Production of high quality powder from Ti64 scrap – an integrated concept

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² Premium AEROTEC GmbH
1. Introduction
Machining of a workpiece. Resources & Scrap.
Scrap recycling. Production of compacts.
Additive manufacturing & Powder.

2. Electron Beam (EB) melting
EB melting of compacts and electrode withdrawal.
Key aspects of electrode production with EB.

3. Electrode atomization using EIGA
EIGA process & Performed tests.
Powder - particle size, SEM pictures, chemical composition.

4. Conclusions
Material loss during production of a sample workpiece

<table>
<thead>
<tr>
<th>Stage</th>
<th>Scrap</th>
<th>10 kg</th>
<th>100 kg</th>
<th>400 kg</th>
<th>640 kg</th>
<th>40 kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>1190 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melting</td>
<td>10 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forging</td>
<td>100 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-machining</td>
<td>400 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final processing</td>
<td>640 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workpiece</td>
<td>40 kg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

87% of material is turned into machining scrap.
Energy consumption for production of a sample workpiece

- Raw material: 44 MWh
- Melting: 5 MWh
- Forging: 9 MWh
- Pre-machining: 0.5 MWh
- Final processing: 1.5 MWh
- Workpiece: 60 MWh

73% of energy for raw material production
Preparation of scrap compacts

Pre-machining → Scrap material → Control → Purification → Refinement → Production of compacts

Data is kindly provided by AEROTEC

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Additive manufacturing (AM) from powder

**AM advantages**

<table>
<thead>
<tr>
<th>Material consumption</th>
<th>Weight of a part</th>
<th>CO₂ emission /aircraft/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>➔ scrap production</td>
<td>➔ costs per part</td>
<td>➔ weight</td>
</tr>
<tr>
<td>➔ weight</td>
<td>➔ CO₂ footprint</td>
<td>➔ fuel consumption</td>
</tr>
</tbody>
</table>

- conventional machining
- present AM

**AM real applications**

- Bracket
- Cabin
- Door
- Vent Bend (fuel system)
- Bracket Door Frame
- Manifold (feasibility study)

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Additive manufacturing (AM) from powder

**Powder production**

- EIGA – Electrode induction melting for Inert Gas Atomization

**AM real applications**

- Manifold (feasibility study)
- Bracket Door Frame
- Bracket Cabin Door
- Vent Bend (fuel system)

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Scrap \(\rightarrow\) high-quality powder

- minimal number of steps
- no additional scrap production

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Electrode production using EB-cold hearth refining

- Scrap material compacts
- Compacts feeder
- Melting chamber (1.5 \times 10^{-4} mbar)
- EB guns
- Compacts
- Cold refining hearth
- Crucible
- Electrode withdrawal
- Ready-to-atomize electrodes
- 40 min/piece

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EB melter for EIGA electrodes - key features

- Ready-to-use electrodes (no machining needed)
- Vacuum:
  - degassing
  - evaporation of essential volatile elements (solved with composition offset)
- Multiple gun concept – cold hearth refining
- Single gun concept – direct solidification into crucible
- Production of EIGA electrodes with
  - length < 2 m & diameter < 150 mm
- Multiple electrode withdrawal for increased productivity
- Ingot chamber concept for up to 16 electrodes before onload
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- Ceramic-free
- Robust, simple & reproducible
- Direct conversion (electrode → powder)
- High reliability
- High productivity (short cycle times)

EIGA
Simulation assisted design of induction coils:
- refractory metals (Nb, Ta)
- scale-up solutions (e.g. φ 150 mm Ti64)
EIGA (scale-up & reduction of production costs)

- Increased productivity (increasing demand for EIGA powder)
- Substantial powder production cost savings
- Semi-automatic electrode exchange system required

<table>
<thead>
<tr>
<th>Performance data for different EIGA models</th>
<th>EIGA 50-500</th>
<th>EIGA 100-1000</th>
<th>EIGA 150-1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max. electrode dimensions mm * mm</td>
<td>50 * 500</td>
<td>100 * 1000</td>
<td>150 * 1000</td>
</tr>
<tr>
<td>Charge weight (TiAl&lt;sub&gt;6&lt;/sub&gt;V&lt;sub&gt;4&lt;/sub&gt;) kg</td>
<td>4.4</td>
<td>33.4</td>
<td>74.3</td>
</tr>
<tr>
<td>Nominal melt power kW</td>
<td>60</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>Melt rate kg / min</td>
<td>0.5</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Atomization time min</td>
<td>9</td>
<td>23</td>
<td>30</td>
</tr>
<tr>
<td>Total cycle time min</td>
<td>15</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>Specific Argon consumption m³ / kg</td>
<td>24</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>Annual powder production t</td>
<td>70</td>
<td>250</td>
<td>400</td>
</tr>
</tbody>
</table>

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EIGA – atomization of EB-recycled electrodes

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Production of high quality powder from Ti64 scrap: particle size distribution

Particle size distribution has been obtained using Dynamic Image Analysis (EIGA).

