Effect of Orientation on Pin-bearing Strength for Bolted Connections in Pultruded Joints

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Content:
- Test method for determining pin-bearing strength.
- Strength variation with orientation of connection force.
- Suitability of Hankinson formula for design strength calculations.
Distinct modes of failure (single-bolted connections)

Failure mode can be made to change by varying the geometric ratios $e_1/d$ (or $e_1/d_n$) and $w/d$ (or $w/d_n$), with $w = 2e_2$. $d$ is bolt diameter, $<d_n$.

Mix modes for off-axis and block shear with multi-rows.

Strength Formula – Bearing Mode of Failure

$R_{br} = t \cdot d \cdot F_{\theta}^{br}$

$t$ is thickness of FRP
$d$ is diameter of bolt
$F_{\theta}^{br}$ is pin-bearing strength for the orientation of material to the resultant connection force. Can Hankinson formula give $F_{\theta}^{br}$ from $F_0^{br}$ and $F_90^{br}$?

Specimens cut from the web of a 203 × 203 × 9.53 mm WF of the Pultex 1525 series with a thermoset polyester resin, from Creative Pultrusions Inc.

Test results for $0^\circ$, $5^\circ$, $10^\circ$, $20^\circ$, $45^\circ$ and $90^\circ$ material orientations, at room temperature.
Pin-bearing Strength Test Results

Warwick University (WU) batch strengths at 0°, 5°, 10°, 20°, 45° and 90° and for four different pin (bolt) diameters

<table>
<thead>
<tr>
<th>Pin diameter d (mm)</th>
<th>9.7</th>
<th>12.2</th>
<th>18.8</th>
<th>25.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean d/t ratio</td>
<td>1.06</td>
<td>1.34</td>
<td>2.05</td>
<td>2.78</td>
</tr>
</tbody>
</table>

Characteristic strength $F_{br}^{hr}$ (N/mm²)

<table>
<thead>
<tr>
<th>Orientation in degrees</th>
<th>0°</th>
<th>5°</th>
<th>10°</th>
<th>20°</th>
<th>45°</th>
<th>90°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normalised strength</td>
<td>1.00</td>
<td>0.938</td>
<td>0.893</td>
<td>0.871</td>
<td>0.881</td>
<td>0.842</td>
</tr>
<tr>
<td>1.00</td>
<td>0.981</td>
<td>0.962</td>
<td>0.916</td>
<td>0.923</td>
<td>0.928</td>
<td>0.788</td>
</tr>
<tr>
<td>1.00</td>
<td>1.015</td>
<td>0.925</td>
<td>0.903</td>
<td>0.910</td>
<td>0.925</td>
<td>0.677</td>
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<tr>
<td>1.00</td>
<td>0.975</td>
<td>0.992</td>
<td>0.950</td>
<td>0.925</td>
<td>0.928</td>
<td>0.908</td>
</tr>
<tr>
<td>1.00</td>
<td>0.940</td>
<td>0.900</td>
<td>0.900</td>
<td>0.900</td>
<td></td>
<td>0.918</td>
</tr>
</tbody>
</table>

Characteristic value = Mean – 1.72SD (batches of 10)

Characteristic value = Mean – 1.77SD (batches of 6)

Types of Bolted Connections and Joints

Hankinson formula with 0° and 90° characteristic values from the Warwick University (WU) test results reported in Slide 5

Hankinson formula is used (AF&PA/ASCE 16-95) to predict the off-axis dowel (or pin-bearing) strength of timber.
• Trends for 0° and 5° have a tendency to coincide for the highest $d/t$ ratios.
• Curves for characteristic strengths at 20° and 45° orientations cross each other.

Hankinson's formula predicts a very gradual fall-off in strength with orientation.
• Measurements from WU and Ascione, Feo and Maceri (2009) give a more rapid strength reduction for orientations ($\theta$) of 0° to 35° before levelling off when $\theta > 45°$. 
Concluding Remarks

- Reduction in pin-bearing strength is minimal for the two material orientations of 0° and 5° and, at the higher d/t ratios, there is a tendency for their two means to coincide.
- Results do not contradict the current proposed design guidance in the American pre-standard to use the 0° characteristic strength for orientations between 0 and 5° and the 90° value for all other orientations.
- Variation of pin-bearing strength of (standard) pultruded FRP cannot be predicted using the (simple) Hankinson formula.
- To establish a 'good' curve fit with orientation requires a polynomial expression of order six, and this is not suitable for a strength formula in a design standard.

Thank you for your attention.
Any questions?