Master Alloys Today for Tomorrow's Applications
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Presentation Overview

• Part 1: Production of Master Alloys

• Part 2: Key Master Alloy Materials & Focus on Vanadium
Master Alloys

- A combination of two or more metals in a metallurgically alloyed form
- Added with base metals into a melt furnace charge to achieve desired final ingot chemistry
- Typically available in a powder/aggregate form
- Process control to regulate precise chemistry consistency and non-metallic inclusions is essential
Use of Master Alloys for Titanium Alloys

**Preparation**

- **Master Alloy + Ti Sponge**
  - Formed Into Briquettes
  - + Ti Scrap

**Melting**

- **Cold Hearth Melting**
  - Titanium Ingot

- **VAR Melting**
  - or

**Welded Electrode**
Aerospace Quality Master Alloy Production

• Mix high quality raw materials
• Charge into refractory free melt vessel
• Ignite to start exothermic reaction
• Refine, cool, ingot blast
• Inspect 1, size, inspect 2, optional X-Ray

Keys to Aerospace Quality Master Alloys

• Robust raw material supply chain
• Refractory free melting practices
• In-line automated inspection techniques
• Comprehensive High Density Inclusion (HDI) program
Vanadium Master Alloys

- Al - V chemistries include
  - 65V/35Al
  - 75V/25Al
  - 85V/15Al

- Applications
  - Airframes
  - Engines – rotating parts
  - Medical
  - Industrial
  - Consumer

- Approximately 80% by weight of all Master Alloys
- Available as a binary Aluminum + Vanadium alloy
- Widely used in the production of Ti-6Al-4V
Molybdenum Master Alloys

- Approximately 10% of master alloy consumption
- Available as a binary Al-Mo or tertiary Al-Mo-Ti alloy
- Used in the production Ti-6Al-2Sn-4Zr-2Mo, Ti-6Al-2Sn-4Zr-6Mo, & Ti-15Mo

Chemistries include
- 35Al/65Mo
- 42Al/55Mo/3Ti
- 50Mo/50Ti

Applications
- Primarily used in high temperature jet engine applications
- Increasingly used in medical applications
Niobium Master Alloys

- Chemistries include
  - 40Al/60Nb

- Applications
  - Used in alloys such as Ti-6Al-7Nb for medical implant applications
  - Used in high temperature titanium aluminides

- Approximately 5% of master alloy consumption
- Available as a binary Al-Nb
Multi-Component Master Alloys

- Master alloys with 3-5 alloying elements
- Often tailored to the customers process

- Often contain combinations of Zr, Cr, Si, Sn, Nb and Mo
- Master Alloys for Titanium Alloys
  - Ti-17
  - β 21

- Applications
  - Often used in stabilized Ti alloys designed for high service temperatures
Key Issues for Master Alloy Producers

- Quality is non-negotiable
- Certification of raw material suppliers
- Documentation & traceability
- Supplier understanding and acknowledgement of the risk of High Density Inclusions (HDI)
- Risk prevention strategies
- Comprehensive inspection strategy
- Robust audit & record retention
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Key Raw Materials for Master Alloys

Aluminum Powder

- Pure aluminum
- Produced by gas atomization
- Commercially available
- Use at fuel for the aluminothermic melt process
- Key master alloy addition

Vanadium Pentoxide

- Used as an oxide
- Vanidate ore is concentrated, chemically refined and roasted into V$_2$O$_5$
- Used for ferro vanadium used by the worldwide steel industry
- Only a small fraction of V$_2$O$_5$ is produced in high purity form for Titanium

Molybdenum Trioxide

- Used as an oxide
- Mo rich ore is concentrated into MoS$_2$ that is roasted and refined into pure MoO$_3$
- Used in ferro Mo for the worldwide steel industry
- Master alloys are a minor use for MoO$_3$
Oxide Trend 2004 to Present

Vanadium Pentoxide

Molybdenum Trioxide

V2O5 History

MoO3 History
Recent Vanadium Volatility

Recent volatility attributed to:
• Suppliers exiting market
• China rebar regulations
• Vanadium redox batteries

The following provides a survey of recent publications related to the V2O5 Market.
Vanadium Demand & Supply Dynamics

Vanadium Consumers
- Steel: 93%
- Titanium: 4%
- Chemical: 3%

Vanadium Supply by Raw Material
- Coproduct Steel Slag: 10%
- Primary V Ore: 17%
- Secondary: 73%

V₂O₅ Suppliers to the Titanium Industry

- Total 76,750 MT

Source: TTP Squared

• Vanadium demand & price is driven by the worldwide steel industry
• More than 70% of Vanadium Pentoxide supply is NOT suitable for Titanium production
High Purity Vanadium Consumption

- Largo’s April 2019 estimate
- 2018 total V supply ~90,000 mTon V
- 9% of V high purity (~8,100 mTon V)
- 50% of high purity used for Aerospace (~4,050 mTon V)

Source: Largo Corporate Presentation April 2019
Vanadium Demand Forecasts

World supply expected to continue to be less than demand in 2019 (~105,000 mTon V)

TTP Squared & Technology Metals Australia predict a supply gap of 30,000 mTon V by 2025

Source: Technology Metals Australia investor presentation & TTP Squared
China Rebar Demand

- The new standard for 600 MPa tensile strength rebar was enacted in November 2018
- Estimate shows that V demand used in rebar could reach 40,000-50,000 mTon per year
- Roskill also believes that this will result strong demand and limited excess supply

"Roskill's base case sees market in structural deficit until 2023. Impact of new rebar regulations in China, substitution effects, and development of new projects are key factors impacting supply/demand over medium term."
CRU Predicts 2019 Turbulence Due to China Rebar

- CRU predicts that V stocks will continue to decline
- China has been managing the implementation of the new rebar standard and demand is predicted to begin accelerating
- China is importing more Ferro Niobium as a substitute for Vanadium

Source - CRU Insight Article 5 April 2019
Vanadium Redox Batteries (VRB)

- A battery technology suited for power grid level storage used with wind and solar
- The technology is targeted to solar installations to enable power delivery after dark
- VRB technology is reliable and maturing
- Installations require large amounts of vanadium and deployment is dependent on Vanadium price

Vanadium prices, oil prices, and CO₂ emission regulations will be a major factor in the rate of adoption
Largo is expanding its Maracas Menchen vanadium mine by 25% to produce about 12,000 mTon of V2O5 per year.

Seeking Alpha ‘Vanadium Miners News – 29 March 2019’ list 12 separate vanadium production projects under review in Australia, South Africa, Canada, and the USA.

Our industry must be ready for price volatility!
Vanadium in 2019

• China Vanadium demand will continue to drive the price in Europe and North America

• New vanadium capacity is entering the market during 2019 but will need qualification

• Chinese rebar mandates and VRB demand will create additional demand over the next few years – expect turbulence

• The high purity vanadium pentoxide market will remain concentrated with multi-national producers leveraging pricing

Master Alloy users and suppliers must continue to strengthen partnerships