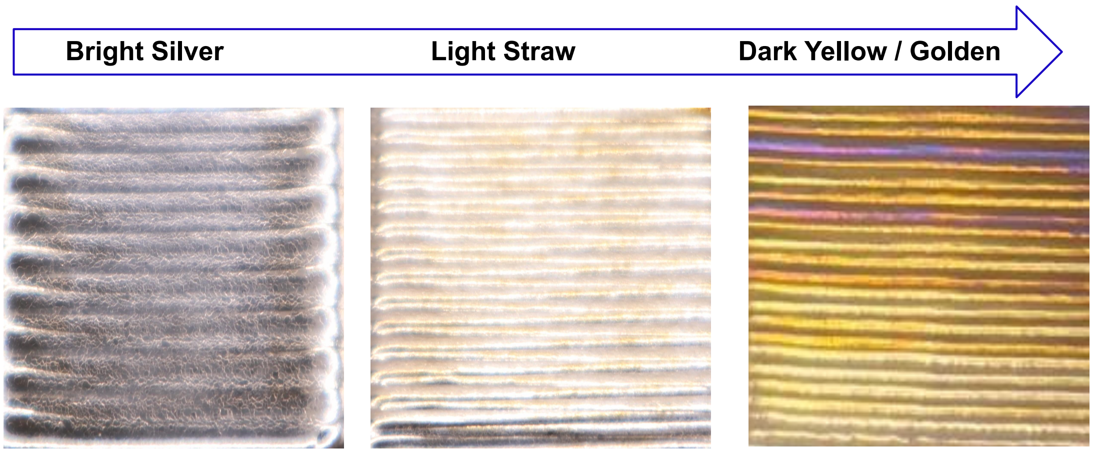
Even with adequate protection systems, a small amount of residual oxygen (50 ppm) may remain in the deposition zone or when exposed to oxygen after the additive process. The interaction of hot titanium with this oxygen generates surface oxide layers that manifest themselves in different colours in the heat-affected zone.

For this reason, the quality of titanium deposition or welding, as well as the process acceptance criteria, can be visually assessed by the discolouration present in the processed areas. These colour variations are directly related to the degree of oxidation of the material during the process.

To visually assess the degree of oxidation of titanium during the manufacturing process, a classification is established based on the surface colour observed in the deposition or welding area. This classification is divided into three acceptance levels: Acceptable, Rejectable, and Unacceptable.

Visually Acceptable Level

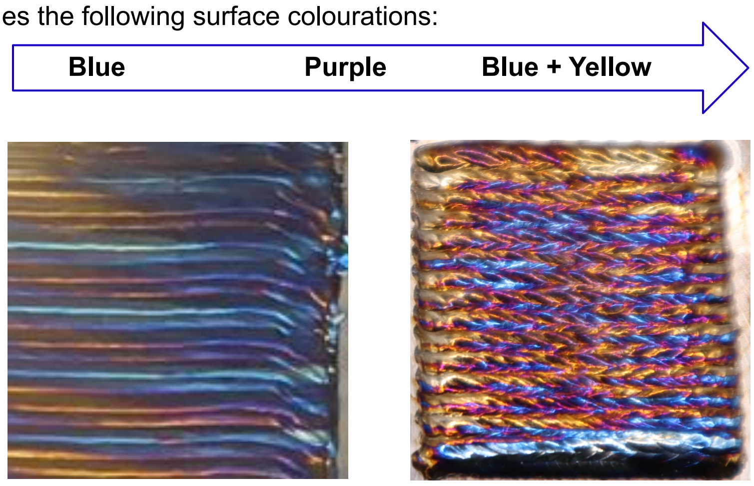
This level includes three surface conditions that indicate adequate or slightly compromised protection of the material during the process:



Bright silver is the ideal condition for a titanium part, as it indicates that no oxidation has occurred and that the material has been properly protected by the inert atmosphere throughout the printing process. On the other hand, **light straw or dark straw** shades indicate the presence of slight oxygen contamination in the deposition area. Although these colours reflect some interaction of the material with oxygen, the level of oxidation remains low and the quality of the deposition remains within acceptable limits for most applications.

