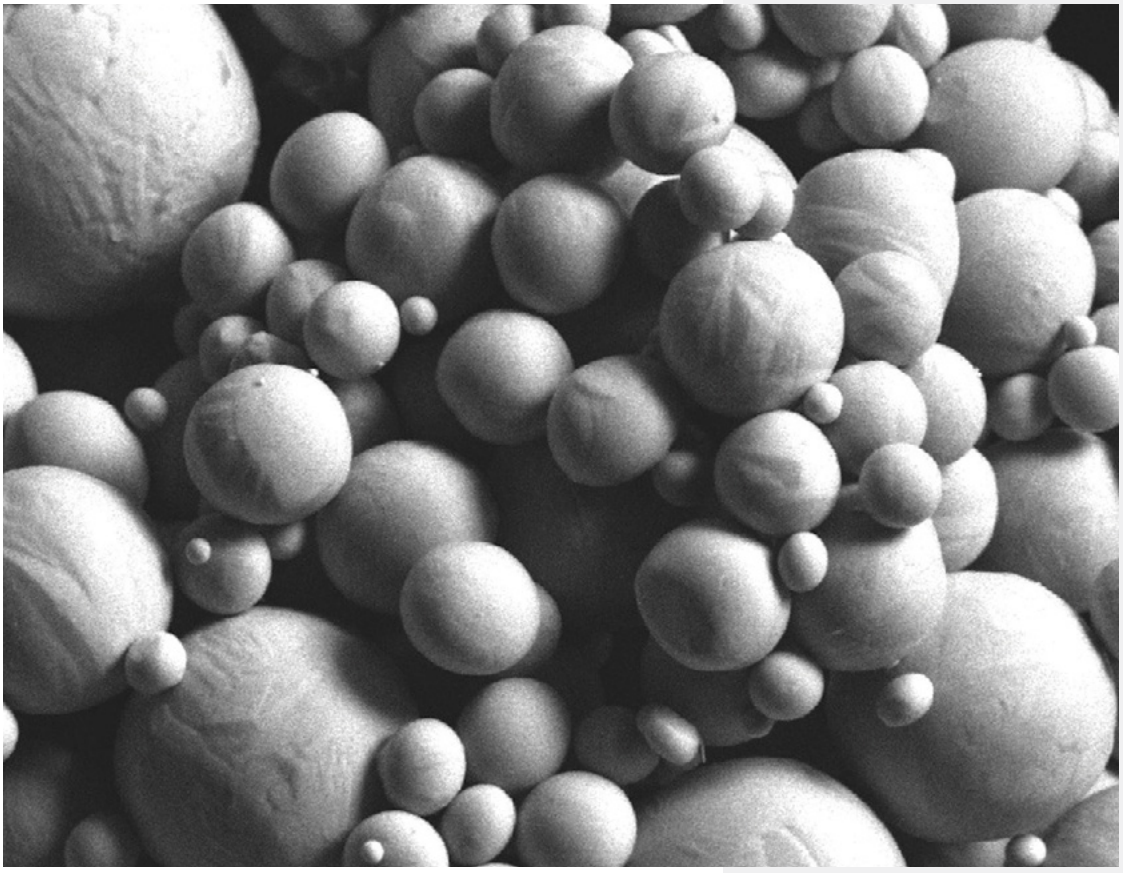
CARPENTER ADDITIVE®

WHITE PAPER



COMPARISON OF PLASMA AND ELECTRODE INERT GAS ATOMIZED POWDER

Quality and performance of L-PBF titanium powder

SUMMARY

EIGA vs. PA powder for additive manufacturing

Titanium 6-aluminum 4-vanadium (Ti64) is a core specialty alloy used in additive manufacturing (AM). However, the cost of spherical titanium powder has been a hurdle to mass adoption. The current and projected increased demand in the medical and aerospace sectors has renewed attention to the properties and processes for producing titanium powder.

