Agenda

- What is GLARE®?
  - GLARE® characteristics.
  - GLARE® damage behaviour.
- Present repairs, riveted.
- Future repairs, bonded.
  - How to perform repair
  - Testing of repairs
- GLARE® repairs patches
- General developments
What is GLARE®?

- GLARE is a hybrid material built-up from alternating layers of aluminium and glass fibre reinforced metal adhesive.
GLARE® build up.

• GLARE® build-up:
  • Aluminium layer thickness: 0.2 - 0.3 - 0.4 - 0.5 mm
  • Fibre/adhesive layer build-up from multiple 0.125 mm UD layers
  • FM94 epoxy adhesive for structural metal bonding

• Standard grades:

<table>
<thead>
<tr>
<th>GLARE</th>
<th>Fibre/adhesive layer thickness</th>
<th>Fibre/adhesive layer build-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>2A</td>
<td>0.25 mm</td>
<td>0°/0°</td>
</tr>
<tr>
<td>2B</td>
<td>0.25 mm</td>
<td>90°/90°</td>
</tr>
<tr>
<td>3</td>
<td>0.25 mm</td>
<td>0°/90°</td>
</tr>
<tr>
<td>4A</td>
<td>0.375 mm</td>
<td>0°/90°/0°</td>
</tr>
<tr>
<td>4B</td>
<td>0.375 mm</td>
<td>90°/0°/90°</td>
</tr>
<tr>
<td>5</td>
<td>0.5 mm</td>
<td>0°/90°/90°/0°</td>
</tr>
</tbody>
</table>

• Example: GLARE 4B-4/3-0.4

  0.4 mm thick aluminium layers
  4 aluminium layers, 3 fibre/adhesive layers
GLARE® characteristics.

• Static strength properties
  • Design values for GLARE® in 4/3-0.4 lay-up (MPa):

<table>
<thead>
<tr>
<th></th>
<th>2024-T3</th>
<th>GLARE 2</th>
<th>GLARE 3</th>
<th>GLARE 4</th>
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<tbody>
<tr>
<td>Tensile ult. L</td>
<td>440</td>
<td>910</td>
<td>625</td>
<td>795</td>
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<tr>
<td>Tensile ult. LT</td>
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<td>300</td>
<td>610</td>
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<tr>
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<td>325</td>
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<td>290</td>
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<tr>
<td>Tensile yield LT</td>
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<td>260</td>
<td>230</td>
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<tr>
<td>Compr. yield L</td>
<td>270</td>
<td>305</td>
<td>260</td>
<td></td>
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<tr>
<td>Compr. yield LT</td>
<td>310</td>
<td>230</td>
<td>270</td>
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<tr>
<td>Bearing ult.</td>
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<td>680</td>
<td>760</td>
<td>630</td>
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<td>Blunt notch L*</td>
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<td>600</td>
<td>425</td>
<td>510</td>
</tr>
<tr>
<td>Blunt notch LT*</td>
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<td>190</td>
<td>415</td>
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<tr>
<td>E-modulus L</td>
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<td>66500</td>
<td>59500</td>
<td>59000</td>
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<tr>
<td>G-modulus</td>
<td>27600</td>
<td>20500</td>
<td>20500</td>
<td>18700</td>
</tr>
</tbody>
</table>

*:typical values
GLARE® characteristics. (cont’d)

- Mix of composite and metal properties/behaviour, GLARE® offers:
  - Static strength (tensile, compression, etc)
  - Damage Tolerance
    - Excellent Fatigue behaviour
    - Impact resistance
    - Residual strength
  - Corrosion resistance
  - Lightning strike resistance
  - Fire resistance
  - Easy workshop handling
  - Easy reparability

- Properties can be tailored:
  - Thicker or thinner aluminium layers
  - More or fewer fibre/adhesive layers
  - fibre adhesive layers at specific angles (e.g. ±45°)
**GLARE® damage behaviour**

- FOD causes a dent (impact) or a scratch, similar to aluminium
- Inspectability of FOD similar to aluminium
- Penetration energy higher than for aluminium and composites
- Debonding sizes resulting from impact are small compared to the dent size
- Effect of FOD on compression properties similar to aluminium
- GLARE exhibits slow fatigue crack growth and high residual strength in the presence of FOD
Present repairs, riveted.

