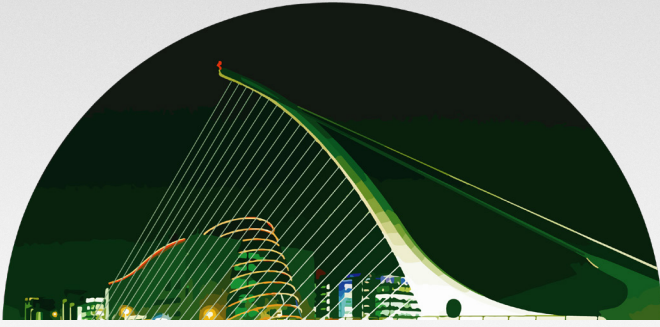




TITANIUM EUROPE 2024

EXECUTIVE SUMMARY

TITANIUM EUROPE 2024 Draws Companies, Speakers To Discuss Manufacturing Technology, Business Trends

By Michael C. Gabriele

The International Titanium Association (ITA), Denver, organized and hosted the TITANIUM EUROPE 2024 conference and expo at the Clayton Hotel Burlington Road, May 7-9 in Dublin, Ireland. The show had over 40 exhibitors and featured speakers who focused on economic trends and manufacturing technology innovations for the global titanium industry. Nearly 400 attendees came to the event from 31 countries.

Several presentations weighed in on titanium applications in the medical field, while others focused on metal-recovery techniques, powder metal production and additive manufacturing (AM) trends. In addition, Takeshi Nakashima, the deputy general manager of the titanium division of Toho Titanium Co. Ltd., provided in-depth analysis on the global titanium sponge market.

Aerospace Outlook

Jeff Carpenter, Boeing's senior director for contracts, sourcing and category management, and the special guest speaker for the conference, offered an upbeat assessment of global aerospace industry trends, saying that steady long-term forecast for the

industry is driven by solid economic fundamentals. "Industry recovery (from the Covid-19 downturn) is progressing broadly as anticipated." Of particular importance to the titanium industry, Carpenter forecasted that airlines will need 42,600 new airplanes during the next 20 years, with single-aisle jets

trillion in 2022. Revenue Passenger Kilometers (RPKs) would grow to 20 trillion by 2024 from 6 trillion in 2022. Cargo traffic, measured in revenue ton kilometers (RTK) will reach 630 billion by 2042, up from 260 billion in 2022.

Boeing, to be sure, has faced its share of challenges during the last



accounting for 32,420 units and wide-body jets 7,440 units.

Carpenter provided a similar outlook during his presentation at the TITANIUM USA 2023 conference held in Denver. He said the world economy's gross domestic product (GDP) would reach \$155 trillion by the year 2042, compared with \$92

12 months regarding issues with its 737 fleet. *The New York Times*, in its March 28 edition, wrote that recent reports "paint a worrying picture about a company long considered to be at the pinnacle of American engineering." As a result, two top executives announced they were stepping down from their positions.

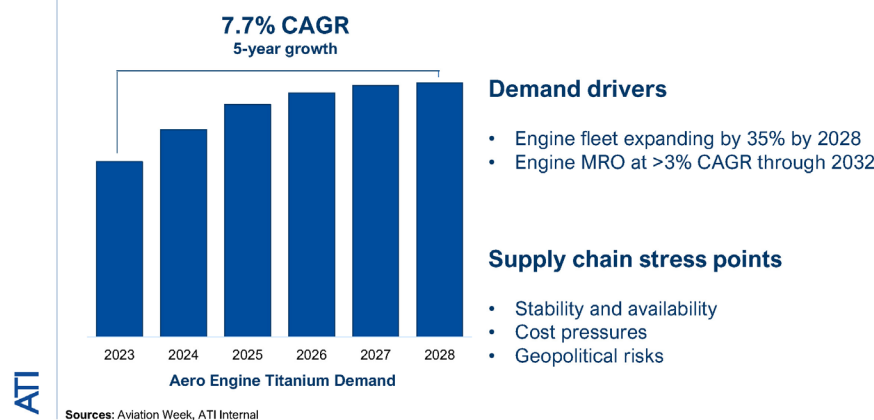
Last October at the titanium conference in Denver, Carpenter thanked all the players in the titanium supply chain that do work with Boeing. “In 2022 we (Boeing) made some tough choices on where to get supply,” presumably a reference to the disruptions caused by Russia’s invasion of Ukraine. Boeing suspended purchasing of titanium from Russia in 2022. “It caused

longer vertically integrated back to (titanium) sponge, nor the cost-based” sponge price stability that came with it.” He displayed a chart that estimated 2023 titanium sponge global capacity at 825 million pounds, according to the January 2024 U.S. Geological Survey of Mineral Commodity Summaries, which excludes Russian supply due to assumed, continued sanctions.

chief executive officer and director of Airbus SE, who said “the geopolitical tensions and supply chain challenges are upon us (a presumed reference to the ongoing invasion of Ukraine by Russia). In this context, the supply chain remains the pacing factor for the ramp up of the aerospace industry.”

Sam Stiller, vice president, commercial for Howmet Engineered Structures (a division of Howmet Aerospace Inc.) addressed “Titanium Demand Trends in Defense Aerostructures.” Stiller said that global defense market trends “play to the strength of titanium aerostructures and drive innovations.” He cited defense market trends such as air superiority, off-the-shelf technologies, speed to market and hypersonics. Titanium’s strengths include resistance to high operating temperatures, compatibility with composite structures, environmental resistance and reduced weight and near-net shapes. He listed innovations of

✦ Current titanium state: Tight supply



everyone a lot of work—melters, forgers, process houses. A lot of forgers are under strain.”

Robert S. Wetherbee, ATI board chair and CEO, focused on “Commercial Aero-Engine Trends and Demands” in his presentation. He began by pointing out that there would be a 7.7 percent compound annual growth rate (CAGR) for aero engine titanium demand through the year 2028.

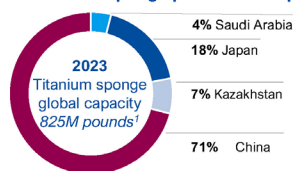
Supply chain stress points include stability and availability, cost pressures and geopolitical risks. “Customers are committing to eliminating single points of failure in their supply chains,” Wetherbee said, adding that there’s a tight supply for premium-quality titanium bar and billet. “Continued inflation creates pressure. The U.S. titanium industry is no

✦ Geopolitical risks have become the norm

Issue: Geopolitical risks

Ongoing uncertainty is a geopolitical reality, potentially disrupting the industry

Growing at 9% CAGR, China dominates Ti sponge production capacity

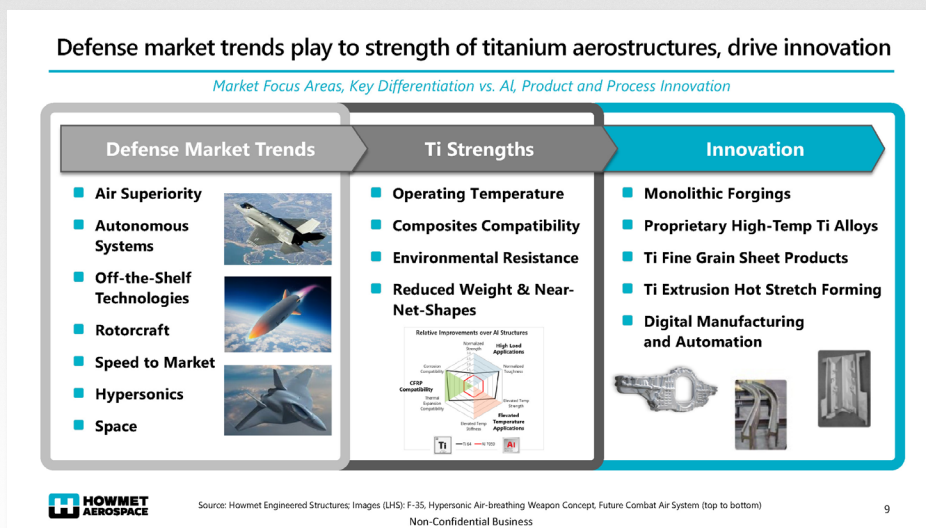


Excludes Russian supply due to assumed, continued sanctions

¹Source: U.S. Geological Survey, Mineral Commodity Summaries, January 2024

Wetherbee stated that the “titanium industry needs to be proactive to avoid being the ‘rate limiter.’” To underline points in his presentation, he quoted an April 2024 statement by Guillaume Faury, the

monolithic forgings, proprietary high-temperatures, titanium fine-grain sheet production, titanium extrusion in hot-stretch forming, and digital manufacturing and automation.