Powder of varying size distributions is used across the different additive manufacturing technologies, including direct energy deposition (DED), laser powder bed fusion (L-PBF), and electron beam powder bed fusion (EB-PBF). Traditional crucible gas atomization (GA) methods such as open melt or vacuum inert gas atomization (VIGA) are not suitable for titanium alloys due to the deleterious effect of refractory inclusions on fatigue and toughness. Currently this leaves crucible-free plasma atomization (PA) and Electrode Inert Gas Atomization (EIGA) the preferred methods of producing powder for L-PBF machines. This work compares the powder properties of Ti64 powder produced by the EIGA and PA processes.

The data support the key conclusion that EIGA and PA Ti64 powders for additive manufacturing are statistically equivalent along several quantitative measures.



Quantitative measures:

Oxygen level

The EIGA supply chain includes less feedstock processing, resulting in lower oxygen levels.

Contamination

The absence of any refractory components in the EIGA process minimizes the risk of high-density contaminants, such as tungsten.

Density

The particle skeletal density[1] of the EIGA and PA samples are equivalent, indicating no difference in internal porosity.

Flowability

The quantitative flow measurements used in this study indicate the EIGA sample has superior flow properties despite having a finer particle size distribution.

Morphology

The sphericity and agglomeration of EIGA and PA powders is equivalent, as examined through quantitative and qualitative techniques.

[1] *Skeletal density is the density of the material that constitutes the particle, excluding porosity.*

Plasma atomization (PA)

One industry-leading option for the production of titanium alloy powder for additive manufacturing is plasma atomization (PA) of wire feedstock. A pre-alloyed wire (e.g. Ti64) is fed into plasma torches and converted into molten droplets that rapidly solidify, with limited interstitial element pickup (e.g. O, N, H), as highly spherical powder particles. The main drawbacks of this process are the requirement for expensive wire feedstock and the risk of high-density inclusions (e.g. tungsten) resulting from plasma torch erosion.

Electrode Inert Gas Atomization (EIGA)

Electrode Inert Gas Atomization (EIGA) continuously melts a rotating, high-purity, pre-alloyed bar (e.g. Ti64) into a conical induction coil to form a molten stream that falls directly into a gas nozzle to produce highly spherical powder particles. The method has multiple advantages over the PA process, including the use of bar feedstock, as opposed to wire, allowing for greater supply chain freedom and flexibility for tailored compositions.

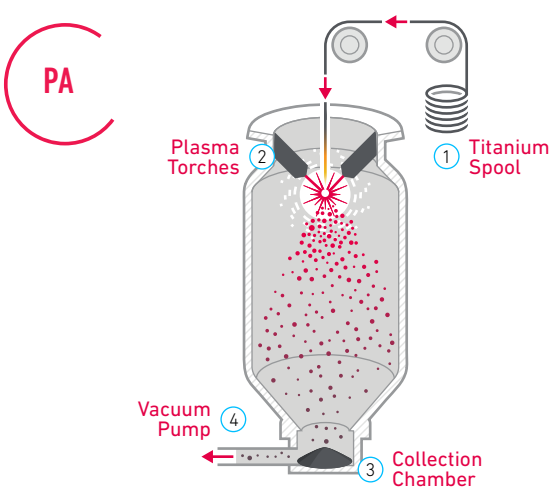
Powder manufactured by EIGA gains as little as 100 ppm of oxygen on top of the existing oxygen levels from the feedstock (bar), depending on the size range being characterized. The bulk oxygen content of bar feedstock is typically lower than that of wire because the bar has gone through fewer processing steps and has less surface oxide per unit volume of material than wire feedstock. This results in oxygen contents in EIGA powder between 200-300 ppm lower than that of PA for equivalent alloys, which is particularly important for AM applications desiring high re-usability.

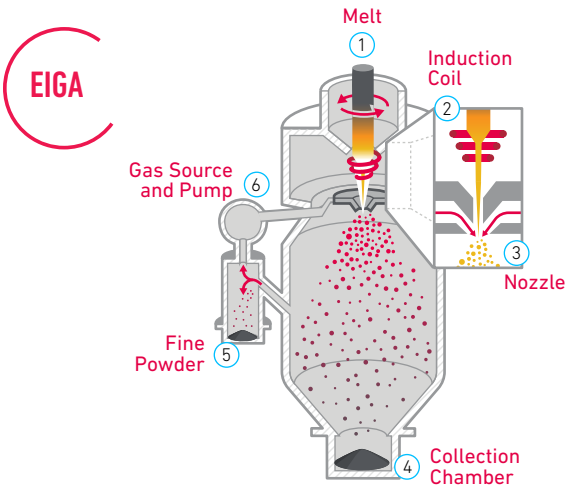
The EIGA processing equipment uses no refractory materials and therefore is not at risk of introducing any high-density inclusions.

