Characteristics and Applications of Ti-alloy powders produced via Electrode Induction-Melting Gas Atomization
Titanium powder manufacturing

**Titanium spherical powder production**

- **CICAP**: Cold-wall Induction Crucible Atomization Process
- **PREP**: Plasma Rotating Electrode Process
- **PWAP**: Plasma Wire Atomization Process
- **EIGA**: Electrode Induction-Melting Atomization Process

### Table: Comparison of Titanium Powder Production Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Energy consumption</th>
<th>Fine powder yield</th>
<th>Feedstock</th>
</tr>
</thead>
<tbody>
<tr>
<td>PREP</td>
<td>moderate-high</td>
<td>low</td>
<td>expensive</td>
</tr>
<tr>
<td>PWAP</td>
<td>moderate-high</td>
<td>moderate</td>
<td>expensive, thin wire</td>
</tr>
<tr>
<td>CICAP</td>
<td>high</td>
<td>moderate</td>
<td>several options</td>
</tr>
<tr>
<td>EIGA</td>
<td>low-moderate</td>
<td>moderate</td>
<td>Cast bar stick</td>
</tr>
</tbody>
</table>

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Advantages of inert gas atomization

- Spherical shape
- Low oxygen content
- Good packing characteristics
- Flowability

Applications

Additive Manufacturing
- MIM
- CIP/HIP

Hot Extrusion

Titanium alloys
- Materials
  - Ni-based Superalloys
  - Steels
  - Aluminum alloys

Zirconium

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Electrode Induction-Melting Gas Atomization EIGA

- Ceramic-free atomization process.
- A prealloyed feedstock electrode is lowered into an induction coil.
- Melting takes place at the surface due to the applied induction field.
- This technology can be applied to any material capable of being inductively heated.

**Technical Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bar diameter</td>
<td>30 - 90 mm</td>
</tr>
<tr>
<td>Bar Length</td>
<td>200 - 700 mm</td>
</tr>
<tr>
<td>Production Capacity</td>
<td>150 T/y</td>
</tr>
<tr>
<td>Gas</td>
<td>Argon</td>
</tr>
<tr>
<td>Gas pressure</td>
<td>20-35 bar</td>
</tr>
<tr>
<td>Batch size</td>
<td>5 Kg - 1 T</td>
</tr>
<tr>
<td>Mean particle size (d50)</td>
<td>55 - 70 μm</td>
</tr>
</tbody>
</table>
Commercial titanium based powders

<table>
<thead>
<tr>
<th>Titanium alloys</th>
<th>Titanium aluminides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti Gd1 Gd2</td>
<td>Ti-48Al-2Cr-2Nb</td>
</tr>
<tr>
<td>Ti-6Al-4V, Eli, Eli low</td>
<td>Ti-45Al-2Nb-2Mn (4522XD)</td>
</tr>
<tr>
<td>Ti-6Al-2Sn-4Zr-2Mo</td>
<td>Ti-43,5Al-4Nb-1Mo-0,1B (TNM)</td>
</tr>
<tr>
<td>Ti-6Al-7Nb</td>
<td></td>
</tr>
<tr>
<td>Ti-5Al-5Mo-5V-3Cr</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ti6Al4V</th>
<th>O₂ ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>45-100 µm</td>
<td>600</td>
</tr>
<tr>
<td>&lt;45 µm</td>
<td>800</td>
</tr>
<tr>
<td>&lt;15 µm</td>
<td>3500</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Nb</th>
<th>Cr</th>
<th>O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti-48-2-2 Electrode</td>
<td>33</td>
<td>4,9</td>
<td>2,6</td>
<td>0,03</td>
</tr>
<tr>
<td>Ti-48-2-2 Powder</td>
<td>32,54</td>
<td>4,9</td>
<td>2,61</td>
<td>0,06</td>
</tr>
<tr>
<td>TNM Electrode</td>
<td>28,7</td>
<td>9,2</td>
<td>2,3</td>
<td>0,08</td>
</tr>
<tr>
<td>TNM Powder</td>
<td>28,32</td>
<td>9,09</td>
<td>2,26</td>
<td>0,12</td>
</tr>
<tr>
<td>4522XD Electrode</td>
<td>30,3</td>
<td>4,9</td>
<td>2,41</td>
<td>0,07</td>
</tr>
<tr>
<td>4522XD Powder</td>
<td>30,36</td>
<td>4,83</td>
<td>2,44</td>
<td>0,1</td>
</tr>
</tbody>
</table>

Deviation in the chemical composition

Due to the higher specific area of fine particles, they are more prone to be oxidized.
Particle size and morphology

![Graph showing cumulative value Q3 (%) vs. particle size (µm) for Ti-6Al-4V and Ti-48Al-2Nb-2Cr powders.](image)

Density Ti6Al4V: 4.43 g/cc  
Density Ti 48-2-2: 3.8 g/cc

The physicochemical properties of the material such as density, viscosity and surface tension influence on the resulting particle size.
## Research projects

### National Projects
- Medi-MIM
- GenFly
- REPTIL
- Ti-Foam

### European Projects
- Fantasia
- Impala
- Fast-EBM
- TiAlCharger

## Objectives

- Developing new manufacturing chains and repair techniques for laser metal deposition (LMD)
- Developing flexible and efficient manufacturing processes of custom parts or small batches
- Conservation of resources by reducing gas consumption and increasing the yield of titanium powders
- Developing of fine Titanium powders d50=3 µm
Process parameters influencing on industrial production cost of Ti powders

- **Raw material:** Electrodes are usually manufactured by VAR.
- **Yield desired:** Fine powders are noticeably expensive.
- **Gas consumption:** Argon is required for Ti powder production.
- **Powder quality:** Formation of Satellites and Agglomeration.
Alternative for reducing the production cost

State of the art for EIGA System

Previous works

• Electrode diameter: 50-60 mm
  Flow rate: 0.83 Kg/min
• Electrode diameter: 140 mm
  Flow rate: 1.5 Kg/min
Powder atomized: 1.5-2.5 Kg

Increasing the melt mass flow rate by using electrodes with higher dimensions.
More material will be atomized with the same gas consumption.
To obtain a suitable drip melting, a fine tuning between power supply and induction coil is necessary, as well as lowering the feed rate.

Material atomized: **50 kg**

- Electrode diameter: 55 mm  
  Mass flow rate: 0.6 Kg/min
- Electrode diameter: 90 mm  
  Flow rate: 1.0 Kg/min

Mass flow rates up to 1 Kg/min yield similar particle size distribution.
Influence of mass flow rate on powder quality

Research Activity
Material: Ti6Al4V
Mass flow rate 1 Kg/min
No flowability
Bad packing characteristics
Apparent Density: 2.08 g/cc

Current Production
Material: Ti6Al4V
Mass flow rate 0.6 Kg/min
Flowability: 28 s/50g (ASTM B213)
Good packing characteristics
Apparent Density: 2.38 g/cc

At higher mass flow rates, more particles collide at the atomization zone which induces the formation of satellites.

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Conclusion and Outlook

• For industrial production the use of electrodes with higher dimensions in diameter is an attractive solution for reducing argon consumption, however the powder quality is affected by the higher amount of liquid metal atomized.

• A new configuration in the gas nozzle which allows ejecting the fine particles from the atomization zone will be designed.

• The behavior between mass flow rate and powder morphology regarding other materials like γ-TiAl will be studied.
Thanks for your attention!!