Sponge and Scrap

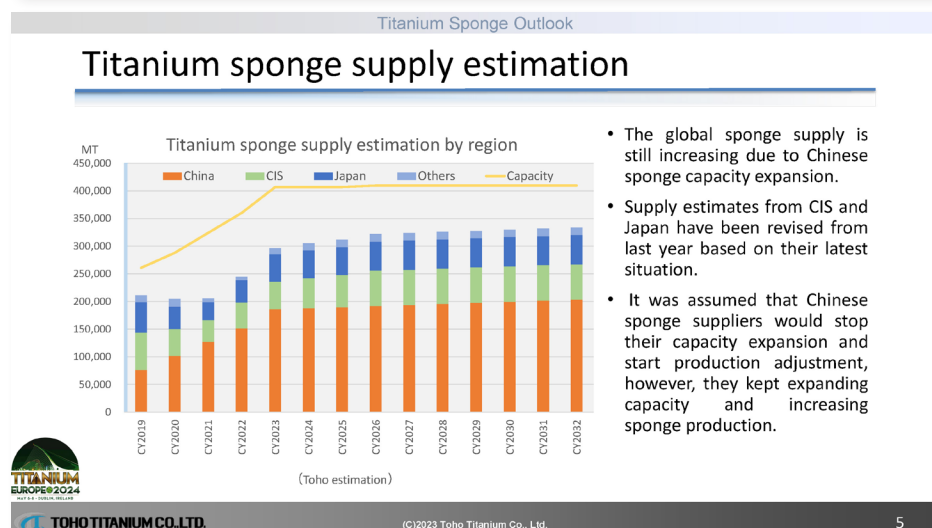
Takeshi Nakashima, the deputy general manager of the titanium division of Toho Titanium Co. Ltd., Japan, a producer of titanium sponge, provided a global titanium sponge outlook. Nakashima said that sponge demand for the aerospace market continues to grow steadily while demand for Industrial market grows slower than before. “In February 2024, the airline industry achieved full recovery in total passenger traffic, surpassing the 2019 level by 5.7 percent. In 2023, Airbus achieved a high A320 build rate while Boeing’s 737 build rate remains constrained. However, both OEMs are confident about higher build rates in the future. Both Boeing and Airbus still have very aggressive building plans. The 2026 delivery results should exceed the previous historical record set in 2018.”

As for the titanium sponge market situation in 2023 and 2024, Nakashima indicated that Japanese suppliers run their factories at more than 90 percent of capacity. “UKTMP (Kazakhstan) has hardly ramped up their sponge production due to a delay in importing equipment from Russia. VSMPO-AVISMA seems to produce sponge at full capacity for Airbus and Russian

military demand. While there has not been an announcement of sponge capacity expansion from any aerospace-grade sponge supplier,

it is believed that Japanese sponge suppliers are studying the possibility of expansion.”

Nakashima, who also addressed the 2023 TITANIUM USA conference, pointed out that Airbus is still purchasing titanium products from Russia, which balances current sponge demand and supply in aerospace market. “If Airbus tried to reduce or suspend titanium products procurement from Russia, the sponge shortage would be serious. Even if Airbus continues procurement from Russia, there will be a sponge shortage. Only if aerospace-grade sponge production capacity expands, will it be avoided. Chinese surplus sponge supply will have only a limited influence on the

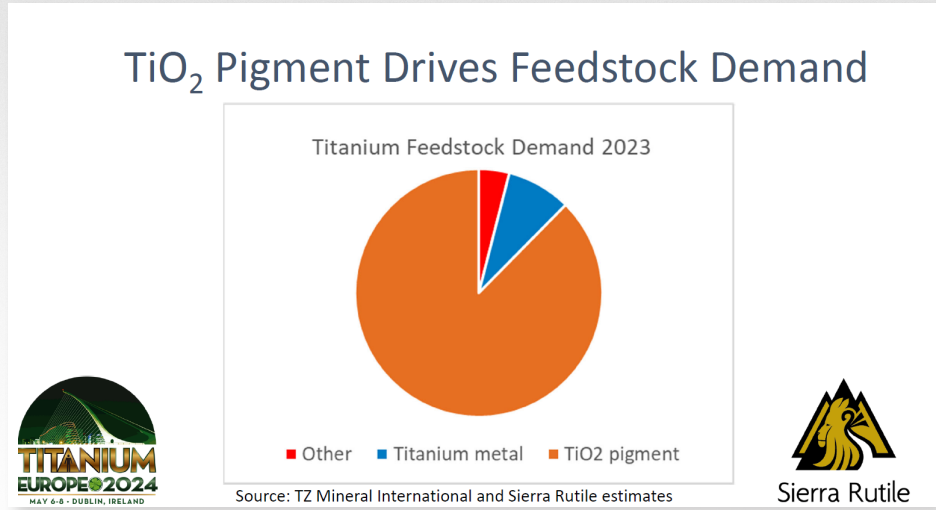


aerospace industry.”

Quality concerns and geopolitical risks still exist for the global sponge market, according to Nakashima. “Considering the huge demand and supply gap, the Chinese sponge price decline is expected to continue. It looks as if many Chinese sponge suppliers are trying to assure their running rate at the cost of their profitability. It is uncertain if Chinese sponge suppliers will start reducing their production to improve their sponge price.”

Fundamentals leaning towards sponge production capacity expansion are improving for aerospace-grade sponge suppliers, Nakashima observed. “The U.S. import sponge price continues to increase. The Japanese government is trying to improve aerospace industry supply chain resilience, including Titanium sponge, which may provide financial support policies for Japanese sponge suppliers. However, current sponge suppliers still hesitate to expand capacity. Construction of a new sponge factory will cost hundreds of millions of dollars in (capital expenditures). Sponge suppliers have suffered from low profitability due to unstable demand and unfavorable prices to them despite their cost reduction. Only capacity expansion of aerospace-grade sponge suppliers can solve the looming sponge shortage in aerospace industry.

Nakashima cautioned that there will be a supply and demand gap in the future due to the growing requirements of the industry. “The aerospace supply chain including OEMs should consider how to convince sponge suppliers to approve new investments. Sponge suppliers want assurances of their profitability before deciding on capacity expansions. The aerospace supply chain would secure sponge supply if



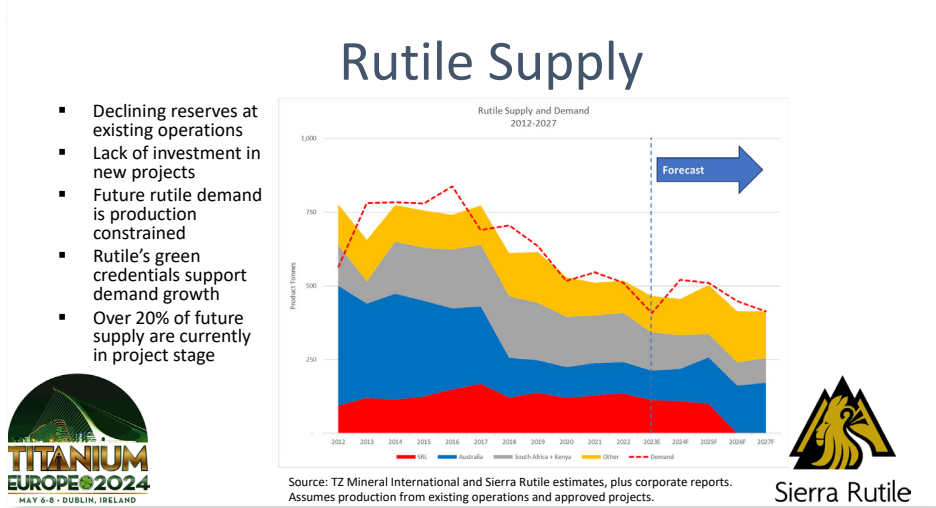
they could assure sponge suppliers Security; Critical to Manufacturing

Risks facing rutile supply

Category	Considerations
Quality	Consistency, TiO ₂ content, impurities, process yields, track record, qualification
Economics	Capital and operating costs, brown field versus green field, infrastructure, ore grade, mine-life, investment
ESG	Company credentials, governance, licence to operate, community, reputation (local and global)
Geopolitical	Regional stability, permitting and fiscal arrangements, conflict zones
Supply Chain	Inputs, staffing, export routes, final delivery (port)
Climate	Seasonality, force majeure type events

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MAY 6-8 • DUBLIN, IRELAND

Sierra Rutile



of stable sponge demand as well as a reasonable sponge price.”

