

High Performance Metal Solutions

Additive Manufacturing

Printing Solutions for the Future



High Performance Metal Solutions

H.C. Starck Solutions – Your Partner for AM

Combining 100 years of experience in refractory metals with competency in 3D printing technologies, H.C. Starck Solutions provides cutting edge knowledge in the quickly evolving field of additive manufacturing (AM).

Additive Manufacturing at H.C. Starck Solutions

H.C. Starck Solutions' expertise in AM methods as well as refractory metal part manufacturing makes us the ideal partner for our customers' current applications, as well as for the development of solutions to their future challenges. Our competency in material selection, part design, process validation and full scale manufacturing provides a leading edge in the fast-paced AM industry. With refractory metal feedstocks including both powder and wire, we are able to support multiple AM methods and our refractory metal parts portfolio covers all key markets.

Materials

Based on 100 years of experience in manufacturing and development of refractory metals, H.C. Starck Solutions has powder and wire feedstock with tailored properties perfectly suited for AM. The company's core competencies of W, Mo, Ta and Nb, in pure and alloyed forms, ensure materials with the highest quality and performance for our customers.

As an integrated player, we use our feedstock materials and turn them into innovative finished products using the best suited additive manufacturing methods.

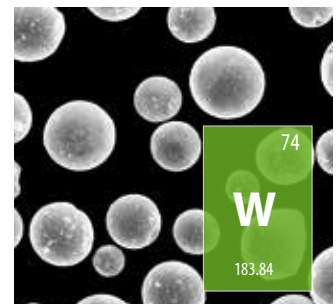
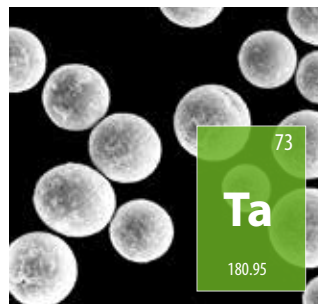
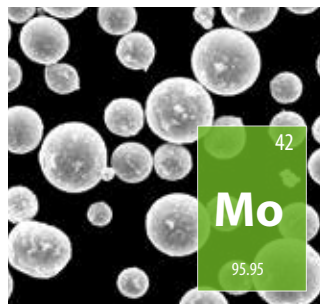
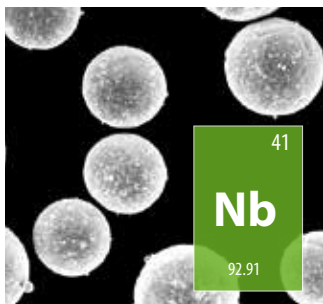
Methods

Since the introduction of AM, a large variety of process technologies have been developed of which no single method fits all applications. H.C. Starck Solutions works closely with its customers and partners to select the correct feedstock and method that will provide the most value to any given application. We have successfully demonstrated refractory metal AM with multiple methods.

Markets

H.C. Starck Solutions' refractory metal 3D printing solutions support our customers in all key end markets and enable them to benefit from the unique advantages of AM.

Industries currently served include Medical, Aerospace, Industrial, Nuclear and Defense. H.C. Starck Solutions continuously broadens its portfolio and works on innovating and designing parts for applications in markets that have not previously utilized refractory metals.



Materials

H.C. Starck Solutions' AM powder and wire feedstock offers world class quality and performance with perfectly tailored properties suited for all relevant AM methods.



Our Feedstock Solutions

H.C. Starck Solutions' innovative powder and wire manufacturing technology coupled with our vertically integrated supply chain and metallurgical expertise ensures the highest quality materials for demanding applications and environments. Our advanced technological processes enable us to customize our refractory metal feedstock to precise requirements achieving outstanding material properties and optimum performance for additive manufacturing.

Our Powder Advantage

H.C. Starck Solutions' powders are specifically designed to meet the demanding requirements of additive manufacturing technologies. Their properties exceed traditional production specifications and offer:

- **High purity**
- **High bulk density**
- **Spherical powder morphology**
- **Exceptional flowability**
- **Low oxygen**
- **PSD optimized for specific printing methods**

TYPICAL PROPERTIES OF AM POWDERS

| Property | Unit | Niobium | Molybdenum | Tantalum | Tungsten |
|------------------------|-------|---------|------------|----------|----------|
| Purity | % | >99.95 | >99.95 | >99.95 | >99.95 |
| Mean Particle Size D50 | µm | 20-30 | 20-30 | 20-30 | 20-30 |
| D10/D90 | µm | 10/40 | 10/40 | 10/40 | 10/40 |
| Bulk Density | g/cc | 4 | 5 | 8 | 10 |
| Hall Flow | s/50g | 14-16 | 8-10 | 5-9 | 5-8 |
| Oxygen | ppm | 1500 | 400 | 300 | 250 |

Wire

H.C. Starck Solutions' traditional refractory metals are available in wire form for directed energy deposition processes. Wire size and material can be optimized depending on the specific process and application.