Powder properties and specifications

A comparison study was performed on Ti64 Grade 23 powder samples manufactured using the PA and EIGA techniques. Both samples were procured from a commercial distributor to the same 15/45 µm size specification, representing a powder typical for use in L-PBF AM. The critical characteristics of titanium powder that were tested included chemistry, particle size distribution (PSD), true density, flowability, and morphology.

A consistent powder that flows predictably enables the end user to optimize parameters on an AM machine to achieve the desired properties in a final built part.





CHEMISTRY

Compositions of the two samples were compared to ASTM F3001-14 Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium ELI (Extra Low Interstitial) with Powder Bed Fusion requirements. Both samples were within specification for Ti64 Grade 23.

Oxygen, nitrogen, and hydrogen are interstitial elements within the Ti64 alloy that vary with particle size distribution due to the available surface area.

These elements strongly influence the mechanical properties of the end part, and improper control can result in parts with insufficient properties.

In these samples, the EIGA material had lower oxygen and hydrogen despite having a finer PSD, as discussed next.

SAMPLE COMPARISON

ELEMENT	ASTM F3001-14		EIGA SAMPLE	PA SAMPLE	TEST METHOD[1]
	MIN	MAX			
Aluminum	5.50	6.50	6.21	6.37	ICP-AES
Vanadium	3.50	4.50	4.00	3.83	ICP-AES
Iron	—	0.25	0.05	0.17	ICP-AES
Oxygen	—	0.13	0.10	0.13	IGF
Carbon	—	0.08	0.01	0.02	Comb
Nitrogen	—	0.05	0.02	0.01	IGF
Hydrogen	—	0.012	0.001	0.002	IGF
Yttrium	—	0.005	<.001	<.001	ICP-AES
Other elements, each	—	0.10	.02 (Si)	.02 (Si)	ICP-AES
Other elements, total	—	0.40	0.05	0.05	
Titanium	Balance		Balance	Balance	

[1] *ICP-AES = Inductively Coupled Plasma—Atomic Emission Spectrometry (ASTM E2371); IGF = Inert Gas Fusion (ASTM E1409, ASTM E1447); Comb = Combustion Analysis (ASTM E1941)*

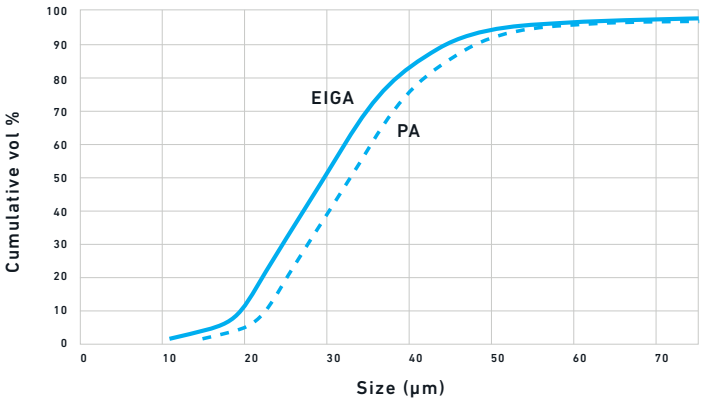
PARTICLE SIZE DISTRIBUTION (PSD)

PSD testing was performed on the as-received samples to confirm the nominal 15–45 µm particle size distribution, as the particle size directly impacts flowability. Two different laser diffraction units and one digital imaging unit were employed and, in all cases, the EIGA powder had a slightly finer distribution than the PA powder. Both samples have unimodal, log-normal particle size distributions.

