ADDITIVE MANUFACTURING

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6K ADDITIVE

High-Quality Refractory Metal Powders Come to Additive Manufacturing

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Refractory metals are essential in the manufacturing of hypersonic missiles, defense systems, and other rocket applications where high temperature and high-strength properties are needed. 6K Additive's refractory metal powders unleash the potential of additive manufacturing for these complex parts with design freedoms impossible to execute with conventional manufacturing techniques.

When GE Aerospace developed its first 3D printed jet engine fuel nozzle back in 2011 a new era was born in additive manufacturing. AM enabled GE engineers to design a part that could not be made with CNC machining technology, consolidating 20 parts into a single build, and providing superior performance over prior designs. Made from cobalt chromium powder, the nozzles also featured exceptionally long life.

But AM has struggled to find comparable successes in ultra-high-temperature applications, mainly because high-quality refractory AM powders were not available in production volumes. Refractory materials such as tungsten have been very difficult to process into powder because of their very high melting temperatures and several other factors. If designers wanted to use these materials, they had little choice but to machine the parts conventionally, which placed serious limitations on design flexibility.

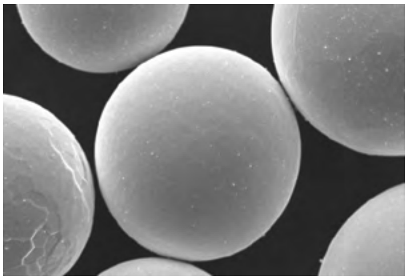
6K Additive is changing all that with its refractory powders, including tungsten, niobium, rhenium, tantalum, molybdenum, and others. Manufacturing these powders to high-quality standards is made possible by 6K's UniMelt® microwave reactor process which uses plasma to refine powder to high levels of density, size consistency, and roundness. The resulting powder is low in porosity and satellites, aiding its flow and spreadability and, ultimately, its printability.

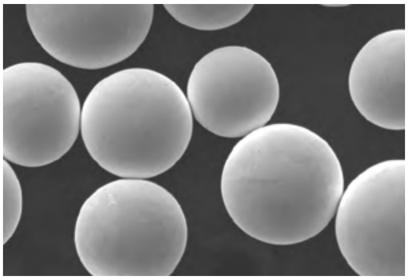
▼ Refractory materials are used for defense, aerospace and rocket applications where high temperature and high strength properties are required. 6K Additive's UniMelt® microwave reactor process refines powder to high levels of density, size consistency, and roundness.

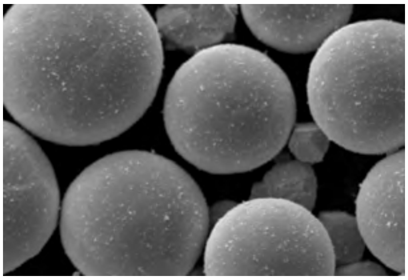
Making Better Rockets

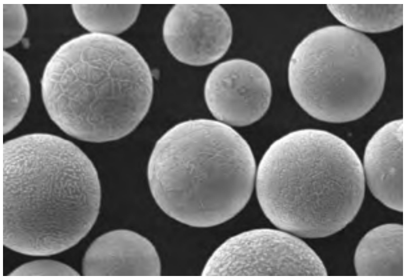
One of the early users of 6K Additive's refractory powders is Quadrus Corporation. Quadrus is a highly respected engineering company that provides expert software, design and test services, and process development for the aerospace and defense industries, with particular expertise in rocket propulsion systems. Quadrus has been developing metal additive manufacturing parts since 2014 for its very demanding customers at NASA, the US Navy, and many other space and defense companies.

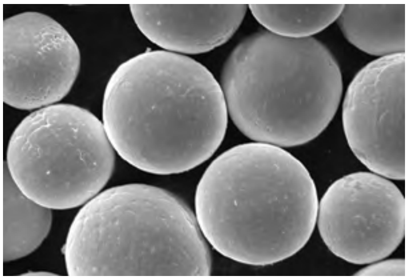
Joe Sims, Ph.D., is Director of Advanced Manufacturing at Quadrus and has long experience with solid and liquid rocket propulsion systems as well as AM process development, making him uniquely qualified to address the advantages and challenges of 3D printing complex components for super-high temperature applications. "Combustion devices are the hottest end of a rocket," he says. "We need materials with the necessary properties for parts that can go from room temperature to 5600 degrees (F) quickly." Moreover, cutting-edge applications such as hypersonic rocket propulsion systems require perfor-

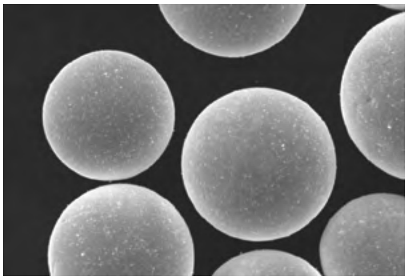

Molybdenum


Rhenium


Tungsten/Rhenium


Niobium C103


Tantalum


Tungsten

mance refractory materials to withstand extreme temperatures and forces due to speed, shifting directions and altitude dynamics.