The unique arc melting processes utilized in the manufacture of our materials results in low interstitial and volatile impurity content making them ideally suited for AM methods that require melting.

Customization

H.C. Starck Solutions' pure metal powders are available in a wide spectrum of particle size distributions to match the requirements of the printing method.

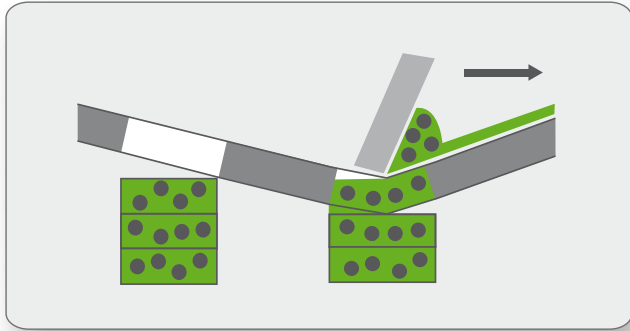
Our customized alloy powder product portfolio includes:

- **Tantalum Alloys:** Ta-3W, Ta-10W
- **Molybdenum Alloys:** TZM, Mo-La, Mo-Re
- **Tungsten Alloys:** WHA, W-Re
- **Niobium Alloys:** Nb C-103

We continuously develop new materials and methods and are ready to support your unique requests.

Methods

H.C. Starck Solutions provides the expertise to select the best material and method for each application, maximizing customer value by balancing cost vs dimensional accuracy and part performance.



3D Screen Printing

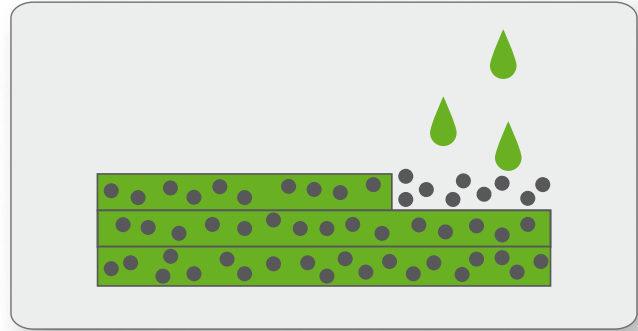
H.C. Starck Solutions' 3D Screen Printing method for refractory metals uses a metal printing paste that is applied in vertical layers to create the required geometry. The technology is successfully utilized in producing complex grid structures.

The process enables us to print very small feature sizes with tight tolerances. It utilizes traditional powders resulting in exceptional customer value.

Post-print sintering is typically required as a finishing step and allows us to achieve properties that exceed traditional powder metallurgy specifications. This enables our customers to take advantage of the benefits of AM without sacrificing on material characteristics.



Selected 3D screen printed tungsten parts



Binder Jet Printing

Binder Jet printing is a powder-bed method using polymer adhesives to bond the powders in layers. The method uses relatively thick printing layers and short build times to maximize the benefit to our customers.

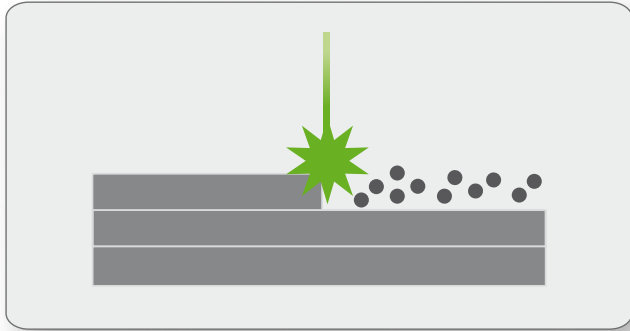
Similar to 3D screen printing, the printed part requires post-print sintering or infiltration to achieve final properties. This technology allows H.C. Starck Solutions to exceed e.g. ASTM B777 properties for tungsten heavy alloy.



