Challenges of Machining Beta Titanium Alloy

Dr. S. Treiber and Dr. E. Ng
McMaster University

Presented by Dr. E. Ng
Titanium in Commercial Aircraft

Body Structure & Wings:
- Aluminum
- Titanium
- Composites

Engine:
- Titanium
- Ni-Alloys

Landing Gears:
- Stainless Steel
- Titanium
Landing Gear Components

- Titanium 10-2-3
- 300M Steel
Importance of Titanium in Aerospace

• Designers have switched to Titanium for load bearing components because Titanium is less dense and in the case of $\beta$ Alloys, stronger than steel

• Over time landing gear components have switched to $\alpha\beta$ Alloys such as Ti 10-2-3 and now to $\beta$ Alloys such as Ti 555-3

• The challenge for manufacturers is that manufacturing these components out of Titanium is much more expensive than Steel
Titanium Alloy Structure

Hexagonal Closed Packed

- 880°C / 1620°F

Body Centered Cubic

Alpha structure
- Lower density
- Lower strength
- Higher creep strengths
- Improved machine ability

Ti-6Al-4V

Beta structure
- Higher density
- Higher strength
- Lower creep strengths
- Poor machine ability

Ti-10V-2Fe-3Al

Ti-5Al-2.5Sn

Materials:
- Ti-5Al-2.5Sn
- Ti-6Al-4V
- Ti-10V-2Fe-3Al
Objective

• Identify the best tooling and best machining strategies for manufacturing landing gear components

• Five major carbide tool manufacturers from Sweden and USA, participated in this experimental analysis
Facilities at McMaster University

- Analysis equipments; Piezo electric dynamometer (6), tools’ maker microscope, scanning electron microscope, surface roughness measurement, residual stress measurements, co-ordinate measuring machine, fatigue testing facilities, high speed computing facilities, etc.

Matsuura LX-1
60,000 rpm, 6 HP, 90 m min\(^{-1}\)

Makino MC 56-5XA
15,000 rpm, 40 HP, 15 m min\(^{-1}\)

Okuma Cadet-Mate
8,000 rpm, 15 HP, 20 m min\(^{-1}\)

Okuma Crown-S
3,500 rpm, 24 HP, 20 m min\(^{-1}\)

Nakamura SC450
2,500 rpm, 40 HP, 12 m min\(^{-1}\)

Flow AF-6080, 5-Axis, Head speed : 15 m min\(^{-1}\), Pressure : 60,000 psi
Strategy

• Design a test part that has key features of components made of β-Alloy Titaniums

• Using base case tooling and strategies cut the part while measuring forces, tool wear, deflection and surface finish

• Try different tooling and cutting strategies and compare material removal, forces, tool wear, deflection and surface finish
Purchased Ti 555-3
Step 1 - Conduct Research on Ti 555-3

- We conducted some basic research on tool life.
- In machining, the strain rate attainable can be as high as $10^5$ s$^{-1}$ and the maximum strain of 500% to 700% can be observed.
Relative Tool Life on Hard Workpiece Materials

- Cast Iron
- Carbon steel
- Alloy steel
- Austenitic SS
- αβ Alloy Titanium
- Nickel based alloys
- B Alloy Titanium
- Cobalt based alloys

Tool Life

HRC 52
HRC 32
HRC 35
Tool Life Relative to Ti 6Al 4V

The chart compares tool life relative to Ti 6Al 4V for different materials:
- **Ti 6AL4V** shows the highest tool life.
- **Ti 10-2-3** has moderate tool life.
- **Ti 5553** has the lowest tool life.

The tool life values are indicated by the height of the bars.
Metal Cutting Characteristics of Titanium Alloys

Tool Life is Shorter than with Much Harder Metals Due to:

- High thermal loads on cutting edge due to the relatively low thermal conductivity of titanium.
- More sensitive to strain hardening compared to Ti-6Al-4V.

\[ \overline{\sigma}_{JC2} = [A + B(\bar{\varepsilon})^n] \]

<table>
<thead>
<tr>
<th>Material</th>
<th>A</th>
<th>B</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti5553</td>
<td>1250</td>
<td>403</td>
<td>0.47</td>
</tr>
<tr>
<td>Ti64</td>
<td>783</td>
<td>498</td>
<td>0.28</td>
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</tbody>
</table>

- Solution: COOLANT: Appropriate type of coolant, concentration of coolant, flowrate, pressure and delivery method.
Metal Cutting Characteristics of Titanium Alloys

Tool Life is Shorter than with Much Harder Metals Due to:

- Titanium is chemically reactive with cutting tool materials at high temperatures.

- Solution: TOOL COATING: Type of Material, configuration (Mono, Multi-layer)

<table>
<thead>
<tr>
<th>Mono-layer</th>
<th>Thickness</th>
<th>Products</th>
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<tbody>
<tr>
<td>Substrate</td>
<td>0.5 – 50 µm</td>
<td>Balinit® A (TiN)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balinit® D (CrN)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Balinit® X.Treme (TiAlN)</td>
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<table>
<thead>
<tr>
<th>Multi-layer (nano-structure)</th>
<th>Thickness</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate</td>
<td>100 nm /layer</td>
<td>Balinit® FUTURA NANO (TiAlN)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supercote 11 (TiAlNCrYN)</td>
</tr>
</tbody>
</table>
Metal Cutting Characteristics of Titanium Alloys

Tool Life is Shorter than with Much Harder Metals Due to:

• Titanium tends to weld on the tool rake face.

• Solution: Coolant, Force Reduction (rake angle, coating, control cutting edge radius and thickness of coating), must avoid machining strain hardened surface.
Metal Cutting Characteristics of Titanium Alloys

Tool Life is Shorter than with Much Harder Metals

Due to:

• Titanium generates a cyclic or segmental chip formation.

• Solution: SLOW DOWN, carbide substrate must have both toughness and hardness to withstand cyclic loading.
Metal Cutting Characteristics of Titanium Alloys

Tool Life is Shorter than with Much Harder Metals Due to:

• Due to all of forgoing generates high forces

• Solution: Rigid Fixturing is Critical (Forces can be large enough to warp clamps)

• Proper cutter path strategy. Helical or trochoidal milling. Such milling strategies can lower cutting forces.
Compare Results

• Metal removal rates
• Tool life
• Forces
• Surface Finish
Conclusions

• We found that from benchmark tests with Ti5553
  – Material removal rates could increase by 1/3
  &
  – Tool life could be increased by >100%
  &
  – Forces could be reduced by 30%
• Move measurement equipment (dynamometer and microscope) and workpiece to plant milling machine....