Master Alloys - Critical Raw Materials for Critical Applications
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What are Master Alloys?

- A combination of two or more metals in a metallurgically alloyed form
- Added with other materials into a furnace charge
- Provide required final chemistry to melted ingots
How are Master Alloys used in the production of Titanium?
The Titanium Master Alloy World

**Vanadium Master Alloys**

- Approximately 80% by weight of all Master Alloys
- Al/V chemistries include
  - 65V/35Al
  - 75V/25Al
  - 85V/15Al
- Applications
  - Airframes
  - Engines – rotating parts
  - Industrial
  - Consumer
  - Medical
The Titanium Master Alloy World

Molybdenum Master Alloys

- The next largest master alloy by volume
- Approximately 10% of the MA Market
- Products include
  - 35Al/65Mo
  - AlMoTi
  - MoTi
- Applications
  - Primarily used in jet engine applications
  - Also increasingly used in medical applications
The Titanium Master Alloy World

**Niobium Master Alloys**

- Nb alloys represent about 5% of the MA market
- Primarily 40Al/60Nb
- Applications
  - Primarily medical applications (Ti 6Al-7Nb)
  - Aerospace (Ti Aluminides)
The Titanium Master Alloy World

Other Master Alloys

- These make up the balance
- Includes multi-component products
  - Ti-17
  - NbAlSiTi
- Other binary alloys
  - AlCr
  - AlSi
- Used in a wide variety of applications
Key Master Alloy Raw Materials

- Aluminum Powder

- Used in metallic pigments, chemicals, rocket propellants

- Price driven by metal exchanges (LME, COMEX, etc)

- Used as
  - fuel for Master Alloy aluminothermic reaction
  - Master Alloy composition

\[ \text{Metal Oxide} + \text{Al} \rightarrow \text{Master Alloy} + \text{Al}_2\text{O}_3 + \text{heat} \]
Key Master Alloy Raw Materials

- Vanadium Pentoxide
- Molybdenum Trioxide

- Demand for both is highly dependent on the global steel industry
- Oxide prices currently part of the global resurgence in commodity pricing
- Other key raw materials
  - Nb$_2$O$_5$
  - Cr Oxide
  - Sn Oxide
Vanadium

Consumption of Vanadium

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

Vanadium pricing primarily driven by steel demand
Vanadium Production by Raw Material Type 2016

V205 Suppliers to the Titanium Industry

- Total 76,750 MTV
  - Coproduct Steel Slag: 73%
  - Primary V Ore: 17%
  - Secondary: 10%

Source: TTP Squared
Vanadium - An Industry Restructuring

- World Steel Capacity Utilization averaged over 70% in 2017

- ~1.7BT of 2017 steel production represented ~ 5% increase over 2016

- The commodity rout of 2015-2016 eliminated about 12,000 MT of V from the system - especially high purity V205
  - Highveld Steel / Mapochs Mine – 5,500 MTV
  - Vanchem – 5,000 MTV
  - Gulf Metallurgical – 1,200MT

- Largo Resources Maracas vanadium mine is now running close to capacity
  - ~2,500 MT V2O5 in Q4 2017

- Net production capacity / consumption delta is negative

- Current Index V205 pricing is well above the production costs of major vanadium producers
Global V Production and Consumption

2004 – 2020 (est)

Source: TTP Squared
Recent Vanadium Production and Consumption

Vanadium Production

- 2014
- 2015
- 2016
- 2017E

Vanadium Consumption

- 2014
- 2015
- 2016
- 2017E

Source: TTP Squared
Vanadium Wildcard #1 – Chinese Rebar

- The Chinese vanadium market will be affected by revised standards for the tensile strength of rebar products and a ban on vanadium slag imports.
- The new standard proposes eliminating 335MPa-tensile strength rebar and replacing it with 600MPa-tensile strength rebar, which has greater earthquake resistance.
- Rebar producers will have to add greater quantities of vanadium to their production mix.
- Some estimates have this mandate increasing vanadium demand in China by 30% or 10,000MTV.
- That represents approximately 10% of world V consumption based on 2017 estimated levels.