Binder jet printed tungsten heavy alloy components



With 3D printing being one of our focus growth areas, we are continuously expanding product functionality and always unlocking new refractory metal applications by taking advantage of AM design.



Powder Bed Fusion

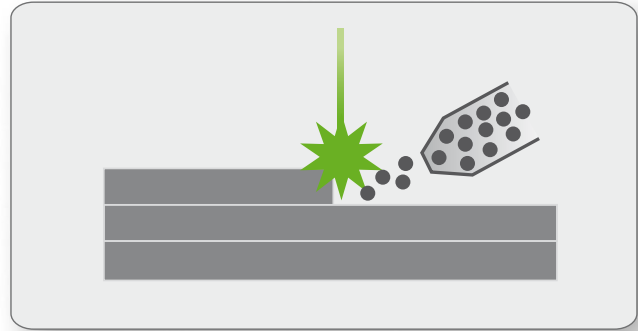
Probably the most well know AM method for metal parts is powder bed fusion. During this process, metal powders are spread in layers while laser or electron beam energy is used to melt and fuse the material together.

Powderbed fusion allows for the production of full density parts, while maintaining highest design accuracy. It is a preferred option for materials that can be used in an as-welded condition.

H.C. Starck Solutions takes advantage of the benefits of powder-bed fusion to e.g. dramatically reduce the size of the finished part as well as to improve its efficiency. This includes our Ta alloy heat exchangers, providing an optimized design for application in the Chemical Processing industry.



Cross sectional view of a high efficiency heat exchanger



Directed Energy Deposition

Directed energy deposition describes the technique of “directing” metal powder or wire at a specific location while a laser beam, electron beam or plasma arc melts and fuses the material together.

Advantages of this method include high deposition rates, the ability to apply AM material structures on an existing part and the flexibility to create gradient material structures within a single part.

Even the most intricate structural parts become achievable using direct energy deposition, which H.C. Starck Solutions is able to demonstrate with its porous Ta coatings on Ti for potential biomedical applications. This technology is also suitable for rapidly applying thick coatings, applicable for tubular sputtering targets.



Ta tubular sputtering target

Markets

H.C. Starck Solutions' promise of highest quality and optimal performance make us an ideal partner for even the most critical application areas of AM refractory materials.

Radiation Imaging

H.C. Starck Solutions' diverse AM product portfolio includes 3D lead-free products for complex-geometry collimators and anti-scatter grids for CT scanners, SPECT and gamma cameras.

The high radiation attenuation, high elastic modulus and high temperature mechanical properties of our refractory metals are also used throughout the Medical Technology industry in applications such as:

- **Radiation/Isotope shielding**
- **Beam collimation**
- **High Temperature X-ray technology**

Aerospace and Defense

H.C. Starck Solutions provides high performance AM solutions for critical applications in Aerospace and Defense industries including propulsion, ballistics and warheads.

Our refractory metals have robust physical and mechanical properties with high-density and high-temperature characteristics for the most demanding applications and products:

- **High temperature rocket nozzles and vanes**
- **Counter-balance weights**
- **Fragmentation warheads**
- **EFP (Explosively Formed Penetrator) and MEFP liners**



Medical Imaging



Space Propulsion



The reach of AM in end industries is expanding daily. H.C. Starck Solutions' constant research into new applications and materials allows us to actively participate in the design of future solutions.

Biomedical

AM offers definite performance advantages for various medical applications in its ability to form porous structures to enhance bone osteointegration, tailor material properties to enhance implant design, and reduce overall part mass.

H.C. Starck Solutions materials are known to have high biocompatibility. Specific tantalum, tungsten and molybdenum alloys have FDA and CE approved biomedical applications, including:

- **Implants for orthopedic, dental, spinal**
- **Cardiovascular stents**
- **Markers for radiation imaging**



Biomedical Implants

Industrial

The corrosion resistance, durability, workability, and heat transfer properties of H.C. Starck Solutions materials make them ideal for challenging applications in the Chemical and Pharmaceutical industries. In addition, today's demanding applications in heat treating, sintering, brazing, annealing, metalworking, and other thermal processing areas require innovative AM refractory metal product solutions.

Products include:

- **Condensers, coils, pipe spools, heat exchangers, and a variety of components exposed to corrosive fluids**
- **Complex furnace parts, crucibles, heating elements, and other fabricated components**



Chemical Processing

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