Production of TiAl alloys

Melissa Allen, Volker Güther
GfE Metalle und Materialien GmbH, Nuremberg (Germany)

Titanium Europe 2018, Sevilla (Spain), May 14th – 16th, 2018
Outline

1. Introduction
2. Production technologies of TiAl alloys
3. Production technologies of TiAl based semi-finished products
4. Recycling technologies of TiAl
5. Summary
Introduction

**GEnx aircraft engine family (GE)**
- 2011 into commercial service
- $\gamma$-TiAl in last stage of LPT
- Ti 48Al -2Cr -2Nb (at.-%)
- Production route: casting

**PurePower PW100G family (PW)**
- 2016 into commercial service
- $\gamma/\beta$-TiAl in last stage of LPT
- Ti 43,5Al -4Nb -1Mo -0,1B (at.-%)
- Production route: forging

**LEAP engine family (CFM)**
- 2016 into commercial service
- $\gamma$-TiAl in last stage of LPT
- Ti -48Al -2Cr -2Nb (at.-%)
- Production route: casting
Introduction

Challenges

- properties depend extremely on microstructure and, thus, on local chemical composition
  → outstanding low deviation of alloying elements (e.g. 30,0 +/- 0,5 wt.-% Al)

- intermetallic materials are very sensitive against interstitial impurities
  → processing under vacuum
  → processing in cold hearth furnaces only

- conventional wrought processing such as forging and rolling not applicable

Metallurgical processing to small sized feed stocks / semi-finished products
Outline

1. Introduction

2. Production technologies of TiAl alloys

3. Production technologies of TiAl based semi-finished products

4. Recycling technologies of TiAl

5. Summary
Basically, Ti-alloy ingot production technologies are applicable to γ-TiAl
Vacuum Arc Remelting (VAR) of compacted consumable electrodes to ingots

positioning of consumable electrodes into the VAR crucible

**VAR L300 (ALD)**

Even triple melted VAR ingots do not exhibit the homogeneity which is required for γ-TiAl products
Outline

1. Introduction
2. Production technologies of TiAl alloys
3. Production technologies of TiAl based semi-finished products
4. Recycling technologies of TiAl
5. Summary
Production of $\gamma$-TiAl semi-finished parts

There is a demand for small sized parts of outstanding homogeneity only

- feed stocks for investment casting
- feed stocks for forging, rolling, extrusion pressing
- parts for direct mechanical machining
- electrodes for gas atomization
Production of \(\gamma\)-TiAl semi-finished parts

**GfE's approved solution:**
Remelting of VAR ingots in a VAR skull melter and subsequent centrifugal casting in permanent molds

**Centrifugal casting**
Based on casting wheels
With permanent moulds
Production of $\gamma$-TiAl semi-finished parts

VAR ingot as consumable electrode

remaining skull in the crucible
Production of $\gamma$-TiAl semi-finished parts

Homogeneity exceeds by far the homogeneity of ingots or extrusions

<table>
<thead>
<tr>
<th>heat 103959 - TNM</th>
<th>No.</th>
<th>Pos.</th>
<th>A-Nr.</th>
<th>Ti</th>
<th>Al</th>
<th>Nb</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>B</td>
<td>193560</td>
<td>59,45</td>
<td>28,90</td>
<td>9,03</td>
<td>2,32</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>B</td>
<td>193561</td>
<td>59,40</td>
<td>28,85</td>
<td>9,08</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>B</td>
<td>193562</td>
<td>59,45</td>
<td>28,85</td>
<td>9,07</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>B</td>
<td>193563</td>
<td>59,50</td>
<td>28,85</td>
<td>9,13</td>
<td>2,36</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>B</td>
<td>193564</td>
<td>59,45</td>
<td>28,85</td>
<td>9,02</td>
<td>2,32</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>B</td>
<td>193565</td>
<td>59,45</td>
<td>28,85</td>
<td>9,06</td>
<td>2,33</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>B</td>
<td>193566</td>
<td>59,40</td>
<td>28,85</td>
<td>9,06</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>B</td>
<td>193567</td>
<td>59,50</td>
<td>28,80</td>
<td>9,07</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>B</td>
<td>193568</td>
<td>59,55</td>
<td>28,85</td>
<td>9,05</td>
<td>2,33</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>B</td>
<td>193569</td>
<td>59,60</td>
<td>28,80</td>
<td>9,12</td>
<td>2,36</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>B</td>
<td>193570</td>
<td>59,55</td>
<td>28,80</td>
<td>9,10</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>B</td>
<td>193571</td>
<td>59,55</td>
<td>28,80</td>
<td>9,10</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>B</td>
<td>193572</td>
<td>59,55</td>
<td>28,80</td>
<td>9,11</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>B</td>
<td>193573</td>
<td>59,55</td>
<td>28,80</td>
<td>9,10</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>B</td>
<td>193574</td>
<td>59,55</td>
<td>28,80</td>
<td>9,11</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>B</td>
<td>193575</td>
<td>59,60</td>
<td>28,80</td>
<td>9,06</td>
<td>2,33</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>B</td>
<td>193576</td>
<td>59,55</td>
<td>28,85</td>
<td>9,07</td>
<td>2,33</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>B</td>
<td>193577</td>
<td>59,55</td>
<td>28,80</td>
<td>9,09</td>
<td>2,34</td>
<td></td>
</tr>
</tbody>
</table>

