Superplastic Forming Properties of TIMETAL®54M

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Outline

- Brief Introduction of TIMETAL®54M (Ti-54M)
- Key Factors for Superplastic Formability of Titanium Alloys
- Superplastic Properties of Ti-54M
  - SPF Temperature, Elongation, Flow Stress, Strain Rate, Strain Rate Sensitivity
- Evaluation (Examples)
- Summary
Ti-54M was developed by TIMET in 2003.


The alloy possesses superior machinability to Ti-6Al-4V under most of machining conditions.

General mechanical properties are equivalent to those of Ti-64.

Ti-54M can be produced through Electron Beam Single Melt Process (EBSM), as well as multiple VAR melting.

More than 260MT of Ti-54M has been produced for Automotive forgings.

Various product forms such as billet, bar, plate, sheet and extrusions have been produced for trials and evaluations.
Characteristics of Ti-54M Alloy

- Typical Chemistry
  Ti-5%Al-4%V-0.7%Mo-0.5%Fe
- Beta Transus: 1720~1770°F (938~966°C)
- Alloys Design Philosophy

- **Lower Al** --- Improved forgeability and machinability
- **Mo addition** --- Alpha grain refinement
- **Fe addition** --- Diffusion Acceleration. Limited addition to avoid a risk of beta fleck
- **Low Beta Transus** --- Low flow stress at elevated temperatures
### Alpha/Beta Titanium Alloys (Commercial)

<table>
<thead>
<tr>
<th>Alloys</th>
<th>Al</th>
<th>V</th>
<th>Mo</th>
<th>Fe</th>
<th>Cr</th>
<th>Sn</th>
<th>Zr</th>
<th>Nb</th>
<th>Si</th>
<th>T Beta</th>
<th>SPF Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti-834</td>
<td>5.8</td>
<td>0.5</td>
<td></td>
<td></td>
<td>4</td>
<td>3.5</td>
<td>0.7</td>
<td>0.3</td>
<td></td>
<td>1915 F (1046C)</td>
<td>~1825 F</td>
</tr>
<tr>
<td>Ti-367</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
<td></td>
<td></td>
<td>1850 F (1028C)</td>
<td>~1650 F</td>
</tr>
<tr>
<td>Ti-64</td>
<td>6</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1830 F (1000C)</td>
<td>1455 ~1725 F</td>
</tr>
<tr>
<td>Ti-62222</td>
<td>6</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td>0.2</td>
<td></td>
<td></td>
<td>1805 F (985C)</td>
<td>1475 ~1725 F</td>
</tr>
<tr>
<td>Ti-550</td>
<td>4</td>
<td>4</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>0.5</td>
<td></td>
<td>1785 F (974C)</td>
<td>1490 ~1706 F</td>
</tr>
<tr>
<td>SP700</td>
<td>4.5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1660 F (904C)</td>
<td>1400~1475 F</td>
</tr>
<tr>
<td>Ti-54M</td>
<td>5</td>
<td>4</td>
<td>0.6</td>
<td>0.4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1740 F (949C)</td>
<td></td>
</tr>
</tbody>
</table>

- Lower beta transus alloys exhibit SPF at lower temperatures.
- SPF temperatures vary depending on “grain size”, “strain rate” and chemical composition.
SPF Requirement

- Larger m Values
  - m > 0.5 preferred
- Lower SPF Temperature
  - Longer tool life
  - Reduce surface contamination (alpha-case)
  - Suppress grain growth
- Higher Elongation
  - > 500% preferred
- Lower Flow Stress
  - Thicker gage can be applied
- Higher Strain Rate SPF Capability
  - Increase in productivity
  - Reduce contamination
Optimum Material

- Finer Grain Size
- Optimum Volume Fraction ($\alpha / \beta$)
- Higher $\alpha / \beta$ Grain Boundary Area Per Unit Volume
  
  \[\text{Accelerate grain boundary sliding}\]

- Lower Beta Transus
  - Low temperature SPF potential
  - Grain refinement of material

- Effective Alloying Element
  - Fast diffusers --- Fe, Ni, Co etc
  - Grain refinement --- Mo etc

- Producibility
  - Less segregation
  - Alternative melting (EBSM, EB-VAR etc)
• Material gages
  0.050” (1.27-mm)

• Chemical Composition (sheet analysis, wt%)

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>V</th>
<th>Mo</th>
<th>Fe</th>
<th>C</th>
<th>O</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.94</td>
<td>3.83</td>
<td>0.55</td>
<td>0.45</td>
<td>0.018</td>
<td>0.15</td>
<td>0.007</td>
</tr>
</tbody>
</table>

• RT Tensile Properties

<table>
<thead>
<tr>
<th>Orient.</th>
<th>0.2% TYS</th>
<th>UTS</th>
<th>Elongation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MPa</td>
<td>ksi</td>
<td>MPa</td>
</tr>
<tr>
<td>Avg. L</td>
<td>845</td>
<td>123</td>
<td>926</td>
</tr>
<tr>
<td>Avg. T</td>
<td>879</td>
<td>127</td>
<td>944</td>
</tr>
</tbody>
</table>

