Master Alloys:
production, applications and influences on future supply
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AMG ADVANCED METALLURGICAL GROUP N.V.

- approx. 3,000 employees
- US$ 1.060 billion annual revenues in 2017

<table>
<thead>
<tr>
<th>AMG Business Units</th>
<th>AMG Critical Materials</th>
<th>AMG Engineering</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Conversion, mining and recycling business</td>
<td>Vacuum systems and services business</td>
</tr>
<tr>
<td>AMG Lithium (BR)</td>
<td>AMG Aluminum (US)</td>
<td>AMG Engineering (DE)</td>
</tr>
<tr>
<td>AMG Titanium Alloys &amp; Coatings (DE)</td>
<td>AMG Antimony (FR)</td>
<td></td>
</tr>
<tr>
<td>AMG Superalloys (UK)</td>
<td>AMG Brazil (BR)</td>
<td></td>
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<tr>
<td>AMG Vanadium (US)</td>
<td>AMG Graphite (DE)</td>
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<td></td>
<td>AMG Silicon (DE)</td>
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Innovative metallurgical solutions for the global markets of:

- Energy
- Transportation
- Infrastructure
- Specialty Metals & Chemicals

Peter Baumeister, Master Alloys
A Master Alloy contains two or more alloying elements for the final Ti alloy or grade with a defined composition.

### Number of Elements:

<table>
<thead>
<tr>
<th></th>
<th>Binary</th>
<th>Ternary</th>
<th>Multinary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elements</td>
<td>2</td>
<td>3</td>
<td>&gt;3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Products, e.g.:</th>
<th>Binary</th>
<th>Ternary</th>
<th>Multinary</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAI</td>
<td></td>
<td>VAIFe</td>
<td>AISnZrMoCr</td>
</tr>
<tr>
<td>(for Ti 6-4)</td>
<td></td>
<td>MoAlTi</td>
<td>(for Ti 17)</td>
</tr>
<tr>
<td>MoAl</td>
<td></td>
<td></td>
<td>AlMoVCrTi</td>
</tr>
<tr>
<td>NbAl</td>
<td></td>
<td></td>
<td>(for Ti 5-5-5-3)</td>
</tr>
</tbody>
</table>
Aerospace **Master Alloys** require **high purity raw materials** with aerospace quality requirements.

### Master alloy class:

<table>
<thead>
<tr>
<th>Master alloy class:</th>
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<tbody>
<tr>
<td>V Vanadium</td>
</tr>
<tr>
<td>Mo Molybdenum</td>
</tr>
<tr>
<td>Nb Niobium</td>
</tr>
<tr>
<td>Cr Chromium</td>
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</tbody>
</table>

### Raw materials:

<table>
<thead>
<tr>
<th>Raw materials:</th>
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</thead>
<tbody>
<tr>
<td>Vanadium Oxides</td>
</tr>
<tr>
<td>Molybdenum Oxides</td>
</tr>
<tr>
<td>Niobium Pentoxide</td>
</tr>
<tr>
<td>Chromium Trioxide</td>
</tr>
</tbody>
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**Peter Baumeister, Master Alloys**
MASTER ALLOYS FOR THE TITANIUM INDUSTRY

Master Alloys *market share* by volume

- SiTi, NbAlSiTi, AlSnZrMoCr (Ti17) (~5%)
- Zr, Si, Sn (Others) (~5%)
- MoAl, MoAlTi (~10%)
- Nb, Niobium (~5%)
- Cr, Chromium (~5%)
- V, Vanadium (~80%)
- VAI, VAIFe, VAIC

Products (examples)
**Master Alloys** are used for the Titanium Ingot Production.