- EIGA typical particle size range for Ti-alloys: $50 \, \mu m \leq d_{50} \leq 120 \, \mu m$
- $d_{50}$ is within acceptable range and can be reduced by tuning the process parameters

Particle volumetric fraction

- 10%: $d_{10} < 30.4 \, \mu m$
- 50%: $d_{50} < 78.0 \, \mu m$
- 90%: $d_{90} < 167.4 \, \mu m$

Particle diameter $d$

Powder from the scrap: particle size distribution

$10\%$: $d_{10} < 30.4 \, \mu m$
$50\%$: $d_{50} < 78.0 \, \mu m$
$90\%$: $d_{90} < 167.4 \, \mu m$
Powder from the scrap: *SEM pictures*

- Spherical morphology
- Super-clean, ceramic-free
- Rapid solidification, homogeneous microstructure
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Chemical analysis:
- Samples from each process step have been sent to two independent laboratories
- **Instrumental Gas Analysis (IGA)** for gas-forming elements (C, H, O, N)
- **Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES)** for metallic elements (V, Fe, Al)

<table>
<thead>
<tr>
<th>Process step:</th>
<th>Powder from the scrap: chemical composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Scrap</td>
<td></td>
</tr>
<tr>
<td>2. EB skull</td>
<td></td>
</tr>
<tr>
<td>3. Electrode</td>
<td></td>
</tr>
<tr>
<td>4. Powder</td>
<td></td>
</tr>
</tbody>
</table>

Loss/gain of elements*%

*referenced to the scrap initial composition

**AVERAGE**

<table>
<thead>
<tr>
<th></th>
<th>V, wt%</th>
<th>ΔV, %</th>
<th>Fe, wt%</th>
<th>ΔFe, %</th>
<th>Al, wt%</th>
<th>ΔAl, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4.29</td>
<td>0</td>
<td>0.227</td>
<td>0</td>
<td>6.60</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>4.38</td>
<td>2</td>
<td>0.220</td>
<td>-3</td>
<td>5.17</td>
<td>-22</td>
</tr>
<tr>
<td>3</td>
<td>4.37</td>
<td>2</td>
<td>0.221</td>
<td>-3</td>
<td>4.83</td>
<td>-27</td>
</tr>
<tr>
<td>4</td>
<td>4.38</td>
<td>2</td>
<td>0.219</td>
<td>-4</td>
<td>5.20</td>
<td>-21</td>
</tr>
</tbody>
</table>

**AVERAGE**

<table>
<thead>
<tr>
<th></th>
<th>C, ppm</th>
<th>ΔC, %</th>
<th>N, ppm</th>
<th>ΔN, %</th>
<th>O, ppm</th>
<th>ΔO, %</th>
<th>H, ppm</th>
<th>ΔH, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>636</td>
<td>0</td>
<td>97</td>
<td>0</td>
<td>2440</td>
<td>0</td>
<td>66</td>
<td>0</td>
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<tr>
<td>2</td>
<td>752</td>
<td>18</td>
<td>80</td>
<td>-18</td>
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<td>3</td>
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<td>18</td>
<td>78</td>
<td>-20</td>
<td>3362</td>
<td>38</td>
<td>9</td>
<td>-87</td>
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<td>4</td>
<td>761</td>
<td>20</td>
<td>55</td>
<td>-43</td>
<td>3101</td>
<td>27</td>
<td>3</td>
<td>-95</td>
</tr>
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Loss/gain of elements* %
*referenced to the scrap initial composition

- **O**
- **C**
- **V**
- **Fe**
- **Al**
- **N**
- **H**

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How good small test probes represent the scrap composition?
Inhomogeneity of the scrap - (e.g. O(1): 3100, 4500, 2210, 2090 ppm)
More integral measurement of O and C in the scrap is required.

Almost no change for heavier composition elements
Evaporation of volatile composition element (solved by the initial composition offset)
Degassing of light elements in vacuum
Conclusions

It has been shown that the Ti64 scrap can be recycled into a high-quality spherical powder using only two steps:

1. Preparation of electrodes using the EB-furnace
2. Atomization of electrodes in EIGA process

with minimal machining of the tip and almost no scrap production;

The recycling route has a potential for the further scale-up and substantial reduction of the powder production costs;

Further improvements of the recycling cycle (finer powder, précised chemical composition) will be achieved.
Thank You for attention!