• ASTM E2448-06 (for sheet specimens)
• Flow stress and strain rate sensitivity (m-value)
• 20% of strain rate jump at every 0.1 of true strain.
Microstructure - Ti-54M

Ti-54M Regular Grain and Fine Grain

Average d\(\alpha\) 11 \(\mu m\)

Average d\(\alpha\) 7 \(\mu m\)

Average d\(\alpha\) 2~3 \(\mu m\)
Elevated Temp Tensile Test - Ti-54M

Ti-54M Regular Grain and Fine Grain

Microstructure after the test

Grip area

Reduced section
Jump Strain Rate Tests on Ti-54M Regular Grain (~11 µm)

Strain Rate: 5x 10^{-4}/S

True Stress (ksi)

MPa

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

0 2 4 6 8 10 12 14

Strain Rate: 5x10-4/S

1350F(732C)

1400F(760C)

1450F(788C)

1500F(816C)

1550F(843C)

1650F(899C)
Flow Curves - Ti-54M

Jump Strain Rate Tests on Ti-54M Fine Grain (2~3µm)

Strain rate: $5 	imes 10^{-4}$/sec

True Stress, ksi

True Stress, MPa

1250F (677C)

1300F (704C)

1350F (732C)

1400F (760C)

1450F (788C)

1500F (816C)
## Summary of SPF Tests

### Comparison of Flow Stress and m-value of Ti-54M and Ti-64

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Ti-54M</th>
<th>Ti-64</th>
<th>Ti-54M Fine Grain</th>
<th>Ti-64 Fine Grain</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow Stress (ksi) at 0.2 true strain</td>
<td>Avg. m-value</td>
<td>Flow Stress (ksi) at 0.2 true strain</td>
<td>Avg. m-value</td>
</tr>
<tr>
<td>1650°F (899°C)</td>
<td>1650ºF (899ºC)</td>
<td>2.72</td>
<td>0.53</td>
<td>2.72</td>
</tr>
<tr>
<td>1600°F (871°C)</td>
<td>1600°F (871°C)</td>
<td>2.73</td>
<td>0.54</td>
<td>2.73</td>
</tr>
<tr>
<td>1550°F (843°C)</td>
<td>1550°F (843°C)</td>
<td>2.30</td>
<td>0.63</td>
<td>4.12</td>
</tr>
<tr>
<td>1500°F (816°C)</td>
<td>1500°F (816°C)</td>
<td>3.41</td>
<td>0.68</td>
<td>4.97</td>
</tr>
<tr>
<td>1450°F (788°C)</td>
<td>1450°F (788°C)</td>
<td>4.25</td>
<td>0.60</td>
<td>7.22</td>
</tr>
<tr>
<td>1400°F (760°C)</td>
<td>1400°F (760°C)</td>
<td>5.92</td>
<td>0.61</td>
<td>2.84</td>
</tr>
<tr>
<td>1350°F (732°C)</td>
<td>1350°F (732°C)</td>
<td>7.89</td>
<td>0.57</td>
<td>4.33</td>
</tr>
<tr>
<td>1300°F (704°C)</td>
<td>1300°F (704°C)</td>
<td>5.97</td>
<td>0.47</td>
<td>10.17</td>
</tr>
<tr>
<td>1250°F (677°C)</td>
<td>1250°F (677°C)</td>
<td>8.82</td>
<td>0.55</td>
<td>11.67</td>
</tr>
</tbody>
</table>
Flow stress of fine grain Ti-54M is 1/3~1/4 of Ti-64, which can be an advantage in design and production of SPF parts.
Evaluations – SPF Capability

Timet T54M - Evaluation of sample sheets.
SPF Temperatures: 800°C (1472°F)

Courtesy of Aeromet International PLC
# Evaluations – Hot Forming Test

Timet T54M - Evaluation of sample sheets.

<table>
<thead>
<tr>
<th>Sample Temperature</th>
<th>Operation</th>
<th>Results</th>
<th>Alpha Case - inches - after forming</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>350 °C</td>
<td>2 off each Longitudinal and Transverse bends at 3T bends</td>
<td>Forming successful - no cracking - no springback</td>
</tr>
<tr>
<td>720 °C</td>
<td>1 off 'V' forming over 2.5T bend</td>
<td>Forming successful - no cracking</td>
<td>NA</td>
</tr>
</tbody>
</table>

Sample parts and hot form tooling

Courtesy of Aeromet International PLC
• Ti-54M shows superior superplastic forming properties compared to Ti-64.

• SPF of Ti-54M can be performed at temperatures as low as 1450°F (788°C) and further development work indicates that SPF temperature can be as low as 1350°F (732°C) with finer gains.

• Side by side test of SPF capability between Ti-54M and Ti-64 indicated a clear difference at 800°C.

• Ti-54M sheet exhibit satisfactory results in hot forming test as well.

• Scale up test is underway and a joint development program will commence in 4Q 2010.
MAI Project on SPF/DB of Titanium Alloy Sheets

- A three-year program from 2010~2013.
- TIMET leads the program partnered with OEM’s.
- Ti-54M is a central material of the project. Other alloys will be studied as well.
- Full size parts will be fabricated for demonstration.