Production Guide for Metal 3D Printing

High-throughput metal manufacturing with ColdMetalFusion technology

Introduction

Introducing ColdMetalFusion (CMF), a cutting-edge sinter-based 3D-printing technology for creating metal parts from scratch using a 3D-model. With CMF, you can produce over 100,000 parts per year without limitations or compromises on quality. What sets CMF apart is its seamless integration with existing metal injection molding processes, making it incredibly user-friendly and broading access to a wide portfolio of metal feedstocks. And with the help of Nexa3D's QLS printers, you can achieve fast, efficient, and cost-effective production. Say goodbye to the barriers of traditional 3D printing and embrace the future of metal part manufacturing with CMF.

3D Printing with Cold Metal Fusion

We all know 3D printing has been an agent of change for metal manufacturing and now ColdMetalFusion is a game-changer in the world of 3D printing.

Right now, the most commonly referenced technology for 3D printing metal parts is Metal Powder Bed Fusion (M-PBF) also known as Direct Metal Laser Melting. But the resulting high part costs, low part output along with limited material availability hampers the broad adoption of M-PBF in the market and does not allow the mass production of 3D printed parts.

This innovative sinter-based approach opens up a whole new realm of possibilities so you can say goodbye to high costs, low production outputs, and limited materials. ColdMetalFusion is here to revolutionize the market, allowing for mass production of high-quality 3D printed metal parts.

Get ready to experience a whole new world of limitless potential.

Features of ColdMetalFusion at-a-glance:

- 3D-printing of metal parts on polymer laser sintering systems
- No build plate and support structures required for the 3D-printing process (compared to Metal Powder Bed Fusion processes)
- High productivity and low costs for series of up to 100,000 parts per year
- Full reusability of non-processed feedstock powder
- High green part strength allows automated depowdering solutions and handling within a production environment
- Process compatibility to MIM debinding and sintering processes
- Part characteristics (density, yield strength, tensile strength, elongation) meet or exceed ASTM and ISO standards and on par with MIM processes
- High material availability alongside the powder metallurgy range
- Low processing temperature ('Cold Metal') saves heating time and energy. A post-printing heat-treatment (cross linking, etc.) is not necessary

When it comes to the economical series production of complex metal parts, there is no way around 3D- printing with the CMF technology

The Cold Metal Fusion Process

The ColdMetalFusion process is a sinter- based 3D printing process combining the best of QLS sintering technology from Nexa3D and a debinding/sintering process used for decades in Powder Metallurgy.

The centerpiece of the ColdMetalFusion technology is Headmade Materials' unique metal feedstock.

These materials contain metal powder which is integrated in a plastic binder matrix. It's designed for use on polymer SLS systems including Nexa3D's QLS printers. Because the metal particles are integrated in a binder-matrix, this enables the use of standard metal powders as well as non-spherical powders with a wide range of particle size distributions and particle shapes. The necessary powder flow of the feedstock for the QLS process is aided by the binder system.

Step 1 The CAD-file is scaled up to account for expected shrink. The scaling depends on the material used but is comparable to the MIM-process - for example 15% for Stainless Steel 316L or 14% for Titanium Ti6Al4V - and leads to a more uniform shrink rate compared to other binder 3D printing approaches. A lower shrink rate enhances the design possibilities for 3 printing (overhangs, etc.) significantly.

Step 2 The part is formed layer by layer by melting the feedstock to get a green part. The process takes place below 70° C, usually at 50° C, which minimizes heating and cooling time significantly. The process window also allows for operation in many environments without the need for external cooling. Furthermore, the low process temperature also minimizes stresses for the SLS-system and leads to low wear, i.e. allowing for lower amortization over a longer machine lifetime.