MICROTRAC® S3500 MEASUREMENT

% UNDER	PA	EIGA
D10 (µm)	22.8	19.6
D50 (µm)	32.9	29.7
D90 (um)	48.9	45.3

PSD (MICROTRAC LASER DIFRACTION)



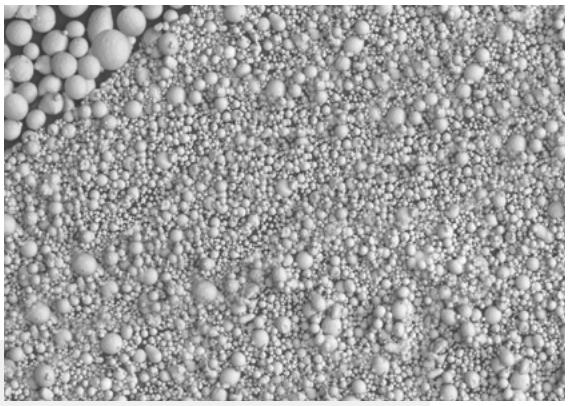
DENSITY

The true (skeletal) density of the particles was measured via helium pycnometry.

Theoretical 100% density of the alloy is 4.43 g/cm3 when no porosity is present. The pycnometry test results demonstrate that powder from the two melt methods are equivalent in terms of internal porosity.

TRUE (SKELETAL) DENSITY

SAMPLE	MELT TYPE	DENSITY G/CM³	STDEV
A1	EIGA	4.404	0.0001
A2	EIGA	4.405	0.0008
B1	PA	4.400	0.0003
B2	PA	4.401	0.0004



PSD

FLOWABILITY

Flowability tests provide quantitative measurements of powder movement and are the most robust laboratory test methods available to predict a material's rheological performance in AM equipment. Flow characteristics are the product of internal influences, such as particle size distribution and morphology, as well as external influences, such as humidity. Flowability measurements provide an indication of how easily powder moves from a feed container to the dosing mechanism of an AM machine and how easily it spreads on the powder bed. Once a powder has been characterized and optimal parameters designed for a component, any change in the powder's behavior can have an impact on the mechanical properties of the final built part. All test results shown below are the average of three tests.

The flowability test results indicate that, despite having a finer PSD than the PA powder, the EIGA powder exhibits superior flowability in the best suite of quantitative test methods for evaluating performance in L-PBF AM machines.

Hall and Carney Flow testing

Hall and Carney Flow testing were performed according to ASTM B213-17 and ASTM B694-16, respectively.

FLOW RATE		
TEST	**PA**	**EIGA**
Hall Flow FR_H (sec/50g)	Did not flow	30
Carney Flow FR_C (sec/150g)	19	17

Angle of repose

Angle of repose is another measure of flowability where a lower value indicates less restricted flow.

ANGLE OF REPOSE	
MELT TYPE	**ANGLE OF REPOSE (DEG)**
EIGA	22
PA	33

Rotating/tumbling flow testing

PERFORMED USING A MERCURY SCIENTIFIC REVOLUTION				
REVOLUTION	**PA**	**EIGA**	**RANGE**	**DESCRIPTION**
Avalanche angle (deg)	40.5	36.2	0-25	Superior flow behavior. The powder cascades over itself at an angle ≤ 25°.
			25-35	Good flow behavior.
			35-45	Acceptable flow.
			>45	Poor flow.
Surface fractal	3.32	2.60		A measure of the smoothness of the powder surface as it cascades. Measured after each avalanche. The scale is from 1 to 11 with lower numbers indicating a smoother surface and, therefore, better flow behavior.
SL ratio	0.41	0.36		A representation of the solid / liquid behavior of the material. The scale is from 0 to 1 with a true liquid having a 0 value and a solid the value 1.

MORPHOLOGY

The morphology of the powder is important to its performance in the AM machine because it impacts the flowability and packing density.

A powder with spherical particles will generally have better flow properties and a greater packing density than one with irregular-shaped and heavily satellited or agglomerated particles.

Non-spherical particles are more likely to interlock, causing "bridging", or powder blockages in equipment, that disrupt powder flow in the dosing mechanism of an AM machine, thus compromising the even spread of powder layers.

