Fatigue and Damage Resistant Materials in Next-generation Aircraft Tyres

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Overview

• Introduction
• Fabric fatigue in aircraft tyres
  - Fatigue test – FEA Vs Bend Over Sheave
  - Rubber hardness and fabric strength on fatigue
• Foreign object damage resistant materials
  - Nylon and Aramid materials
• Fatigue damage analysis - Aramid fabric cords
• Conclusions
Introduction

• Aircraft tyres are designed to meet high performance requirements in service

• Major effect on passenger safety and comfort

• Tyre performance on the ground is critical
Fabric Fatigue in Aircraft Tyres
Fabric Fatigue on Tyre Failure

- Loading/unloading of rubberised fabric occurs during taxiing
- Fabric may delaminate in the clinch area under compressive load
Fatigue and Cord Compression

- Compression in cords results in shear strain

- High shear strain points initiate and propagate cracks through cord-rubber matrix

Ref: G Wahl, Fiberamics in Tires, Proceedings of Tire Tech Conference 2012, Germany
Fabric Fatigue Evaluation: FEA Vs Fatigue Test

- Peak value from critical location in tyre FEA model at load
- Set equivalent FEA model to get test travel distance
- Fatigue life from test
- Fatigue life at different sample condition
Fabric Fatigue Evaluation - FEA

<table>
<thead>
<tr>
<th>Applied Force (N)</th>
<th>Max Strain (%)</th>
<th>Min Strain (%)</th>
<th>Δ Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>375</td>
<td>0.33</td>
<td>-10.42</td>
<td>10.78</td>
</tr>
<tr>
<td>700</td>
<td>0.68</td>
<td>-10.04</td>
<td>10.73</td>
</tr>
<tr>
<td>900</td>
<td>0.88</td>
<td>-9.81</td>
<td>10.69</td>
</tr>
<tr>
<td>1500</td>
<td>1.43</td>
<td>-9.12</td>
<td>10.55</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Spindle Diameter (mm)</th>
<th>Max Strain (%)</th>
<th>Min Strain (%)</th>
<th>Δ Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.70</td>
<td>0.36</td>
<td>-12.99</td>
<td>13.35</td>
</tr>
<tr>
<td>19.05</td>
<td>0.36</td>
<td>-11.90</td>
<td>12.26</td>
</tr>
<tr>
<td>25.40</td>
<td>0.33</td>
<td>-10.42</td>
<td>10.78</td>
</tr>
</tbody>
</table>

- Compressive strain occurs on bottom ply
- Strain was calculated with different load and spindle size

Proprietary & Confidential
Fabric Fatigue Test: Bend Over Sheave

Bend Over Sheave test equipment (Bogimac, Belgium)

Sample with 75 IRHD hardness and 80 EPDM
Rubber Hardness and EPDM on Fabric Fatigue

**Fatigue Performance**

- Dynamic fatigue resistance increased with increase in rubber hardness at lower fabric EPDM and vice versa.
- Sample with 65 IRHD and 80 EPDM showed the best fatigue performance.

**Heat Build-up**

- Heat build-up increased with increase in rubber hardness and fabric EPDM.
- Sample with 65 IRHD and 60 EPDM showed the least heat build-up.
Foreign Object Damage Resistant Materials
Foreign Object Damage

- Foreign object damage (FOD) is the most common cause of premature aircraft tyre failure
- Tyre bursts if the foreign object penetrates through the tread into or through the casing
- Tread peels-off if the cut damage is limited to the tread area
FOD Resistant Materials

- Used as a protective layer against foreign objects to protect belt and carcass of the tyre
- Inter-tread fabric (ITF) used in the tyre was replaced by FOD resistant materials
- Cut damage resistance of the tyres were compared against standard tyre built with nylon ITF and hybrid belt
- In-house developed test method was used for FOD evaluation

Materials

- Nylon-based material
  - Twisted monofilament (Monolyx, Kordsa)
- Aramid-based materials
  - Knitted Aramid fabric (Milliken)
  - Aramid tyre cord fabric (Sicrem)
  - Aramid single end cord - belt (SKS)
Nylon Twisted Monofilament - Monolyx