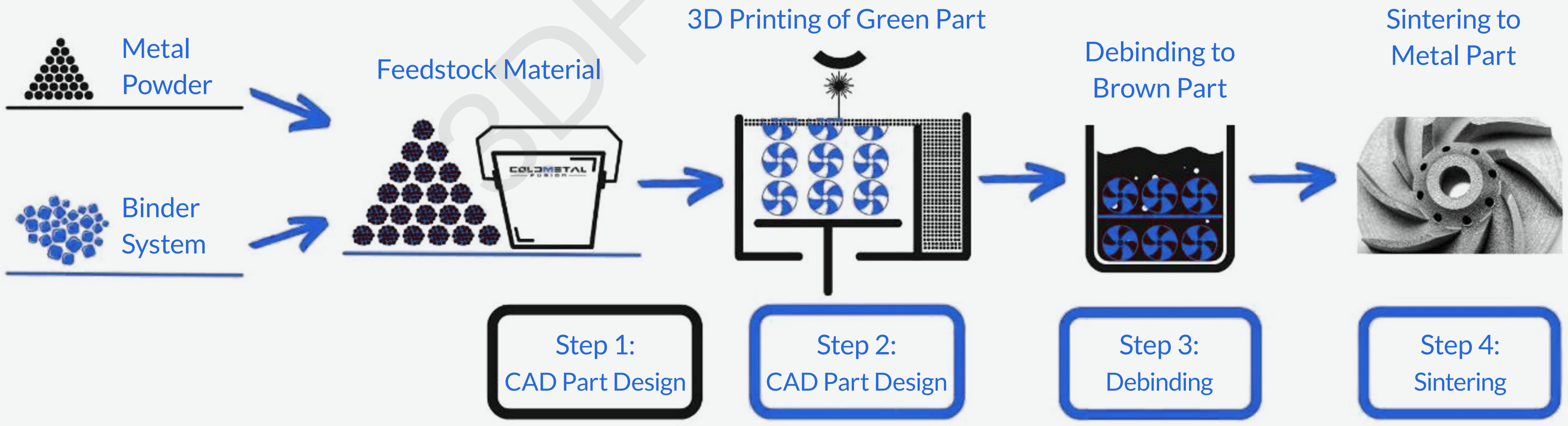


Figure 1: ColdMetalFusion process

The **decaking or break-out process** takes place once the build has cooled down to remove loose and un-melted powder around the green parts. As CMF parts have a high green part strength, the breakout process can be semi-automated using compressed air or water jet. The remaining loose powder in the build can be completely reused for the next job, helping minimize waste and improve your organization's sustainability practices.

The **high green part strength** also allows post- processing of the green parts before the sintering step. This may include grinding, drilling or milling to add features to the part. This post-processing step is especially useful for metals/alloys which cannot be handled easily in sintered form, for example Titanium, hard metals, or heavy metals.

Depowdering with water jet

Step 3

The cleaned green parts are then debound using a solvent. Within the debinding step, one part of the binder system is detached from the green part at around 30 - 40° Celsius to get a brown part that still has high part strength. This is a cost-effective and ecologically-conscious process used for many years in Powder Metallurgy. Better yet, the solvents can be distilled after use and reused indefinitely to establish a closed production circle and to avoid any additional environmental strain.

Left Impeller: Design Fraunhofer IFAM, Bremen

Step 4

The brown parts are then sintered in a furnace. During the sintering process, the chamber is heated up slowly to sintering temperature where an atomic diffusion process takes place and the metal particles fuse together to form a dense metal part. During this process, the remaining part of the polymeric binder burns out with no remaining residue.

The **material handling** of pure metal powders requires stringent safety measures to avoid health concerns or operational emergencies like fire/combustion. Luckily, ColdMetalFusion technology **provides a remedy** here, as the feedstock powder integrates the underlying metal powder into a binder-matrix. The agglomeration of metal powders reduces the necessary safety requirements and simplifies material handling significantly.