Derek Folmer, general manager, marketing for Sierra Rutile, shared his thoughts on “Rutile Supply

Titanium Sponge.” Sierra Rutile is the world’s largest producer of natural rutile, an Australian mining company with assets in Sierra Leone, West Africa. Folmer said TiO₂

pigment drives feedstock demand, with the vast majority going to pigment compared with a small segment for titanium metal.

He identified the titanium feedstock value chain and listed the risks facing rutile supply.

“The world needs rutile and risks must be weighed and considered by source. Sierra Rutile is committed to responsibly supplying the world’s rutile requirements with approval pending on \$300-million Sembehun

Area 5 project (a town in the southern province of Sierra Leone in Africa),” Folmer said.

Aamir Abid, Ph.D., an executive with Retech (a Seco/Warwick company) discussed the “Recycling of Titanium Scrap to Produce High-Quality Ingot and Additive Manufacturing Powder,” and touted the plasma gas atomizer (PGA) process. Abid said PGA “provides an economically viable method to produce reactive and refractory alloy

powders. PGA is inherently scalable due to use of hearth melting via DC plasma and ability to continuously feed, melt and atomize powder. Significant reduction in powder cost-PGA allows for improved yield, use of lower cost raw materials and recycling of revert.” Successfully produced complex refractory (titanium and nickel) alloys on PGA yields “best in class” powder performance, according to Abid.

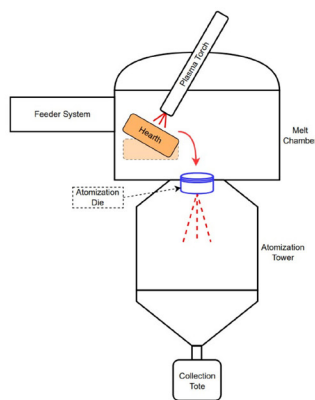
Master Alloys

Michael Wilkes, global product manager for Kymera International, presented an overview on the business dynamics of titanium master alloys. Common master alloy metals include vanadium, the most common master alloy for titanium, along with aluminum, used in the production of the workhorse aerospace alloy Ti6Al4V; and molybdenum and niobium. He pointed out that titanium scrap plays a major role in master alloys.

Wilkes defined master alloys for titanium melting as a combination of two or more metals in a metallurgically alloyed form. “Short-term demand dynamics for master alloying elements will be mainly influenced by the availability of titanium scrap used during the melting practice, and inventory levels of scrap,” Wilkes said. “Longer-term trends suggest continued unpredictability for key master alloy elements. Continued supply surges and dips in the global steel industry, led by China, will drive (business) dynamics. New technologies for green energy storage will compete for the same materials used by the titanium industry. Continuous risk management is recommended.”

He provided charts that illustrated forecasts for vanadium, molybdenum and niobium. The iron and steel industries accounted for 94

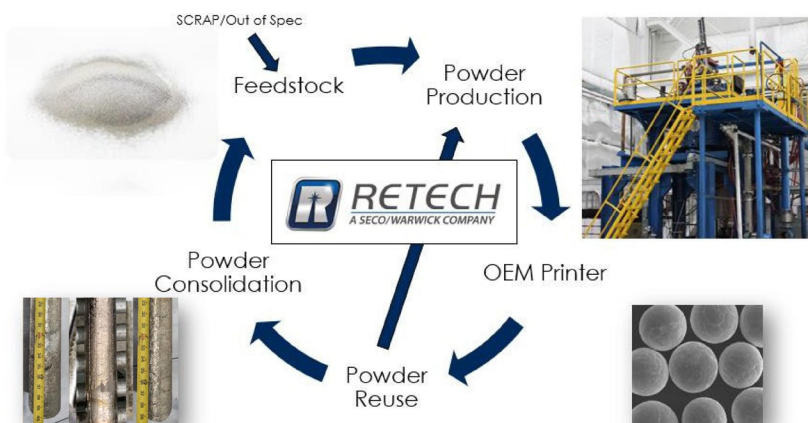
PLASMA GAS ATOMIZER (PGA) SCHEMATIC



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POWDER ECOSYSTEM

POWDER AS SERVICE (PAS)



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Oxides for Titanium Master Alloys

Vanadium Pentoxide



- Vanadate ore or recycled vanadium units refined into V_2O_5
- Used in ferro vanadium used by the worldwide steel industry
- Only a small fraction of V_2O_5 is produced in high purity form for Titanium

Molybdenum Trioxide



- Mo rich ore is concentrated into MoS_2 that is roasted and refined into pure MoO_3
- Used in ferro molybdenum for the worldwide steel industry and master alloys are a minor use for MoO_3
- About 75% of Mo containing minerals are mined as a coproduct of Copper extraction

Niobium Pentoxide



- Mined pyrochlore is concentrated and refined into Nb_2O_5
- Used in ferro niobium (columbium) for the steel industry and nickel niobium for super alloys
- Ti master alloys are a minor use for Nb_2O_5

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percent of total vanadium demand in 2021 and remains a major source of demand, according to Wilkes. The steel market expected to grow at a CAGR of about 3.1 percent until 2030. “Vanadium demand is being revolutionized before our eyes.” For molybdenum, the majority of growth during the next 10 years is expected to occur in the chemical and petrochemical industry, including the hydrogen sector and power generation driven by the demand for sustainable construction and energy, specifically wind and geothermal. “The niobium market is estimated to be at 97,208 metric tons, while growth over the next five years is projecting over 10 percent CAGR, reaching nearly 190,000 metric tons.” Niobium production in 2022 registered 79,000 metric tons.

Medical Markets

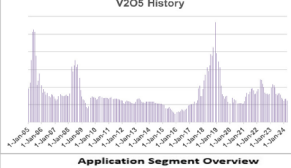
There were several presentations regarding the use of titanium in medical markets, with a focus on AM technology. Nicolas Bouduban of the Swiss m4m Center AG, said his group enables innovations and support in medical and dental applications via AM and related engineering expertise. He evaluated the use of Ti6Al4V as a material choice for long-term medical implants. Matthias Scharvogel, the founder and CEO of Element 22 GmbH, makes use of metal injection molding (MIM), fused filament fabrication, and cold metal fusion as complements to additive manufacturing.

The presentation by Chris Norris of APS Materials Inc. discussed “Titanium Technology in Medical Applications; Thermal Plasma Spraying Biomedical Implants,” and listed the capabilities of plasma spray equipment used by his company.