Visually Rejectable Level

This level includes the following surface colourations:



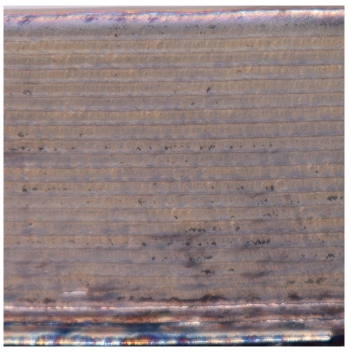
Dark blue, purple, or combinations of blue and yellow indicate more significant contamination during the printing process. In most cases, if the deposition area exhibits any of these colours, the material should be rejected. However, final acceptance may depend on specific service requirements or the intended application.

How to Evaluate Titanium Printed Parts Visually?

Unacceptable Level

This level includes the following colourations:

Grey Blue White (α-case)



Blue-grey, grey or white colours indicate severe contamination during the printing process. These conditions are considered completely unacceptable.

In particular, the white surface usually has loose, porous deposits of titanium oxide in the form of powder. This phenomenon is known as α-case (alpha case) and is indicative of inadequate protection from oxygen during the manufacturing process. This is the most critical condition of oxidation in titanium.
When α-case occurs, the affected surface should not be corrected by machining or surface grinding without prior evaluation, as this fragile, oxygen-enriched layer can significantly compromise the mechanical properties of the material.

Disclaimer – Oxidation in Meltio Technology

The oxidation data presented in the following tables correspond to experimental evaluations performed on samples manufactured using Meltio technology, considering both infrared (IR) and blue laser (Blue) process configurations.

Under the analyzed conditions, the oxidation identified in the samples is predominantly **superficial in nature**, with no evidence of significant penetration into the bulk material or measurable impact on the structural integrity of the components.

It should be noted that oxidation levels in laser-based Directed Energy Deposition (DED) processes may vary depending on processing parameters, shielding conditions, material composition, and environmental exposure. Therefore, the results provided herein are representative only of the specific testing conditions under which the samples were produced and characterized.

These findings are intended to support comparative material characterization and should not be interpreted as absolute or universally applicable values across all Meltio process configurations.

	IR system	**Blue System**
Media	0.255	0.121
Standard deviation	0.054	0.0046

MELTIO

2.2 Variable Deposition Rate with Meltio Engine

The simplest way to apply a variable deposition rate is maintaining the deposition (feeder speed) constant and adjusting the robot speed at each target. When the robot speed is faster, it will deposit less material, while lower robot speed will result in more material being deposited. The volumetric calculation of the material needed and the speed should be calculated for each point along the trajectory, hence defining variable speeds.

Varying layer height within individual layers can improve surface quality, especially for smooth curvatures. Variable layer height based on proximity to the next layer ensures smooth printing of curved sections. The positioner and robot axes help maintain a vertical build direction.

Important: Care must be taken to avoid collisions between head and components.

Variable Deposition Rate Calculation:

The standard approach for variable deposition is by modifying the movement speed, so the software should be capable of defining a different movement speed.

If the robot movement (speed) is slower, having the deposition rate constant, means it will deposit more material. If the robot moves faster, less material is deposited. With this it can be ensured that at every point of the trajectory is accurate.

Feeder Speed=PrintSpeed x7.5 x WireRadius2

Print Speed = BasePrintSpeed x BaseLayerHeigth x BaseLayerWidth x WireRadius2 x WireRadius2Layer width x Layer height

PrintSpeed=BasePrintSpeed x BaseLayerHeight x BaseLayerWidthLayer height x Layer width;

PrintSpeed=BasePrintSpeed x BaseLayerHeight x BaseLayerWidthLayer height x (BaseLayer WidthBaseLayer Height x Layer height);

PrintSpeed=BasePrintSpeed x BaseLayerHeight x BaseLayerWidthLayer height2 x BaseLayer WidthBaseLayer Height;

PrintSpeed=BasePrintSpeed x Base Layer Height2Real Layer height2;

PrintSpeed1=10mm/s x 0.62mm0.852mm= 4.95mm/s

PrintSpeed2=10mm/s x 0.62mm0.452mm= 17.91mm/s

In some cases, manual adjustments may be needed to refine the calculated values (often by changing the layer height), as printing behavior can vary between materials or with different laser power settings. Experience will help determine when adjustments are necessary.