Stress test for a green part made of heavy metal alloy

Metal Part Characteristic

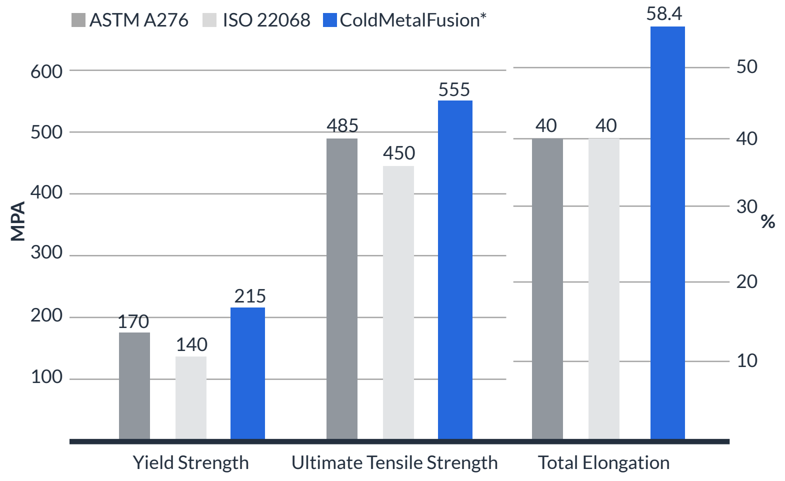
Because ColdMetalFusion uses a workflow similar to other Power Metallurgy processes, the part characteristics achieved are fully comparable to ASTM and ISO industry standards for metal injection molding (MIM).

During the 3D-printing process, only the binder is melted to form the green part. This is important to not alter the material properties of the metal part as it occurs with anisotropic grain structures formed in PBF- processes. The grain structure of a ColdMetalFusion test specimen made of Stainless Steel 316L as shown in Figure 4 reveals a fine equiaxed isotropic grain structure as seen in any other Powder Metallurgy processes.

The density achieved with the ColdMetalFusion process depends on the material, printing and sintering process but is usually > 97 % for Stainless Steel 316L and up to 100 % for liquid-phase alloys. By optimizing the processes for each metal part, repeatable density up to 99 % is possible.

Dimensional accuracy and surface quality are one of the most discussed aspects of 3D-printed parts and there are still trade-offs compared to metal parts produced via milling or metal injection molding. Metal parts produced by the ColdMetalFusion technology allow a dimensional accuracy of around ±100 µm, with optimization of construction and process parameters even higher. If even more dimensional accuracy is required, post-processing of the green part before sintering or of the metal part after sintering is possible. The surface quality is comparable to other 3D-printed parts like Powder Bed Fusion (PBF) or Binder Jetting (BJT). If a better surface quality is required, again post-processing of the green part before sintering or the metal part after sintering is needed. Machining and polishing processes often allow users to meet surface finish and dimensional accuracy requirements.

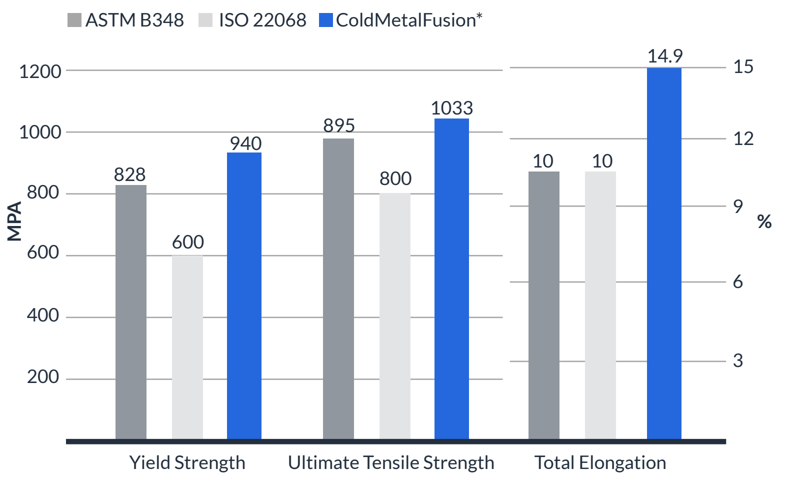
Mechanical properties of Stainless Steel 316L



*Printed on an EOS Forminga P110 - material performance impacted by different factors (part design & geometry, etc.)

Figure 2: Comparison with norm values of part characteristics of Stainless Steel 316L for yield strength, ultimate tensile strength and total elongation

Mechanical properties of Titanium Ti6Al4V



Source: Element22, 2021
*Printed on an EOS Forminga P110 - material performance impacted by different factors (part design & geometry, etc.)