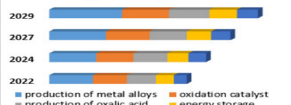
Ali Madani, the managing partner for Avicenne Medical presented an “Outlook for the Orthopedic Market.” Madani estimated that the worldwide market

V2O5 Trend 2005 to Present

Vanadium Pentoxide Trend

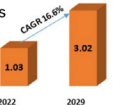


Application Segment Overview



■ production of metal alloys ■ oxidation catalyst
■ production of oxalic acid ■ energy storage
■ others

- V2O5 pricing relatively stable post pandemic
- Estimated apparent consumption of vanadium in 2022 increased 11% YoY
- Iron & steel industry accounted for 94% of total vanadium demand in 2021 and remains the key source of demand
- Steel market expected to grow at a CAGR of about 3.1 percent until 2030
- Emerging technologies coupled with traditional usage, V2O5 projects 16.6% CAGR
- Investors should monitor the Vanadium Redox Flow Batteries (VRFB) projects
- Vanadium demand is being revolutionized before our eyes



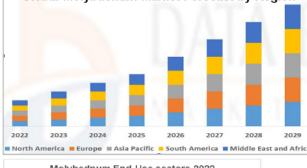
CAGR 16.6%

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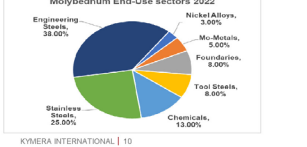
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Molybdenum Forecasts and Emerging Trends

Global Molybdenum Market Forecast by Region

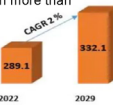


Molybdenum End-Use sectors 2022



Engineering Steels, 38.00%
Nickel Alloys, 3.00%
Mo-Metals, 5.00%
Ferroalloys, 8.00%
Tool Steels, 8.00%
Chemicals, 13.00%
Stainless Steels, 25.00%

- With molybdenum's diverse end-use structure, market research estimating over 2% CAGR in the forecasted period
- Aerospace and Defense accounting for a significant portion of recent growth (~27%)
- Over next 10 years, majority of growth expected to occur in the chemical and petrochemical industry, including the hydrogen sector and power generation driven by the demand for sustainable construction and energy, specifically wind and geothermal
- Molybdenum and copper are used in more than eight clean energy generation and storage technologies
- Investors might want to monitor the renewable sector



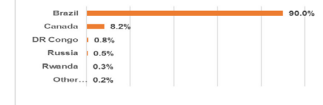
CAGR 2%

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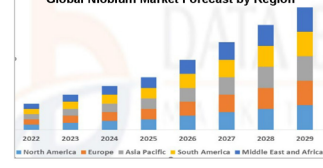
Niobium Forecasts and Emerging Trends

Global Niobium Production Worldwide in 2022



Brazil 90.0%
Canada 8.2%
DR Congo 0.4%
Russia 0.5%
Rwanda 0.3%
Other 0.2%

Global Niobium Market Forecast by Region



- In 2022, niobium production reached 79,000 MT
- Brazil is the worlds largest producer of niobium accounting for ~90% of the global production
- Niobium market is estimated to be at 97,208 tons
- Over next five years, growth is projecting over 10% CAGR, reaching nearly 190,000 tons
- Niobium growth drivers include but not limited to:
 - Demand for the lightweight vehicle and extensive utilization of niobium by the automotive industry is an essential factor driving the niobium market
 - Use of niobium in e-batteries to solving the fast charging, range anxiety and cost issues
 - Niobium-intensive ITER reactor (International Thermonuclear Experimental Reactor)

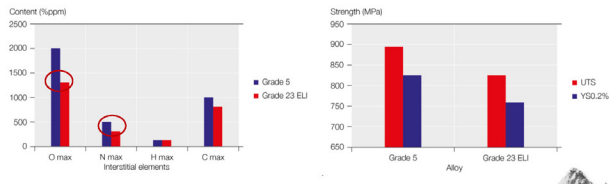
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6 **TITANIUM EUROPE 2024** | EXECUTIVE SUMMARY

Material Selection: Ti-6Al-4V Grade 23

Standards: ASTM F 3001 / F136

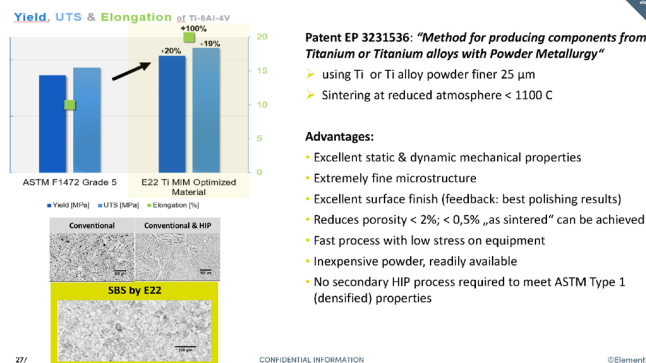


Mechanical properties According to ISO and/or ASTM
Strength UTS/Re: ≥ 900 MPa
Yield strength Re: ≥ 795 MPa
Elongation A: $\geq 10\%$

► Material of choice for long-term implants.

© 2024, Swiss metal Center, Nicolas Boudreau, Ref: <https://steelmetals.com/wp-content/uploads/2024/09/090820240807105.pdf>

SBS Ti6Al4V MIM mechanical properties compared to wrought



for orthopedic implants (knee, spine, trauma and hips) in 2023 at \$51 billion.

Madani then offered a forecast for orthopedic market drivers and market limiters through the year 2030. For orthopedics market drivers, extremities and shoulder applications, currently estimated at around \$5.9 billion, “will almost double in 2030 to \$10 billion.” There will be “historical constant growth” for knee and trauma application, and high volume growth in emerging

markets. This market is suffering from sales prices that are almost frozen.”

The key success factors for an orthopedic company, according to Madani, include having a proven products with a long track-record; continuously introduce incremental innovations in implants and instruments; regulatory and certification expertise; control over distribution networks; and

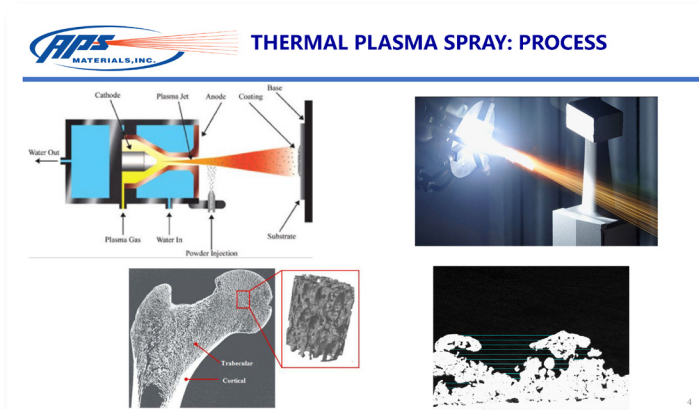
maintaining the efficiency and continuity of their supply chains.

By contrast, market limiters include “continuous regulatory cost increases, while price pressure on the end markets will remain moderate.” He observed that the end-user orthopedics market “has long market visibility and very high barriers to entry. The profitability of established companies is very high. Challengers

Innovations in Manufacturing Technologies

Wei Chen and Carl Boehlert, of the Department of Chemical Engineering and Materials Science at Michigan State University, provided information on the “Characterization of the Microstructure, Tensile, Fatigue, and Creep Behavior of Powder Metallurgy Processed Rolled and Extruded Ti-6Al-4V-1B (wt. percent) Alloys.” They identified their objectives as being able to evaluate processing effects on the elevated-temperature fatigue and creep behavior of Ti-6Al-4V (wt. percent), Ti-64, and to evaluate the effect of B content on the elevated-temperature fatigue and creep behavior of powder metallurgy (PM) rolled plate and PM extrusions.

They evaluated tensile behavior, fatigue behavior, fracture analysis, the creep behavior of Ti-64-xB alloys and creep fatigue interaction. They concluded that “processing significantly influences the fatigue behavior of Ti-64-xB alloys. Powder metal (PM) processing induces an equiaxed grain size, (which) results in enhanced fatigue lives compared to cast metallurgy. The finest equiaxed microstructure (PM extruded) resulted in the



greatest fatigue lives. Texture, induced through the extrusions, enhanced the tensile and fatigue strengths through aligning both the α -phase and the Ti-B phase into 'hard' orientations. The extruded alloys exhibited tensile anisotropy where the extrusion directions were stronger than the transverse directions. However, the anisotropic

have placed orders for more than 1,000 aircraft within the last two years. He said the Asian giant will develop and operationalize 220 airports within the next five years, making it the third largest global civil aviation market. India, he said, is "quickly becoming the go-to source for aero assemblies and subassemblies, with more than \$2

billion of annual exports to major air framers."

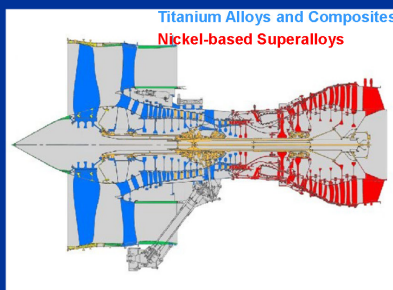
PTC/Aerolloy was established in 1963 as India's first investment casting foundry, operating plasma arc melting technologies, and now operating two advanced manufacturing campuses in India. Collins reviewed the technologies and timelines of Aerolloy's electron beam cold hearth refining; plasma arc cold hearth refining; the cold hearth refining process; vacuum arc remelting; and open die forging and hot rolling. Many of these manufacturing technologies are slated to come online this year and in 2025. He also noted that PTC Industries and Aerolloy are committed to "comply with carbon footprint reduction and greenhouse gas (GHG) protocols in accordance with international standards, meeting the Paris Agreement targets."

