Enabling Lightweight, High Load Aero-Bearings

A. Fox (email: andy.fox@tecvac.com), J.C. Avellar-Batista Wilson, S. Banfield, B. Karadi, H. Vaghela, P. Smith, G. Cassar, A. Leyland, A. Matthews, J. Housden

A Tevac Ltd, Swavesey, Cambridge, UK; b Airbus UK, Filton, Bristol, UK; c NMB-Mineba UK Ltd, Lincoln, UK; d The University of Sheffield, Department of Engineering Materials, Sheffield, UK

Introduction

Titanium and its alloys are widely used in many industries as they possess a range of desirable properties such as high specific strength and low density. However, their use in engineering applications has been severely restricted due to poor tribological properties. Metal-to-metal aircraft bearings must be wear, corrosion and fatigue resistant. Titanium alloy tends to gall quickly under high loads.

To overcome this problem, a range of diffusion-based treatments has been investigated and various tests employed by Airbus, NMB-Mineba, Tecvac and the University of Sheffield were used to rank their effectiveness.

Aerospace Benefits

Metal-to-metal aerospace landing gear spherical bearings use stainless steel and copper alloys for the inner and outer races. The replacement of these materials by lightweight titanium bearings offers:

- Significant weight-saving
- Reduced fuel consumption
- Reduced take-off weight
- Increased range
- Decreased carbon footprint

Assuming a 20 year aircraft lifespan, if a 500kg weight saving is achieved (possible by replacing all landing gear with titanium alternatives) fuel savings amounting to £7.6 million can be made over the lifetime of an aircraft (based on data from 2009) hence there is a strong revenue-driven argument to investigating such alternatives.

Aims

To combat this, triode plasma treatments (TPT) – nitriding and/or oxidation – combined with plasma-assisted electron beam physical vapour deposited (EBPVD) coatings were applied to Ti6Al4V alloy bearings and tested to improve the tribological properties without impairing the fatigue life of the base material. A key objective identified by Airbus was for the treatment to withstand 220MPa based on FEA of existing bearing designs.

Methods

Diffusion and duplex treatments were tested against control surfaces of uncoated Ti6Al4V. Triode plasma nitriding (TPN) and triode plasma oxy-nitriding (TPON) were carried out at 700°C for up to 4 hours’ diffusion time. TPT-1 processes were 240 mins with a substrate bias of ~200V. TPT-2 processes were 180 mins at 200V and 60 mins at ~1000V. Commercial EB-PVD TiN and CrAIN coatings were deposited on untreated and TPT test discs and bushes below 500°C.

Characterisation

Diffusion depth of nitride and oxy-nitride treatments were measured by Knoop microhardness measurements on polished cross-sections under a load of 0.245N (25 g). Coating thickness was measured using the ball crater method. Post-treatment surface roughness was measured on all samples using stylus surface profilometer.

Results & Discussion

The Knoop indentation profile is shown in fig. 1 (above). Unlike the TPN diffusion zone, TPON possesses two zones: one exhibiting reduction comparable to TPN and a secondary diffusion zone 10–20µm in depth with a level hardness profile. In both cases, such thick diffusion layers enhance the load support of Ti6Al4V.

Fig. 2 (above, right) shows the output of the FEA of the bush test, which revealed that the pressure at the centre of the bush was 150MPa and at the edge a pressure of 230MPa.

These values were in excess of the 100MPa calculated using projected area analysis with a 50KN load. Coupled with the bush test failure load results (Table 1, left) we found that CrAIN with TPON-2 passed the test at the highest load.

Table 1: Key process characteristics

<table>
<thead>
<tr>
<th>Treatment/Material</th>
<th>Roughness (Rz ± 0.01)</th>
<th>Treatment Thickness (µm)</th>
<th>Bush test failure load (kN)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti6Al4V</td>
<td>0.04</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>TiN</td>
<td>0.03</td>
<td>2.8 ± 0.2</td>
<td>10</td>
</tr>
<tr>
<td>CrAIN</td>
<td>0.02</td>
<td>1.9 ± 0.1</td>
<td>-</td>
</tr>
<tr>
<td>Nitro+ TiN</td>
<td>0.05</td>
<td>15-20</td>
<td>15</td>
</tr>
<tr>
<td>TPN+1 + TiN</td>
<td>0.05</td>
<td>30-40</td>
<td>25</td>
</tr>
<tr>
<td>TPN+2 + CrAIN</td>
<td>0.05</td>
<td>20-30</td>
<td>2.9 ± 0.2</td>
</tr>
<tr>
<td>TPON+1 + CrAIN</td>
<td>0.05</td>
<td>35-40</td>
<td>2.3 ± 0.1</td>
</tr>
<tr>
<td>Survived to 60kN</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPON+2 + CrAIN</td>
<td>0.06</td>
<td>35-40</td>
<td>2.2 ± 0.2</td>
</tr>
<tr>
<td>Survived to 60kN</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Reciprocating wear tests are shown in figs. 3, 4 and 5 (left).

Fig. 3 plots the average volume loss of the untreated and treated test samples at a 4N load (0.7gPa) against a WC counterface over increasing distances. It was observed that the treated samples greatly surpassed the Ti6Al4V control samples.

Fig. 4 shows the same but with a greater applied load ~ 13.5N (1.0gPa). All samples demonstrated more rapid volume loss. However, all CrAIN-based treatments produced significant counterface wear and no appreciable volume loss occurred.

Fig. 5 plots the volume loss of CrAIN-based samples with a sapphire counterface at 13.5N. Both CrAIN plus TPN-2 and TPON-2 lasted for thousands of metres with negligible volume loss, and the latter demonstrated the best performance of all treatments.

Conclusions

Bush tests and reciprocating sliding wear results indicate that CrAIN applied to TPN-2 or TPON-2 treated Ti6Al4V provides the best TPT-EBPVD Duplex treatment for aircraft bearing applications. CrAIN plus TPN-2 or TPON-2 withstood a load of 60kN.

FEA of bush tests demonstrated a peak pressure of up to 270 MPa (greater than expected compared to projected area analysis) which was achieved without failure by the CrAIN plus TPN-2 and TPON-2, suggesting that both should be able to withstand such pressures in bearing applications.

These treatments have great potential to extend the current lightweight bearing pressures in aircraft up to (and beyond) 220MPa and be applied to full size aircraft for simulated aircraft-life tests.