Figure 3: Comparison with norm values of part characteristics of Titanium Ti6Al4V for yield strength, ultimate tensile strength and total elongation

Characteristics of metal parts produced with the ColdMetalFusion technology correspond to those of the underlying alloy. This means, that a heat treatment or cross-linking, often used by other 3D-printing technologies to reduce internal part stresses or to achieve a specific hardness is not necessary. The hardness of the metal part is determined by the underlying alloy and sintering process but not the 3D-printing process. Currently, a hardness of up to 60 HRC is possible (e.g. Cobalt-Chromium-alloys) without post- processing steps.

Metal parts used in specific applications (e.g. aerospace) are often post-processed by using Hot-Isostatic-Pressing (HIP). This is of course also possible with metal parts produced by the ColdMetalFusion technology to improve density and grain structure of the metal part. Usually we recommend optimizing part design and manufacturing parameters to avoid such additional post-processing steps.

DENSITY

Archimedes
98%

Optical
99%

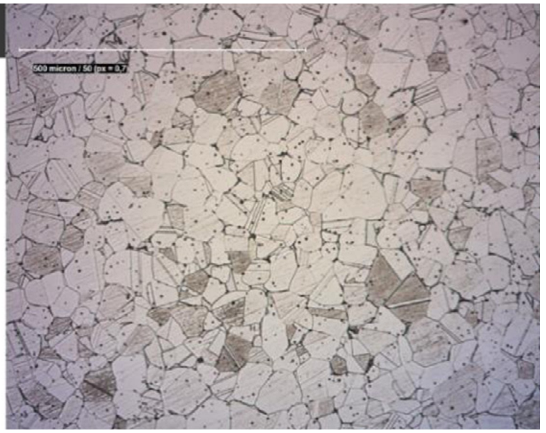


Figure 4: Micrograph and grain structure of Stainless Steel 316L

Metals & Alloys

The feedstock is the centerpiece of the ColdMetalFusion process and connects the existing ecosystems of 3D-printing and Powder Metallurgy. For the ColdMetalFusion technology, the full material spectrum of Powder Metallurgy is available. This not only includes steel alloys but also hard metals, heavy metals and super alloys. As metal powders are integrated in a plastic binder matrix to form the feedstock, spherical particles or flowability of the primary metal powders is not necessarily required. Edged particles, coarse powders or fine powders between 10 to 60 µm can be used as primary particles. The feedstock materials are initially designed to be processable on an existing ecosystem of industrialized machines and established production processes.

Available materials

- Stainless Steel 316L
- Stainless Steel 17-4PH
- Tool Steel M2
- Titanium Ti6Al4V

Materials under development / beta-phase

- Cobalt Chrome
- Aluminum 6061
- Inconel 625

Metal powder feedstock

Finding The Right Use Case

Till now, 3D-printing has been mostly limited to production of complex metal parts for prototypes and very small series. The ColdMetalFusion technology is intentionally designed to deliver economic series production of up to 100,000 parts but also gives advantages for smaller low-volume or customize production as well.

Applications can be divided into three broad categories.

1. The **cost-effective production of up to 100,000 metal parts per year**. Processes like MIM often do not allow an economical production of metal parts in this range due to high tooling costs.

2. **Complex parts for which PM-processes are not suitable** due to tool limitations and lack of design freedom.

3. Parts manufactured with **special alloys** may be printed in small batches economically and with less complex post processing. This holds true especially if the processing of the intended material is difficult to handle with standard processes (e.g. milling) like Titanium. Post-processing parts in their green state can save time and reduce costs significantly.

The possibility to design parts with new features and an optimized design will lead to more features and better products for end users. But of course there are also some design limitations in using the ColdMetalFusion process. The **wall thickness should be at least 1.0 mm up to a maximum of 10.0 mm** to guarantee a sufficient stability but also to ensure a short debinding time. Excessive overhangs should be avoided as these have limited stability during the sintering process. Necessary overhangs can be mitigated by printing sintering support structures.

[1] Depending on part size

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