TITANIUM TODAY, the quarterly online magazine published by the ITA, provided a news analysis feature in the third quarter of 2023 on how the Republic of India is

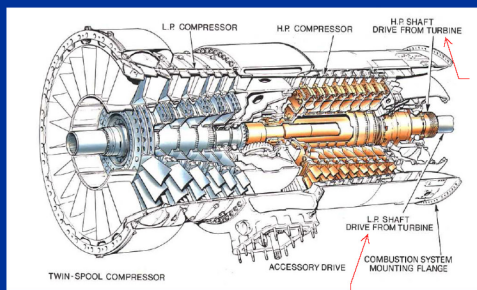
Background

Ti alloys in gas turbine engines:

Ti-64 and IMI 834 (Ti-5.8Al-4Sn-3.5Zr-0.7Nb-0.5Mo-0.35Si-0.06C)



Ref: Trent 800 courtesy Rolls-Royce Plc. Diagrams after Michael Cervenka, Rolls-Royce.



Ref: Figure 3-7. The Jet Engine, Technical Publications Department, Rolls-Royce plc, Derby, England, 1996



Engine working temperature



Fuel consumption
Pollution generation

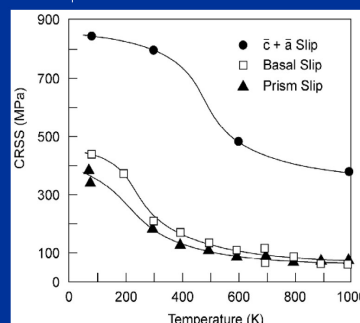
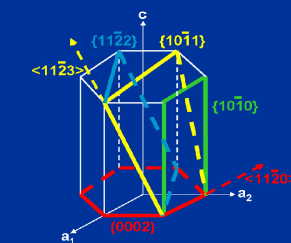
- Weight reduction
- Creep resistance improvement
- Fatigue resistance improvement

behavior was not a 'show stopper' as the transverse orientations for the B-containing alloys remained quite strong."

"Overall, Ti-B alloys have shown promise for fatigue-driven and creep-driven applications of Ti-64 and PM processed Ti-64-xB have the potential to replace Ti-64 for both RT and elevated-temperature structural applications."

Jim Collins, chief technology officer, PTC Industries and Aerolloy Technologies, evaluated "Green Titanium – Enhancing the Aerospace Titanium Market from India." He began by identifying aerospace business opportunities in India, saying that Indian airlines

Texture Evolution Possible Effects



Temperature dependence of CRSS for slip with 'a' and 'c+a' vectors in single crystals of Ti-6.6Al (N.E. Paton, R.G. Baggerly, J.C. Williams. Rockwell Report SC 526.7FR, 1976)

- At elevated temperature 'a' and 'c+a' slip are active for the α phase, in which 'c+a' slip is much more difficult. Whenever the α phase basal plane is oriented perpendicular to the extrusion axis, the 'a' slip is not possible. Thus this is considered to be a hard orientation.
- The β -phase field extrusion may align the $(110)\beta$ so they are either parallel or perpendicular to the extrusion axis.
- Burgers OR: $(110)\beta // (0002)\alpha$; $[1\bar{1}1]\beta // [1120]\alpha$.
- After the transformation it would be expected that the $(0002)\alpha$ is oriented 0° or 90° to the extrusion axis. This would result in a hard orientation.

positioning itself to become a major force in the global aerospace and titanium industries. As noted by Collins, the giant Asian subcontinent is building an industrial infrastructure to compete in the aerospace and titanium sectors.

“With the leverage made from the additional in-house generated renewable energy at 50 percent of the plants operating power and additional high efficiency process equipment/technologies, a further three tons of CO2 saving per kg of Titanium produced at via Aerolloy’s Green Titanium process line. Finally, with the total supply cycle advanced Campus, a significant carbon footprint reduction is to be achieved via the reduction in process logistics.”

Kurt Faller, the founder and chairman of MetCon, talked about “Free, No-Cost Saleable Metal Hiding in Traditional Titanium Conversion.” He said MetCon Introduced Electrochemistry to Titanium Processing, with more than 25 million pounds processed. Faller defined “free” as finding available metal typically removed due to conditioning yield losses. “Yield, yield, yield: the mantra of management.”

He said that free metal can be found as “every hot working step generates certain yield losses: end crops (removing bulged ends), and side trims (removing as-rolled ragged edge). “Hidden” yield losses generally are less understood: alpha case layer removal and conditioning of cooling cracks (cracks covered in alpha case). “Most producers use post-conditioning pickle to reveal hidden defects.”

Faller explained that the MetCon alternative involves “green chemistry:” 96 percent H2O plus citric acid plus ABF; less acidic

Electron Beam Cold Hearth Refining (EBCHR)

EBCHR				
Maximum Ingot Weight (kgs)	Min Ingot/(Slab) Dia/(TXW) mm	Max Ingot/(Slab) Dia/(TXW) mm	Maximum Ingot Length	Annual Melting Capacity
12,500 Kgs	600/(500X1 050) mm	840/(500X1 300) mm	5,000 mm	5,000 Tonnes
Equipment Manufacturer	Installed by	In Production by	Status	Alloys
ALD Germany	September 2024	December 2024	Installation Underway	CP-Ti Ti6Al4V,

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Plasma Arc Cold Hearth Refining (PACHR)

PACHR				
Maximum Ingot Weight (kgs)	Minimum Ingot Diameter	Maximum Ingot Diameter	Maximum Ingot Length	Annual Melting Capacity
400 Kgs	150 mm	200 mm	3,000 mm	>200 Tonnes
Equipment Manufacturer	Installed by	In Production by	Status	Alloys
Retech Systems	Installed	July 2024	Commissioning	Unlimited

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Open Die Forging & Hot Rolling

OPEN DIE FORGE			
Forge Press rating (Tonnes)	Min Billet/(Plate) Dia/(WXT) mm	Max Billet Diameter	Maximum Ingot Length
4,500 Tonnes	80/(1,500X20) mm	900 mm	6,000 mm
Maximum Billet Weight	Annual Forging Capacity	Manipulator Capacity	Installed by
12,500 kg	12,000 Tonnes	25 Tonnes	End 2024
In Production by	Status	Alloys	
Early 2025	Under Manufacture	Titanium & Super Alloys	

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than soft drinks. MetCon electrochemical technology is a rectifier for controlled surface reactions: precision in process; no adiabatic heating; and 100 percent reproducible, with no hazardous waste disposal, no air permits and no scrubbers.

He summarized by saying that free material involves “condition all over” (CAO) and delivers the greatest value (replacing grinding). “MetCon Defect Reveal pickling reveals and eliminates cracks below conditioned layer.” MetCon CAO and MetCon Defect Reveal involve no crack propagation, little post-rolling conditioning, predictable and repeatable process control, and significantly simplifies environmental compliance.”

Dave Ochar, vice president, aerospace sales, Bodycote Metal Additive Manufacturing Services, reviewed the benefits of metal additive production technologies, while pointing out that all AM parts need post processing. These processes include stress relief, hot isostatic pressing, annealing. In particular, he focused on hot isostatic pressing (HIP) at Bodycote, which combines high temperatures

(up to 2,000°C) with isostatically applied gas pressures (up to 45,000 psi).

“HIP is used to eliminate porosity in castings and consolidate powder metallurgy materials into fully dense components. Dissimilar materials can be bonded together to manufacture unique, cost-effective parts. Bodycote

operates a global HIP network with over 50 HIP vessels of varying sizes in multiple locations. We provide two major HIP routes for customers: HIP product fabrication, for the manufacture of components through powder metallurgy and diffusion bonding; and HIP services, providing porosity removal through HIP densification.”

Each week a typical Bodycote HIP plant will process many tons of materials such as titanium, aluminum, steel, cobalt, and nickel-based superalloy castings, removing porosity and uprating the performance of parts such as turbine blades and turbochargers, according to Ochar.