- **Ti Sponge** + **Master Alloys** → **Electrode** → **VAR** → **Cold Hearth Refining / Melting** → **Titanium Ingot**

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**Ti Scrap** in the diagram is not directly related to the process outlined above. It is possible the diagram is illustrating different steps in the production process, including the use of Master Alloys and Ti Sponge, but the Ti Scrap is not explicitly connected to the core production steps shown.
Titanium Alloys are used to

- add alloying elements required to meet the performance targets of the final tailor made application
- improve the mechanical properties, the heat and corrosion resistance of base titanium
- improve and allow subsequent process steps (e.g. forging, forming, rolling)
- save costs by alloying Master Alloys instead of pure metals (e.g. V + Al)
Master Alloys are reducing the melting point inside VAR

Master Alloys allow to melt and include all raw materials close to the melting point of the base Ti material. (e.g. VAl65 melts at 1580 °C close to Ti)
Production process of Master Alloys

**Raw Materials**
- weighing
- mixing

**Melting**
- Aluminothermic Reduction (ATR)
- Vacuum Induction Melting (VIM)
- ATR→VIM two-step-process

**Crushing**
- crushing
- sizing

**Inspection**
- Magnetic separation
- Inspection (visual, x-ray, black light)
- Sampling
- Chemical analysis
- Screen analysis
- Quality release
With an **Aluminothermic Reduction** process (ATR), the alloy is produced via an aluminothermic (thermite) smelting process within a refractory-lined or copper vessel.

- initial ignition
- exothermic chemical reaction
- no additional supply of energy

Raw materials are metal oxides + aluminum as well as auxiliary materials which will be mixed/homogenized.
With the **VIM-Process** process the alloy is produced via a smelting process within a Vacuum Induction Melting furnace.

- endothermic chemical reaction
- supply of external energy necessary
- controlled process

Raw materials are metals and/or alloys, but no oxides.
Examples of titanium alloy applications

The ingot will be mechanically processed to a final part

- Undercarriage / bogie
- Structural part
- Disc
- Blade

Titanium Aluminides

Peter Baumeister, Master Alloys
There are different influences on future demand of Master Alloys.

- Number of new airplanes will increase – mainly driven by the Asian/Pacific region expansion
- New civil aircraft designs require much more titanium alloys per aircraft than past models
There are different influences on future demand of Master Alloys.

- The general tendency is to increase the use of Ti alloy scrap
- Technological changes in materials (composites, Ti Aluminides) will change the usage of master alloys
MASTER ALLOYS FOR TITANIUM ALLOYS – INFLUENCES ON FUTURE SUPPLY

Market

- **Political**
  (trade barriers, duty, strikes, shortage in energy, etc.)

- **Pricing**
  Raw materials are depending on other industry sectors
  (e.g. Vanadium quotation is linked to the steel industry)

- **Currency** exchange rates
  (USD, EUR, RMB, REAL, etc.)

- **Supplier**
  Strategic focus of the approved and certified suppliers;
  New market participants not seen to date
There are **opportunities, challenges** and **risks** for the TITANIUM industry.
Raw material suppliers should

- provide clear **strategic commitments** supporting the titanium industry with sustained supply of consistent quality materials
- show flexibility regarding **pricing**
- **balance the expectations** of the customers and the capabilities while taking into consideration their own constraints
- be willing to **share** commercial **risk**
We, as master alloy producers, must

- **balance the expectations** of our customers and the capabilities of our raw material suppliers while taking into consideration our own constraints
- provide our products to **specification** and **on time**
- be **innovative** in developing technical solutions for present and future master alloy requirements as well as leading cost reduction programs
Customers should:

- balance purchasing orders within the approved and certified supplier base
- understand and accept market influences (currency exchange rates, raw material situation, duty, ...)
- intensify cooperation by e.g.
  - early involvement in R&D activities
  - providing reliable mid/long term forecasts
- bringing us to a position of adjusting capabilities and capacities at the right time
Only a close alliance of the total chain will increase the **security of supply** for the **future**!
A **Master Alloy** is not a commodity.

**Master Alloys** are essential for the titanium industry.

The titanium industry requires a healthy **Master Alloy** supplier base.

**Master Alloys → Master Future!**
MASTER ALLOYS FOR THE TITANIUM INDUSTRY

TITANIUM MASTER ALLOYS

THANK YOU FOR YOUR ATTENTION