Damage Tolerance Assessment of Friction Pull Plug Welds in Two Aluminum Alloy Systems

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NASA safety requirements call for fault tolerance or a minimum risk approach for manned flight hardware. Fracture control is one element of a minimum risk approach. The basic philosophy behind fracture control is mitigating risk associated with a part failing from a crack or crack-like defect.

Plug welds pose a unique challenge to fracture assessment because standard fracture test methods can’t be easily applied

A plug weld is a non-homogenous anisotropic material system
Local deformation and failure behavior not initially understood
Pre-crack placement is non-straightforward
Self-reacting Friction Stir Weld Termination Hole

Hole Enlarged to Accommodate Pull Plug

Pull Plug at “full” Displacement

Pull Plug after Final Machining

Pull Plug at “zero” Displacement
Image of plug weld illustrating complexity of plug-plate interface. The preferential failure plane lies somewhere in the thermo-mechanical zone.
Partial Plan View of Friction Plug Weld

Friction Pull Plug Weld

Base Metal

Initial SR-FSW

Base Metal

Plan View of Region Shown in Macro

Plug Weld – Base Metal Interface
Cross Section of Friction Plug Weld

Cross Section of Friction Plug Weld - Interface at Base Metal

Cross Section of Friction Plug Weld - Interface at Initial Weld
Image of plug weld illustrating precrack location.
Image of plug weld illustrating precrack location.
Failure path in surface crack tension plug panel.
Friction Stir Weld Pull Plug Residual Strength vs Flaw Size
Aluminum-Copper Alloy System

Circled data points did not fail through the flaw.
0.45 < a/2c < 0.60

70°F
-320°F
Friction Stir Weld Pull Plug Residual Strength vs Flaw Size
Aluminum-Lithium Alloy System

Normalized Ultimate Strength

0.45 < a/2c < 0.60

a/t
• Residual strength of aluminum-copper alloy plug systems exhibits a cryogenic strength enhancement that is fairly constant with respect to flaw size.
• Residual strength of aluminum-lithium alloy plug system exhibits a cryogenic residual strength enhancement that decreases with flaw size and reaches a crossover point at an a/t ratio of approximately 0.75.

<table>
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<tr>
<th>Estimated Critical Flaw Depths</th>
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<tr>
<td>Alloy System</td>
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<tr>
<td>Aluminum-Copper</td>
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<tr>
<td>Aluminum-Lithium</td>
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• Critical surface flaws can be reliably detected with liquid penetrant nondestructive evaluation.
• With respect to proof testing as a screen for mission critical defects, aluminum-lithium alloy weld systems may require a higher proof test factor than aluminum-copper alloy weld systems.