- Round filaments twisted together
- RFL dipped for rubber adhesion
- Higher modulus and lower elongation compared to multifilament cord
- Lower fretting, lower heat build-up and high fatigue resistance
- Good adhesion to rubber
- Excellent cut resistance
- Fabric made with 92 EPDM and cord construction of 0.35 x 3 mm was used for FOD evaluation
- Two tyres were built with 2 layers of fabric as FOD layer: 32° bias

Ref: Application Note, Kordsa Global
Knitted Aramid Fabric

- RFL dipped and tackified
- Fabric was used as zero degree layer due to more stretch in this direction
- Two tyres were built with 1 and 2 layers of fabric as FOD layer
Aramid Tyre Cord Fabric

- RFL dipped Twaron 2/840 dtex cords
- Two tyres were built with 2 layers of fabric as FOD layer: 32° bias

Aramid Single End Cords

- RFL dipped and adhesion activated
- Aramid cords were used as belt replacing standard hybrid belt
- Two tyres were built with 4 layers of Aramid belt in the form of jointless band
- No FOD layer was used
**FOD Test**

- Static test
- Flat plate with knife attached to the flywheel of Dynamometer
- Dunlop specified knife with dimension: 50 x 90 mm was used
- Tyre inflated to rated pressure and loaded on to the knife until failure
- Cut/puncture resistance was measured from the load-wheel position trace
Puncture Resistance

- Belt made using Aramid cord with no FOD layer showed best puncture resistance
- Knitted Aramid layers showed very good puncture resistance as FOD layer
Fatigue Damage Analysis
Fatigue Damage Analysis – Aramid Belt

- Aramid belts of two different tyre sizes were tested at Teijin Aramid B.V., The Netherlands
- A tyre after Dynamometer test and a new tyre was analysed
- Retained cord breaking strength was measured using tensile testing machine
- Fatigue damage was analysed using SEM
**Aramid Cord Properties**

**Tested Vs New Tyre**

<table>
<thead>
<tr>
<th>Belt cord properties</th>
<th>Reference</th>
<th>Dynamometer tested tyre</th>
<th>New tyre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breaking strength (N)</td>
<td>1640 ± 160</td>
<td>1353 ± 39</td>
<td>1324 ± 34</td>
</tr>
<tr>
<td>Relative BS to reference (%)</td>
<td>82 ± 8</td>
<td>81 ± 8</td>
<td></td>
</tr>
<tr>
<td>Elongation at break (%)</td>
<td>7.31 ± 0.43</td>
<td>6.35 ± 0.06</td>
<td>5.55 ± 0.24</td>
</tr>
<tr>
<td>Relative EB to reference (%)</td>
<td>87 ± 5</td>
<td>76 ± 6</td>
<td></td>
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</tbody>
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- Tested and new tyre retained 81-82% strength of the reference cord
- No additional strength decay observed in the Aramid belt of the tyre even after Dynamometer test
- 18-19% strength loss to the reference cord is likely from tyre processing
SEM Analysis of Aramid Cords

Reference Aramid Cord

- Flattening of filaments and fibrillisation were observed in reference Aramid cord
- No broken filaments were found in the ply-line
SEM Analysis of Aramid Cords

- Flattening of filaments were observed in cords taken from tested and new tyre
- Not a single broken filament found in the belt ply-line
- Fibrillisation seen in the ply-contact zone was not excessive
SEM Analysis of Aramid Cords

Kink-bands and Cracks

- Initial kink-band formation and cracks in longitudinal direction were found on cords taken from new tyre
- Indication of high compressive forces in specific areas of belt ply-line
Conclusions

- Fabric fatigue in aircraft tyres were studied using finite element analysis and successfully validated using Bend Over Sheave fatigue test equipment.
- Fatigue failure location and failure mode was found to be same as predicted by FEA.
- Fatigue life of tyres can be improved by optimising rubber hardness and fabric density.
- Foreign object damage resistance of tyres were successfully evaluated using in-house developed FOD test.
- Belt made using single end Aramid cords showed 50% higher puncture resistance compared to hybrid belt used in a standard tyre.
- Aramid belt helps to make light-weight aircraft tyres.
- Fatigue damage analysis of Aramid belt showed no evidence of broken filament in the belt ply-line. Occasional kink-bands and longitudinal cracks were observed as a result of high compressive forces.
THANK YOU