SEM imaging of PA and EIGA powders show both powder samples to be predominantly spherical with a similar morphology.

Shape analysis, from a CAMSIZER® XT digital unit, provides average sphericity and convexity measurements for each sample. These parameters have values from 0 to 1.0, with 1.0 representing perfect spheres.

The particle morphology coming from these two melting methods confirms the visual inspection from the SEM imaging. The difference in average sphericity and convexity measurements are only 0.6% and 0.1% respectively, evidence the powders are extremely similar in morphology.

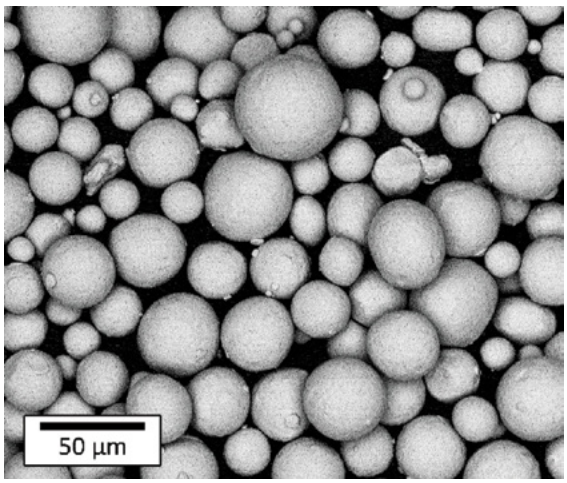
PARTICLE MORPHOLOGY

METHOD	PA	EIGA
Sphericity	0.93	0.92
Convexity	0.98	0.99

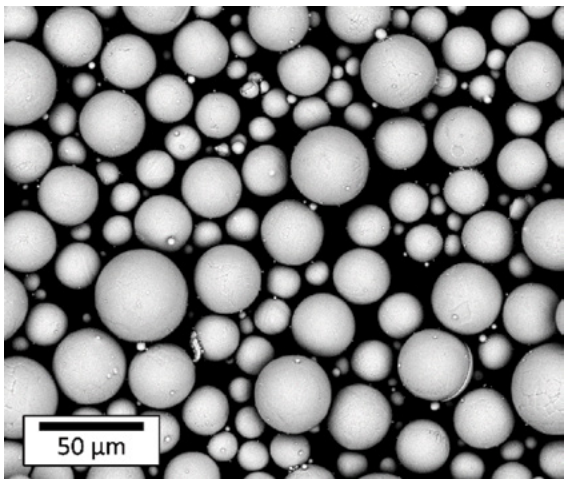
Note: Shape measurements are not standardized and care must be taken if comparing data between instruments.

1000x images of EIGA and PA Ti64, respectively

EIGA



PA



CONCLUSION

EIGA powder for L-PBF machines

The use of titanium powder for additive manufacturing continues to grow globally across a range of industrial sectors because of its premium performance, putting strain on supply chains as companies look for proven solutions. After characterization of two types of Ti64 powder, the sample produced by EIGA proved superior in terms of chemistry and flowability and exhibited no statistically significant differences in morphology or density. The results of this study are consistent with previous powder characterization studies.

EIGA powder provides users an economical supply chain option to reduce cost and oxygen content in titanium while ensuring no trace contaminants are present.

Component manufacturers can use this data to ensure EIGA offers a source of L-PBF titanium powder that meets or exceeds the material quality and performance of PA powder.



For additional information, please contact your nearest sales office:
info@carpenteradditive.com | 610 208 2000

The information and data presented herein are typical or average values and are not a guarantee of maximum or minimum values. Applications specifically suggested for material described herein are made solely for the purpose of illustration to enable the reader to make their own evaluation and are not intended as warranties, either express or implied, of fitness for these or other purposes. There is no representation that the recipient of this literature will receive updated editions as they become available.

Unless otherwise specified, registered trademarks are property of CRS Holdings Inc., a subsidiary of Carpenter Technology Corporation.

© 2020 CRS Holdings Inc. All rights reserved. v 05-20