Estimated consumption of vanadium in steel (grams per 1,000T)

North America = 93
Europe = 73
China = 37

Source: TTP Squared
Vanadium Wildcard #2 – Vanadium Redox Batteries

• Currently only represents a small portion of vanadium demand, but the technology appears to be gaining traction after years of development

• Government funding of VRB projects in China

• Leasing arrangements could make the technology more commercially viable

• Typically require very large amounts of vanadium
Vanadium in 2018

• Supply remains tight with demand continuing to be strong

• Vanadium prices in China continue to drive the price in Europe and North America. Prices forecast to increase further.

• Little additional vanadium capacity expected to be brought on line in the short term

• Chinese rebar mandates and VRB demand will create significant additional demand on top of an already tight supply environment

• The high purity market has been concentrated with multi-national producers leveraging pricing
Molybdenum Demand by Application

- Engineering steel: 5%
- Stainless Steel: 8%
- Chemicals: 13%
- Foundries: 21%
- Tool Steels: 7%
- Mo Metal: 1%
- Nickel Alloys: 2%
- Titanium Alloys: 43%
Molybdenum Global Production and Consumption

Mo Production and Consumption

Source: IMOA, CRU, Internal Estimates
Molybdenum Published Price Index
Molybdenum in 2018

- Significant supply eliminated since 2016
  - Supply is currently tight
  - Excess inventory worked off and market is projected to be in equilibrium through 2020
- Factors driving demand
  - Oil and Gas exploration
  - Infrastructure
- The China Factor
  - China accounts for 36% of world consumption
  - Up from 12% in 2006
  - Intensity of Moly use in steel production is low
- Technavio forecasts Moly demand to increase 3% per year to 2021
- Copper production/demand will also affect Moly supplies
The Titanium Scrap and Sponge Relationship

- There is a constant effort by melters to maximize the economics of their raw material input.

- Advances in melting technology have enhanced their ability to remelt greater quantities of Ti scrap.

- Relative price differentials between titanium scrap and titanium sponge contribute to the selection of charge materials. This has a consequential effect in the demand for Master Alloys.
A Balancing Act

When titanium scrap prices are low, more scrap is included in the melt mix.

When titanium sponge prices are low, more sponge and master alloy is consumed in the melt mix.
Titanium Scrap vs. Sponge
relative price dynamic

Published US Indices

- Titanium Sponge
- Ti 6-4 Bulk Weldable
- FerroTitanium
Forecast of Master Alloy Demand

Source: Ametek Reading Alloys Internal Estimates
Key Issues for Master Alloy Producers

- Quality is non-negotiable
- Certification and approval of raw material suppliers.
- Documentation of procedures
- Supplier understanding and acknowledgement of the risk of HDI’s (High Density Inclusions). Tungsten and Tungsten Carbide most frequent.
- Risk prevention strategies
- Inspection
- Record retention
- Audit schedules
Diversified Supplier Base

- Global commodity situation has reduced the number of suppliers for several commodities

- Especially true with Vanadium and Molybdenum

- MA producers must continually be on the lookout for new high quality suppliers

- A narrow supply chain is increasingly risky for Master Alloy producers in the current environment
Accurate and Reliable Forecasting

- Global logistics make it challenging to respond to demand spikes

- Raw material lead times are typically 6 weeks or longer

- Some producers are sold out well in advance with long term supply agreements

- Inventory pressures apply to master alloy producers as well
Strengthen the Partnership

- Master Alloy producers are more than just suppliers – they are partners
- There is a tremendous amount of collaboration necessary to ensure material is available for anticipated increases in Master Alloy demand
- Master Alloy producers have the same stakes in the current environment as the rest of the aerospace supply chain
- Master Alloy producers are operating under the same financial constraints as the rest of the supply chain
  - Pressure to reduce costs
  - Pricing pressures
  - Inventory reduction
Going Forward Together

With limited capacity for aerospace quality material, it is important that titanium melters continually strengthen their strategic partnerships with Master Alloy suppliers in order to maintain the health of this critical part of the supply chain.
Thank You!