**AV**

<table>
<thead>
<tr>
<th>Ti</th>
<th>Al</th>
<th>Nb</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>59,51</td>
<td>28,83</td>
<td>9,08</td>
<td>2,34</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>heat 103959 - TNM</th>
<th>No.</th>
<th>Pos.</th>
<th>A-Nr.</th>
<th>Ti</th>
<th>Al</th>
<th>Nb</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>H</td>
<td>194159</td>
<td>59,55</td>
<td>28,80</td>
<td>9,11</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>H</td>
<td>193578</td>
<td>59,55</td>
<td>28,80</td>
<td>9,09</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>H</td>
<td>194160</td>
<td>59,55</td>
<td>28,80</td>
<td>9,12</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>H</td>
<td>194161</td>
<td>59,55</td>
<td>28,75</td>
<td>9,13</td>
<td>2,36</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>H</td>
<td>194162</td>
<td>59,60</td>
<td>28,75</td>
<td>9,12</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>H</td>
<td>194163</td>
<td>59,60</td>
<td>28,80</td>
<td>9,09</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>H</td>
<td>194164</td>
<td>59,55</td>
<td>28,75</td>
<td>9,14</td>
<td>2,36</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>H</td>
<td>194165</td>
<td>59,50</td>
<td>28,85</td>
<td>9,08</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>H</td>
<td>194166</td>
<td>59,50</td>
<td>28,85</td>
<td>9,07</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>H</td>
<td>193579</td>
<td>59,55</td>
<td>28,80</td>
<td>9,08</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>H</td>
<td>194167</td>
<td>59,50</td>
<td>28,85</td>
<td>9,09</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>H</td>
<td>193580</td>
<td>59,55</td>
<td>28,80</td>
<td>9,11</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>H</td>
<td>194168</td>
<td>59,50</td>
<td>28,90</td>
<td>9,08</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>H</td>
<td>194169</td>
<td>59,50</td>
<td>28,85</td>
<td>9,07</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>H</td>
<td>194170</td>
<td>59,55</td>
<td>28,85</td>
<td>9,08</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>H</td>
<td>194171</td>
<td>59,50</td>
<td>28,85</td>
<td>9,09</td>
<td>2,35</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>H</td>
<td>194172</td>
<td>59,50</td>
<td>28,85</td>
<td>9,08</td>
<td>2,34</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>H</td>
<td>193581</td>
<td>59,55</td>
<td>28,80</td>
<td>9,09</td>
<td>2,34</td>
<td></td>
</tr>
</tbody>
</table>

**AV**

<table>
<thead>
<tr>
<th>Ti</th>
<th>Al</th>
<th>Nb</th>
<th>Mo</th>
</tr>
</thead>
<tbody>
<tr>
<td>59,54</td>
<td>28,82</td>
<td>9,10</td>
<td>2,35</td>
</tr>
</tbody>
</table>

- Analysis at the bottom of 18 slugs per pour
- Analysis at the head of 18 slugs per pour

Privileged & Confidential
Production of $\gamma$-TiAl semi-finished parts

- cast cylindrical slugs
- remelt stocks
- investment cast LPT blade
Production of $\gamma$-TiAl semi-finished parts

cast cylindrical slugs \quad HIP and machining to forging stocks \quad hot die forging to oversized parts
Production of $\gamma$-TiAl semi-finished parts

- cast cylindrical slugs
- HIPed machining stocks are being segmented
- direct machining to final turbocharger
Production of $\gamma$-TiAl semi-finished parts

- Cast and HIPed cylindrical slugs
- Hot rolling
- Machining to TiAl sheets
Production of $\gamma$-TiAl semi-finished parts

- cast EIGA electrodes
- EIGA processing to powder
Production of $\gamma$-TiAl semi-finished parts

cast and HIPed cylindrical slugs  \rightarrow  segmented slugs  \rightarrow  back extruded valve blanks
1. Introduction

2. Production technologies of TiAl alloys

3. Production technologies of TiAl based semi-finished products

4. Recycling technologies of TiAl

5. Summary
TiAl recycling: materials processing chain

processing at GfE

subsequent processing to products

cylindrical / rectangular slugs
- as-cast
- HIP, thermal treatments*
- surface machined*
- diam. up to 120 mm*
- length up to 600 mm*

*on request
TiAl recycling: origin of revert

funnel / tundish revert
insufficiently filled slugs
feeders
crushed casting plate
crushed casting crown
TiAl recycling: via Induction Skull melting

single step conversion of revert to slugs by applying VAR SM centrifugal casting technology to ISM processing
TiAl recycling: Induction Skull Melting (ISM)

- Basic layout

LEICOMELT 22 (ALD Vacuum Technologies)
- Power 1.300 kVA
- Max pouring weight up to 90 kg
TiAl recycling: ISM processing

ISM furnace after pouring

remaining skull in the crucible
Outline

1. Introduction
2. Production technologies of TiAl alloys
3. Production technologies of TiAl based semi-finished products
4. Recycling technologies of TiAl
5. Summary
Summary

1. $\gamma$-TiAl production is a very complex system
   → GfE has developed and industrialized a unique production process based on VAR, VAR SM and ISM
   → realized with melting equipment from ALD Vacuum Technologies

2. Different applications require specific treatments after the casting process (HIP, machining, heat treatments,…)

3. The capability for the recycling of valuable revert is mandatory for economical and environmental reasons

4. GfE is going to extend the TiAl product portfolio with atomized powders for AM Technologies (EBM, SLM) in 2018