• Repairability
  • The same repair methods can be applied as for aluminium
  • Superficial damage (corrosion, scratches) can be worked out
  • Riveted or bonded patches can be applied
  • Good fatigue and damage tolerance performance of repaired structure
Present repairs, riveted. (cont’d)

• Typical repairs
Future repairs, bonded.

• Advantages:
  • Fatigue insensitive
  • Corrosion
  • Lower design weight, reduced skin thickness
How to perform bonded repair

- Standard (SRM) procedures.
- No special tools or equipment.
- 1st aim hot bonded adhesive, later cold bonded

Cleaning of bonding surface  Bonding film cut to shape  Application of vacuum foil, thereafter start of curing with Heatcom® device, low vacuum pressure
Testing of bonded repairs

Megaliner barrel bonded repairs

- Two CA fatigue tests
- Three outdoor exposure + CA fatigue tests
Testing of bonded repairs (cont’d)

• The tests are still ongoing:
  • No problem to bond a repair (GLARE-)patch to GLARE®
  • Fine tuning of repair patch
  • Feasibility of standard GLARE patch.
  • Outdoor exposure program to be completed. Preliminary results (after 2 years outdoor exposure): no effect of outdoor exposure (Me/Me bonding is not affected)
GLARE® repairs patches

US Air Force/Lockheed Martin C-5A Galaxy: Bonded Patch Repairs

- Material: Two GLARE 2-3/2-0.2 repairs installed October 1995
- Design: Patch bonded over a fuselage longitudinal butt-joint with AF 163-2M
- Due to the poor fatigue performance of the aluminium 7079-T6 skin, significant fatigue damage did occur. When riveted aluminium patches were used, new cracks typically nucleate in the skin at the corners of the patches, leading to ever larger repairs.

- Status:
  - No skin crack extension
  - No debonding
  - No damage to GLARE patch
GLARE® repairs patches (cont’d)

• Status:
  • No skin crack extension
  • No debonding
  • No damage to GLARE patch
General developments

• Integrated systems, e.g.:
  • De-icing system leading edge nose skin
    – No bleed air required (energy decrease)
    – Full electrical aircraft (weight decrease)

• Friction stir welding to eliminate splices. (with 2024 GLARE)

• Improving GLARE properties (and Fibre Metal Laminates)
  • Higher static properties: to be achieved by higher strength alloys
  • Lower density due to lower density aluminium alloys (e.g. Al/Li)
  • Increase stiffness: to be achieved by higher stiffness fibres

• Automation of pretreatment (continue process), lay up and inspection (US).

• Larger Skin panels →
General developments (cont’d)

• Larger panels:
  • Easier Assembly
  • Less joints

Dimensions: 3.5 x 11 meters (10x33ft)
Crack Propagation is no Sizing Parameter

General differences of GLARE® compared with Aluminium:

- Fatigue life is longer
- Crack initiation is earlier
- Contribution of crack propagation period on total fatigue life is larger

![Graph showing fatigue cycles vs cycles to failure for GLARE® 3-3/2-0.3, 2024T3](image)

- N (initiation)
- N (crack growth)
GLARE® Design Features – “Giant” Tool Box

Splice in skin panel or doubler

- Limitation of aluminum sheet width
- Internal stress level in double curved panels

Additional glass fiber layers

- Embedded at frame locations

Inter-laminar doublers

- Spliced or go thru depending on length and orientation

Fiber Orientation and Lay-up

- Adjust properties to loading condition

Transition of GLARE® type

- E.g. from GLARE® 4 to GLARE® 3

Additional layers

- Aluminum sheet locally at frame station
- Glass fiber layers locally between two aluminum sheets

Airbus Customer Benefit from Fiber Metal Laminates - ESAS - Ref. L53PR0805135 - Issue 1

May 2006  Page 5
Fire resistance

- GLARE shows excellent fire resistance behaviour
  - fire wall tests: 15 minutes minimum at 1100°C
  - No flame penetration
  - Exposed aluminium layer melts
  - Epoxy around glass fibres carbonizes and protect remaining aluminium layers.
  - Backside temperature reduced by more than half due to isolating effect of delaminated glass fibre layers