Without a reliable source of high-quality powders, Quadrus was forced to use conventional machining technology which limited design freedom and necessitated the use of multipart assemblies. In Quadrus' early work with AM, "We learned we could create shapes, for example, in tungsten," says Dr. Sims, but what Quadrus really needed was a process and materials that could cost-effectively produce complex parts to extremely high standards of quality and consistency in production volumes.

▼ 6K Additive's tungsten-rhenium alloy enabled Quadrus Corporation to 3D print this non-eroding throat insert for a solid rocket motor nozzle.

This is where 6K's UniMelt process comes in. Unlike atomization, the UniMelt microwave plasma spheroidization and densification process creates premium-quality powders with great speed and consistency. Spheroidization is the process of transforming angular and irregular shaped materials into dense, spherical and uniform powders without altering the stoichiometry of the alloy. 6K's highly uniform microwave-based plasma ensures every particle undergoes the same thermal profile, enabling targeted partial melting and minimized alloy volatilization. Capable of temperatures up to 6000 K, the process is able to transform high melting point materials into powders with extraordinary roundness and size consistency. This enables the rapid production of refractory materials such as molybdenum, tantalum, rhenium, niobium and tungsten.

Quadrus uses 6K Additive's tungsten-rhenium alloy to produce a non-eroding throat insert for a solid rocket motor nozzle. "The tungsten-rhenium powder processes exceptionally well in our selective laser melting machines because of the spherical shape," says Dr. Sims. Because the material spreads so well in a powder bed machine, it enables a more efficient 3D printing process with extremely high repeatability and very little waste, both of which are critical with these very expensive materials.

Overall, 3D printing these high-temperature parts results in lower total cost compared to conventional manufacturing processes. More important, it has freed Quadrus engineers to optimize designs in ways that were impossible before, enabling higher-performance propulsion systems.

How the UniMelt Process Works

6K Additive is perhaps best known for the sustainability aspects of its process. Scrap parts, machining chips, used powder, and other material forms can be recycled into feedstock for the process. Moreover, the process is extremely efficient in terms of material yield and energy efficiency. 6K can tailor the particle size distribution (PSD) specific to AM processes such as MIM, L-PBF, EBM, DED or binder-jetting. 6K's proprietary preprocessing route enables near 100% yield within targeted PSD. Moreover, it is 99% efficient in moving from microwaves to plasma with zero process-induced contamination.

The UniMelt process is also much more environmentally sustainable. A life cycle assessment conducted by Foresight Management comparing the environmental impact of 6K's UniMelt microwave plasma technology to other current atomization processes found that UniMelt delivers a 91% reduction in energy use and a 91.5% reduction in carbon emissions when producing nickel powders.

For Quadrus and for other refractory parts producers, however, the primary issue is more about the quality of the powders generated by the UniMelt system. For additive manufacturing the UniMelt process precisely spheroidizes metal powders while controlling the chemistry and porosity of the final product.

One of the great challenges of manufacturing refractory metals is their high melting points. By definition, a refractory has a melting point above 2000°C (3632°F) with tungsten being the highest at 6191°F. The UniMelt process can run at 6000 Kelvin (a value from which the company derives its name) which translates to 10,340°F. This combination of high heat, highly reactive ions, and designed chemistries creates the perfect environment to compress the process into previously unattainable periods of time.

Conventional chemical and solid-state production processes for advanced materials are multi-step, batch-to-batch, with contaminants and yield loss at every step. And they often take hours or even days to complete. 6K's UniMelt process is a continuous flow operation, a single step from start to finish that is completed in *less than 2 seconds.*

For the UniMelt manufacturing process, the feedstock material is first mechanically sized to the desired particle size before going into the UniMelt reactor to be refined. A probe enters the reactor chamber to create a ball of stable plasma. The microwave allows precise control over the plasma ensuring the exact length and consistency needed for the particular metal that is being processed. Then, two injectors shoot the milled feedstock into the chamber where argon disperses the particles as they fall through the plasma column. The material cools quickly enough that the resulting powder can be collected almost instantly. Each pre-milled grain that goes through the process remains distinct so that the plasma step is only shaping and densifying each particle.