Beate Orberger, director of EuroTitan, outlined “Decarbonized Titanium Recovery from Aluminum and Titanium Production Residues.” EuroTitan is a consortium

The MetCon Alternative



- **Green Chemistry**
 - 96% H₂O + Citric Acid + ABF
 - Less acidic than 
- **Electrochemical**
 - Rectifier controlled surface reactions
 - Precision in process
 - No adiabatic heating
 - 100% reproducible
 - As many pieces can be simultaneously processed as tank can hold
 - Faster throughput than competition
- **Low Capital**
- **ESG**
 - No air permits
 - No NOx, No scrubber
 - Minimal PPE
 - No hazardous waste disposal



MetCon 12

Traditional Pickling Contrasts to MetCon



- HF or HF+HNO₃
 - Among the most dangerous acids known
 - Significant PPE required – SCBA (self contained breathing apparatus)
 - Dangerous
- Legacy liability
- MetCon requires minimal PPE
- MetCon no adiabatic heating vs. HF exothermic
 - No downtime for baths to cool
 - Predictable, consistent removal rates
- MetCon no facility corrosion / degradation
 - No recapitalization of facilities

Hazard Statement

Fatal if inhaled. Fatal when in contact with skin. Fatal if swallowed. Causes severe skin burns and eye damage.



Best Safety and Environmental Solution

MetCon 17

More Free Material? Replace Grinding + Pickle Steps with MetCon Conditioning

12% More Finished Salable Product

Primary Forging Conditioning (25 – 35 cm) thick



As-forged 25 cm slabs for MetCon “Condition All Over” (CAO)



Post MetCon CAO = 98.0% step yield (6% better yield than grinding + pickle)

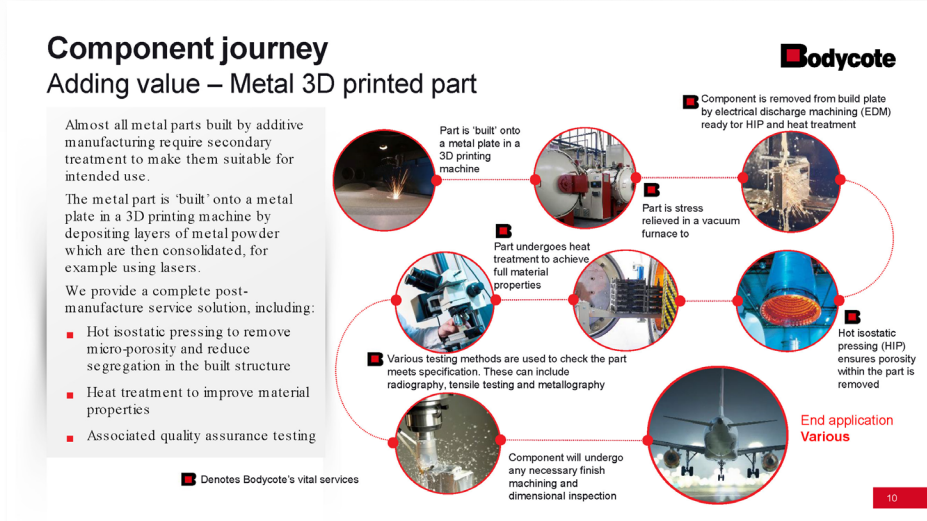
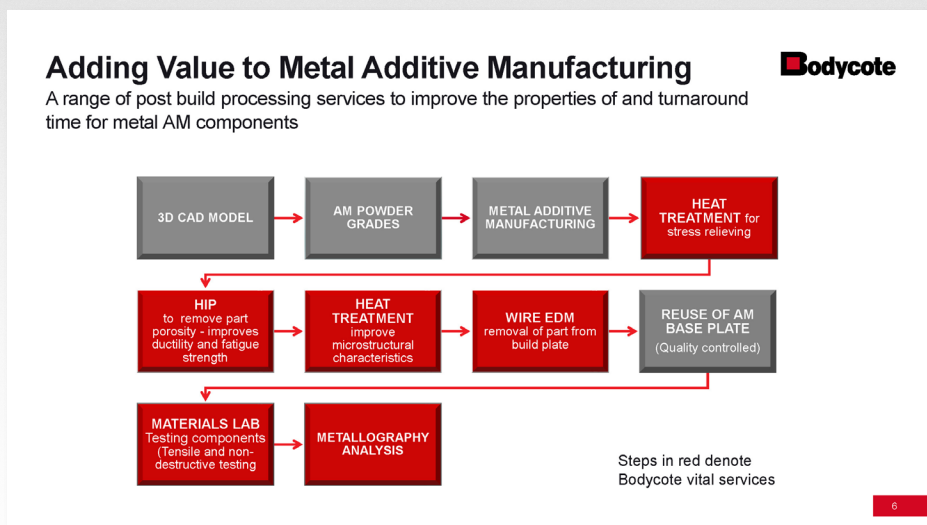
Reroll Conditioning (10 – 20 cm) thick



20 cm Reroll slab Post MetCon CAO = 99.1% step yield (6% better yield than grinding + pickle)



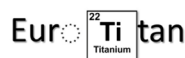
MetCon



of European counties (Germany, France, Greece, the Netherlands and others), with experience from previous and ongoing projects for metals extraction from industrial wastes. Orberger said EuroTitan contributes to solving three challenges: Europe's dependency of titanium metal and its related supply chain; highly polluting titanium metal production via the Kroll process; and Europe's high metallurgical residue volumes in industrial waste streams.

EuroTitan's objectives involve unlocking titanium from European waste streams. "EuroTitan will produce Ti-metal nanopowders through efficient and low-carbon footprint extraction technologies

and in-line process optimization," Orberger said, which results in over 90 percent of CO2 reduction compared to the Kroll process. There will be full integration of H2



Europe's dependency on Ti-metal and its supply chain

- Ti Metal: critical raw material (CRM 5th list of EU/2023).
- 100 % imported.
- 2/3 for the aeronautic sector.

Russia exports to US and European aerospace industries.

VSMPO-AVISMA group world's largest vertically integrated producer of Ti and Ti alloy products.

Political-economical risks

Airbus' Ti-sponge supply in 2021: ensured by 50 % from Russia.

EU is 50 % dependent on Chinese imports.

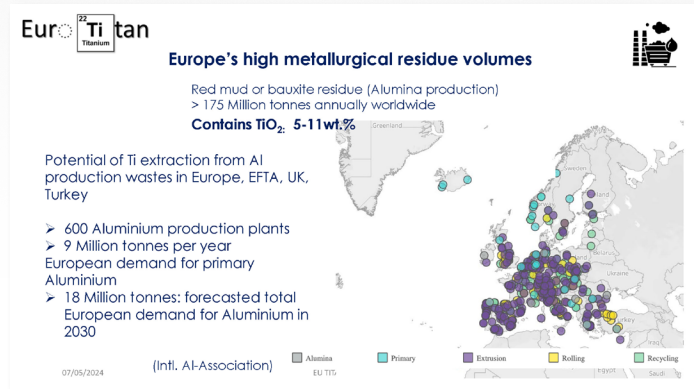
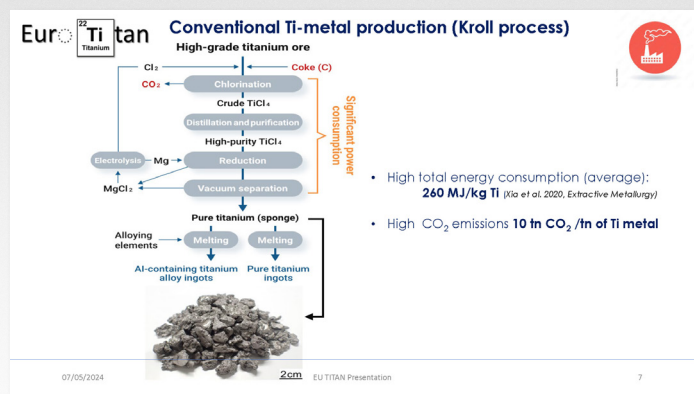


technologies and renewable energy sources, with onsite H2 production (electrolysis and electricity from wind power).

