Titanium Powder Markets – Chances and Risks –
AMCG in Summary

- Consulting company, focused on market intelligence and business development projects
- Customers are the special metals, chemical and engineering industry
- Active for the titanium metal industry since many years
- Serving global players as well as medium-sized companies
- Located in Munich/Germany with associates in North America and Asia
Disclaimer

This presentation contains information, estimates and forward-looking statements. Forward-looking statements may include, in particular, statements about future events, future performance, expectations, competitive environment, supply and demand.

Information, estimates and forward-looking statements are based on our current assumptions and forecasts. These statements naturally entail risks and uncertainties. They are believed to be reliable, but AMCG makes no warranty regarding the accuracy, completeness or reliability of these data.
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Titanium powder – currently a small business, mainly applied for sputtering targets

Titanium metal markets (world)

Market volume (tpy)

130,000

Approx. 2,500

Mill products

Powder (powder metallurgy)

Titanium powder
Total: Approx. 2,500 tpy (world)

– by market segments –

Sputtering targets 73%

Medical 15%

Aerospace 5%

Porous applications 4%

Consumer goods 3%
Demand driven by new powder processing technologies

Applications for titanium powder

Powder processing technologies

Press, sinter
Additive manufacturing
MIM – metal injection molding
Cold spraying

Applications, markets

- Sputtering targets
- Porous applications
- Aerospace
- Medical
- Medical
- Aerospace
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Titanium powder – spherical and irregular shape products

Titanium powders: Manufacturing technologies

Spherical shape
- Atomization (high quality powder)
  - GA – gas atomization
  - PA – plasma atomization
  - PREP – plasma rotating electrode process

Irregular shape

Mechanical route
- HDH – hydride dehydride

Chemical route
- Armstrong
- Metalysis
Types of products and accessible market segments

<table>
<thead>
<tr>
<th>Powder processing technologies</th>
<th>Press/sinter</th>
<th>AM – additive manufacturing</th>
<th>Thermal spraying</th>
<th>MIM – metal injection molding</th>
<th>Cold spraying</th>
<th>Roll compaction</th>
</tr>
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<tbody>
<tr>
<td>Type of powder product</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spherical shape</td>
<td>Not accessible</td>
<td>Accessible</td>
<td>Not accessible</td>
<td>Pretreatment of powder necessary</td>
<td>Accessible</td>
<td>Accessible</td>
</tr>
<tr>
<td>Irregular shape</td>
<td>Accessible</td>
<td>Accessible</td>
<td>Accessible</td>
<td>Accessible</td>
<td>Accessible</td>
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Spherical shape products – high raw material costs

Titanium powders: Raw materials, price levels

<table>
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<tr>
<th>Products</th>
<th>Ti ore</th>
<th>TiCl₄</th>
<th>Ti sponge</th>
<th>Ingots</th>
<th>Billets</th>
<th>Bars</th>
<th>Wire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price level</td>
<td>0</td>
<td>1</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
</tbody>
</table>

- Ti ore
- TiCl₄
- Ti sponge
- Ingots
- Billets
- Bars
- Wire

- GA – gas atomization
- PA – plasma atomization
- HDH
- PREP
- Armstrong
- Metalysis
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Major markets – aerospace and medical

Titanium powder: Market development

- Growth markets
  - Aerospace and medical (with AM and MIM)
  - Ti64, TiAl

- Expansion of powder manufacturing capacities globally

- Huge investments in AM by aerospace sector
Large substitution potential for titanium powder

Titanium mill products
Total: 130,000 tpy (world)

– by market segments –

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<th>Market Segment</th>
<th>Percentage</th>
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<tr>
<td>Defense</td>
<td>9%</td>
</tr>
<tr>
<td>Commercial aerospace</td>
<td>4%</td>
</tr>
<tr>
<td>Industry</td>
<td>52%</td>
</tr>
<tr>
<td>Medical</td>
<td>35%</td>
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</tbody>
</table>

Accessible markets for titanium powder

- Commercial aerospace
- Defense
- Medical

- Substitution of machined parts made from
  - castings
  - forgings (billets, bars)

Cabin bracket © Airbus
Spinal implant (titanium) © Eos
Order backlog for aircrafts lasts for nine years (based on current output)

Large civil aircrafts: Order volume

Aircraft orders (#)

- Boeing: 762 aircrafts
- Airbus: 635 aircrafts

CAGR 5.25%

Airbus
Boeing

Large civil aircrafts: Order backlog
Total: 12,532 aircrafts (2/2016)

- by suppliers -

Airbus 6774 aircrafts
Boeing 5758 aircrafts

Volatile but growing

Source: Airbus, Boeing
Aerospace industry – demand on technologies with lower scrap rate

Yield rates for machined products*

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Industry (e.g. TiCP)</th>
<th>Aerospace (e.g. Ti64)</th>
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<tbody>
<tr>
<td>Titanium ingots</td>
<td>100 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Long products</td>
<td>100 %</td>
<td>90 %</td>
</tr>
<tr>
<td>Flat products</td>
<td>100 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Plates (CP)</th>
<th>Sheets (CP)</th>
<th>Sheets (alloy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Billets</td>
<td>70 %</td>
<td>60 %</td>
<td>50 %</td>
</tr>
<tr>
<td>Bars</td>
<td>65 %</td>
<td>60 %</td>
<td>50 %</td>
</tr>
</tbody>
</table>

Buy-to-fly ratio: 5 - 8 : 1

Components for heat exchanger (e.g. sheet)

15 %

Aerospace

* average values
Various factors are driving the demand on powders

**Pros**

- Lower total costs
- Less material waste
- Decreased manufacturing lead time
- Lower weight (and costs) of components (new designs and geometries possible)
- Fewer processing steps, complexity
- Manufacturing on demand (spare parts)

**Cons**

- Skill shift at customers, shut down of plants
- Repeatable product quality
- Low capacity of processing plants
- Spherical shape powders (yield rate, costs)
- Irregular shape powders (oxygen, pretreatment)
Titanium powder – disruptive technology

Current value chain:
- Chlorination, reduction (sponge)
- Melting (ingots)
- Milling (mill products)
- Forging (closed die forgings)
- Machining (finished parts)

Future value chain:
- Chlorination, reduction (sponge)
- Melting (ingots)
- Milling (mill products)
- Powder manufacturing (atomization etc.)
- Powder processing (AM, MIM etc.)

- Substitution of forging and machining by new processes
- Lower scrap volume, reduced demand on melting and milling capacities
Summary and conclusion

Current market
• Small business, dominated by mature applications

Products
• Various powder products suitable for different processing technologies

Processes
• New manufacturing technologies (AM, MIM) are driving the demand

Outlook
• Future markets are aerospace and medical
• Substitution of conventional mill products

➢ Titanium powder – a disruptive technology for players in the titanium metal value chain
Thank you for your kind attention!