Where powder production more typically produces a range of particle sizes that must be sieved and sorted into

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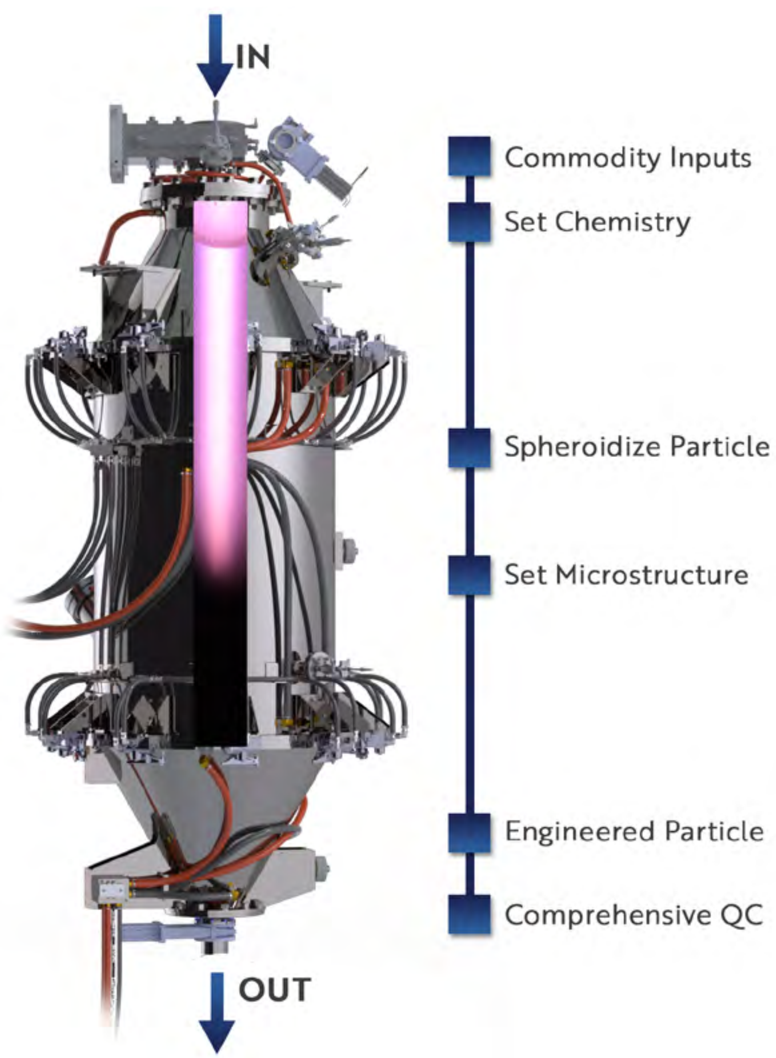

appropriate lots, UniMelt produces only one powder grade at a time. The ratio between input and output is therefore nearly one-to-one, which means that practically all the material that goes into a reactor emerges as product usable for AM. Tantalum, for example, has a poor input-output ratio with conventional gas atomization for AM powder production; perhaps just 20% of what is produced in a melt cycle is usable for 3D printing. With the UniMelt process, it is possible to achieve near 100% output even for the most exotic materials.

The ability to precisely synthesize and tailor an unlimited spectrum of oxides, nitrides, metals & alloys derives from the ability to control all aspects of the plasma process flow. Microwave-engineered plasma provides a thermal production zone of extreme uniformity, guaranteeing every particle sees the same thermal kinetics and the same process history. This enables a large production zone, scalable to 100+ tons per year, and 99% microwave coupling efficiency, translating to higher throughput and lower cost.

▼ 6K's latest expansion includes 20,000 sq/ft of additional powder production capacity with four new UniMelt microwave plasma systems as well as the addition of a 15,000 sq/ft material feedstock preparation building.

Expanding Production

A major obstacle to greater adoption of AM refractories has simply been supply. The raw materials are very expensive and delivery lead times can be months. This is still another reason why the UniMelt plasma technology process is important because as an efficient continuous process it can be scaled without compromising quality. Moreover, 6K's feedstock can come from many different sources and doesn't see the same supply chain volatility as the raw material market.

In October of 2022, 6K Additive announced the expansion of its AM powder production capacity. The plan includes 20,000 sq/ft of additional powder production capacity with four new UniMelt microwave plasma systems as well as the addition of a 15,000 sq/ft material feedstock preparation building. Over the last 12 months 6K Additive has seen rapid growth in the demand for their nickel, titanium and refractory powders and this capacity increase will help the company meet their customers' needs for the coming 12-36 months. This is in addition to two dedicated UniMelt production systems co-located in the company's parent headquarters in North Andover, Massachusetts producing tungsten, rhenium and niobium-based alloys for hypersonics, defense systems, and other rocket applications.

Eric Martin, chief operating officer for 6K Additive says, "The ability to meet the demands of our customers in both quality and delivery is paramount for our organization. The addition of a feedstock preparation facility and the added UniMelt production capacity will help to create a consistent operational flow to meet this demand."

As Quadrus' Joe Sims puts it, "Having a reliable, trusted supply chain partner like 6K Additive for refractory materials is critical to our business and to our defense customers. Our powder quality requirements are extremely high and 6K Additive easily cleared that hurdle for us."

For more information, please visit the 6K website on 6K Additive Metal Powders.