The estimated reduction of energy and water consumption: minimum 20 percent on-site, while minimizing production interruption. The remaining residues are converted into innovative (30 percent lower CO2 emissions compared to cement based) construction materials. Orberger said water will be recycled, and excess heat energy will serve local households. Rest waste (slags) will be converted into construction materials.

EuroTitan's vision is to diversify and secure the supply chain for the aeronautic sectors (master alloy and 3D printing) and decrease Europe's dependency from Russia, according to Orberger.

L.P. Lefebvre of the National Research Council of Canada, and Olivier Bergeron, AP&C-Une Société de GE Additive, discussed "Near Net Shape Precursors for the Production of Titanium Plates, Sheets, Forging and Hipping." The objective involves developing powder metal (PM) precursors for the production of net shape titanium products to take advantage of the availability of high quality rapidly solidified titanium powders, reducing cost by reducing



the number of steps and waste during manufacturing, and developing new materials, such as high-tech composites.

Production capacity of high-quality titanium powders has increased with the development of AM, which only uses a fraction of the particle size distribution. A significant fraction of high-quality fine and coarse powders are now available in significant quantities. This directly impacts the cost and sustainability of AM processes and provides opportunities in processes that could not, until recently, afford procuring such powders.

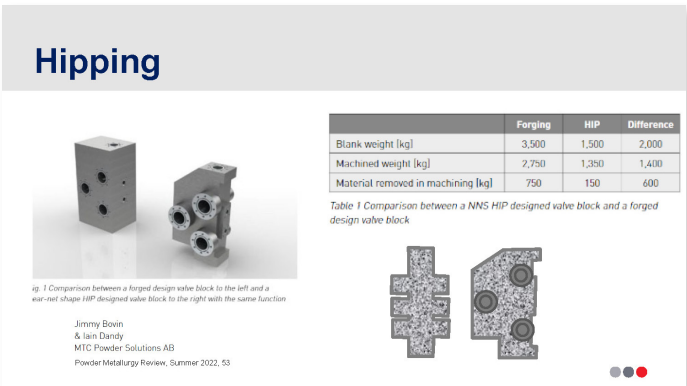
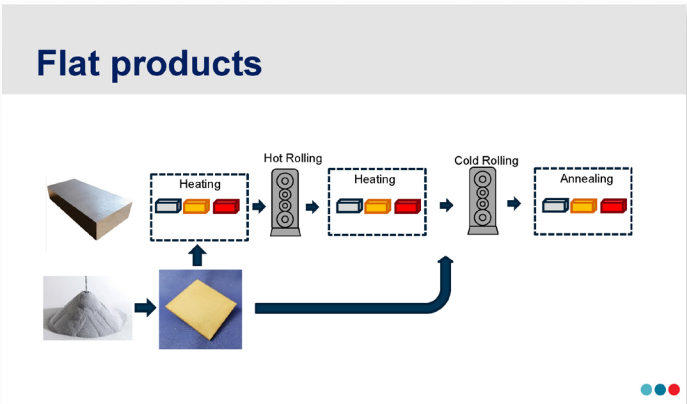
Piet Kooman, grinding specialist, Time Savers LLC service centers, addressed “Unlocking Precision: Wide-Belt Grinders for Titanium Grinding in Aerospace; Grinding Titanium with Finesse and Efficiency.” Kooman underlined the importance of precision titanium grinding, saying it’s essential in aerospace, medical, and other high-performance industries. “Challenges like removing alpha case and passing the bending test can be effectively addressed with wide belt grinders, specialized tools designed for titanium grinding,” he stated.

He asked the audience to consider the benefits of wide-belt grinders, saying they offer effective solutions for precision grinding in titanium processing. “By adopting this technology, engineers and technicians in the aerospace industry can significantly improve efficiency and quality in their titanium applications.” Wide-belt grinders used as specialized tools provide consistent

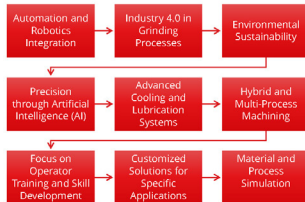
material removal, versatility in abrasives and settings, effective heat management, minimized tool wear, surface finish precision and specialized tooling for titanium.

“Operator training is crucial for maintaining precision and safety in titanium grinding,” Kooman said. “Adhering to industry standards and regulations ensures the integrity of the grinding process and guarantees the safety of both the operators and the final product. Additionally, implementing safety guidelines and quality control measures helps to prevent accidents and ensure consistent quality in titanium precision grinding.”

Martin Jackson, a professor of advanced metals processing at the University of Sheffield, presented information on “Digital Microstructural Fingerprints of Closed-Loop Recycling of Titanium Alloys.” He showed a



FUTURE TRENDS IN TITANIUM GRINDING



May 24



slide on the availability of titanium waste and said there's a need to start to refer to waste or scrap as a valuable feedstock.

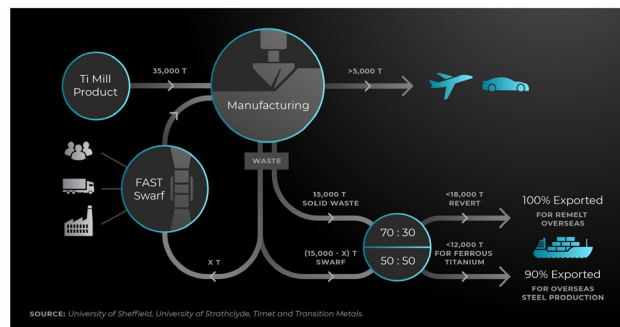
The use of high value alloyed titanium swarf as a feedstock is used for the FAST and FAST-forge process, with the generation of near-net shape components in high strength and good fatigue-life applications, he said. "There's an indication of production volume capability and cost level for automotive industry."

Thomas Klein of the Austrian Institute of Technology reviewed the "Processing of Ti-6Al-4V by Cold Metal Transfer: Microstructure Evolution and Mechanical Properties." Klein acknowledged that Ti-6Al-4V is the "workhorse alloy of the titanium industry and more industries are trying to implement the waDED (wire and arc-based directed energy deposition) process.

"Cold metal transfer (CMT) was shown to break up epitaxially grown β grains and reduce their size with increasing build height, Klein said. "Multiscale automated image analysis and compositional mapping of the microstructure revealed α -lath size variations as a function of build height and formation of fusion boundaries depleted in V and Fe. Hardness maps reveal local variations in hardness dependent on grain orientations; Acceptable strength values were reached while further improvement of ductility remained; Good fatigue strength obtained, whereby scatter was observed."

"CMT is shown to be capable of producing Ti-6Al-4V alloy builds with very high deposition rates. The ability to remove

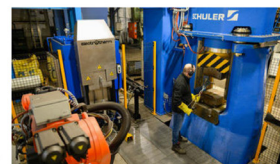
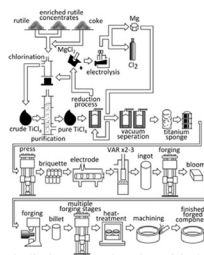
Availability of Titanium Waste



Martin Jackson, Digital Microstructural Fingerprints for Closed Loop Recycling of Titanium Alloys



FAST-forge (Made in Sheffield)



N.S. Weston, M. Jackson, FAST-forge - a new cost-effective hybrid processing route for consolidating titanium powder into near net shape forged components, J. Mater. Process. Technol. 243 (2017) 335-346.

N.S. Weston, M. Jackson, FAST-forge of Titanium Alloy Swarf: A Solid-State Closed-Loop Recycling Approach for Aerospace Machining Waste. Metals (2020), 10, 296.



Martin Jackson, Digital Microstructural Fingerprints for Closed Loop Recycling of Titanium Alloys



FAST-forge of Titanium Swarf



- Forger John Bull at WH Tildesley commented "I have over 50 years' experience in forging and found FAST titanium to be the easiest material I've ever forged."
- This R&D project has allowed John to share his experience with a new generation of apprentices



Martin Jackson, Digital Microstructural Fingerprints for Closed Loop Recycling of Titanium Alloys



w.h.tildesley ltd

Forging Specialists

the mechanical anisotropy and achieving enhanced properties in Ti-6Al-4V alloy makes this process as one of the most suitable AM

processes for adaptation in aerospace and other industries.”

Dr. Alexander Klassen of ALD Vacuum Technologies GmbH,

a subsidiary of AMG Advanced Metallurgical Group N.V., presented information on “Advanced Vacuum Furnaces for Metal Powder Production and Additive Manufacturing—Bridging Raw Materials to Products.” Klassen provided an overview of ALD’s Electrode Induction Melting Inert Gas Atomization (EIGA) systems.

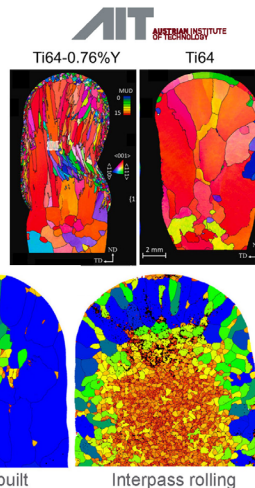
Benefits of the EIGA, according to Klassen, include ceramic-free powder production process, with no contamination of raw material with non-metallic elements, direct conversion of electrode into powder, a robust and simple process, and high productivity due to short cycle times. Materials processed by the EIGA system include titanium metal alloy powders, reactive and refractory metal powders, precious metal alloy powders, and materials with up to 3000 °C melting temperature, such as niobium, molybdenum and tantalum.

Klassen identified ALK EBUILD® 850 as “the world’s largest industrial electron beam powder bed fusion system, and gave examples of parts the system is able to produce.

In his summary remarks, Klassen said AM at ALD features a powder bed fusion electron beam (PBF-EB) build volume of 850 x 850 x 1000 mm³. The system has a beam power of 45 kW @ 150 kV acceleration voltage, with high productivity rates of up to 1000 cm³/h. Powder Recycling at ALD provides a “circular economy” solution for metal powders, with a wide range of powder particle sizes, fast AM-build using up to 400 µm layers, electrode production under vacuum conditions, and closed capsules for easy storage.

CHARACTERISTIC MICROSTRUCTURES

- Thermal gradient results in **large/columnar primary grains**
 - Variation in **processing parameters** (influencing the G and R values)
- Addition of **alloying elements** (providing β -nucleation sites)
- Employment of **interpass deformation** during the AM process

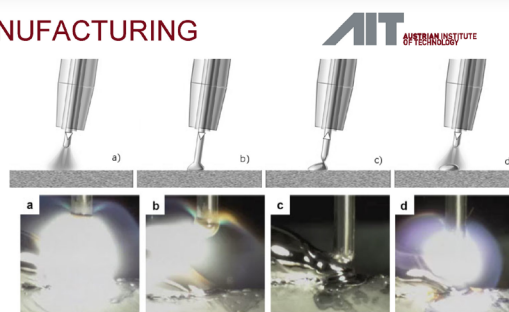
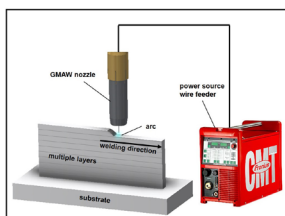


J. Donoghue et al. “The effectiveness of combining rolling deformation with Wire-Arc Additive Manufacturing on β -grain refinement and texture modification in Ti-6Al-4V.” Materials Characterization 114 (2016): 103-114.
Kennedy, J. R., et al. “ β Grain refinement by yttrium addition in Ti-6Al-4V Wire-Arc Additive Manufacturing.” Journal of Alloys and Compounds 895 (2022): 162735.

WIRE ARC ADDITIVE MANUFACTURING

Characteristics:

- Near-net shape components with **medium complexity**
- High deposition rates; Material efficient**
- Component **size unlimited**



Advantages:

- ✓ A **spatter-free waDED process** with a stable arc
- ✓ **Low heat input** and a much higher deposition rate
- ✓ **Reduced residual stress**
- ✓ **Coaxiality of heat source and feedstock** allows for the fabrication of complex structures

T. Klein, M. Schnall, B. Gomes, P. Warczok, D. Fleischacker, P. J. Morais, Addit. Manuf. 37 (2021) 101663

WAAM @ LKR/AIT

Power sources

- CMT Advanced, CMT-TWIN (Fronius)
- Magic WAVE 5000 (Fronius)
- PlasmaMultInverter 350 AC/DC TL (SBI)

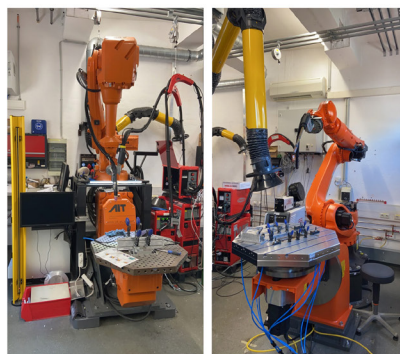
ABB robot system

- Robot with 45 kg max. load
- Tilt-and-turn table

KUKA robot system

- Robot with 300 kg max. load
- Tilt-and-turn table

→ **Basic equipment for light metal waDED**

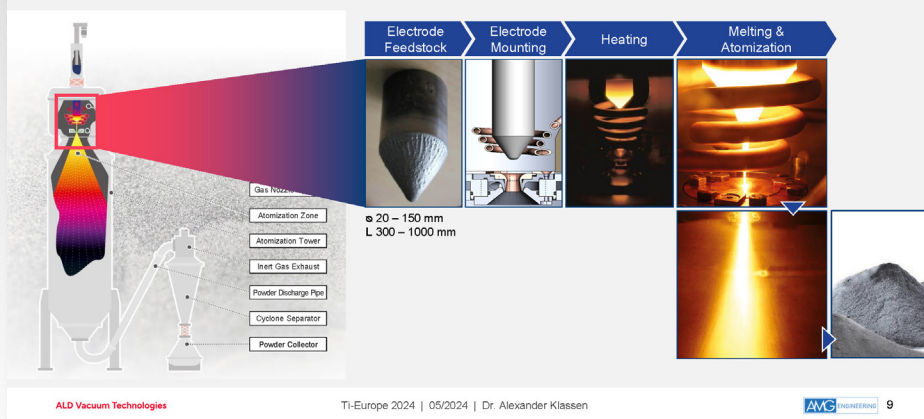


System 1
(ABB + Fronius)

System 2
(KUKA + SBI)

07.05.2024

EIGA SYSTEMS – RAW MATERIALS & PROCESS



EIGA SYSTEMS – STANDARD & PREMIUM

EIGA100-100 Standard	EIGA100-100 Premium
Key data: - Standard melt chamber + EIGA free-fall nozzle - Melt chamber: max. 1.3 bar $d_{50} = 60 - 120 \mu m$ - Specific gas consumption more than $15 m^3 / kg$	Key data: - Pressurized melt chamber + new nozzle system - Melt chamber: max. 25 bar $d_{50} = 20 - 80 \mu m$ - Specific gas consumption $1 - 8 m^3 / kg$

ITA will host TITANIUM USA 2024 at the JW Marriott Hotel in Austin, TX, Oct. 6-9. Visit www.TitaniumUSA.org for registration information. Many managers from prime contractors as well as sub-tier suppliers are coming as they recognize the efficiency of attending a meeting such as TITANIUM.

Because there are producers, distributors and fabricators from all parts of the world across several consuming market segments at the conference, it's a very cost effective means for the delegates to meet

with a wide variety of customers and vendors in a single trip. At the same time, TITANIUM USA, much like TITANIUM EUROPE, offers opportunities to hear from leading industry executives and attend panel discussions on market topics that affect each industry segment.

The ITA is a membership-based international trade association dedicated to the titanium metal industry. Established in 1984, the ITA's main mission is to connect the public interested in using titanium with specialists from across the globe who may offer sales and technical assistance. Working through extensive membership resources, the ITA seeks to expand the knowledge base for the metal, providing technical literature and sponsoring seminars and conferences. Current ITA membership is comprised of more than 120 organizations and over 1,500 individual members worldwide.

ALD EBUILD® 850:
THE WORLD'S LARGEST INDUSTRIAL ELECTRON BEAM POWDER BED FUSION SYSTEM

Productivity AM of large parts and highest build rate in Powder Bed Fusion	
Unique QM features In-process electron imaging	
Materials Wider powder particle size range	

ALD Vacuum Technologies

Ti-Europe 2024 | 05/2024 | Dr. Alexander Klassen

AVCS ENGINEERING 14