Design of Z-Pinned Laminates: Methods and Challenges


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Z-pinning

- Insertion of through thickness rods into laminates before cure
- Arrest or suppression of delaminations
Z-Pinning: Application Examples

FIA F1 Technical Regulation
Article 15.1.13: Car Construction
– Permitted Materials:
“Unidirectional or planar reinforcement with their pre-impregnated form, not including three dimensional weaves or stitched fabrics (but three-dimensional preforms and Z-pinning technology are permitted)”
Z-pin Ultrasonic Insertion

1 DCH basic 20kHz 1100W power supply module with enclosure
2 PT250 hand held welder housing with hand grip

Hand Held Insertion Gun
(with 1 sq. inch, carbide coated horn)

Branson Ultrasonics

Ultrasonic Power Unit

'Standard' Z-pin preform

Low density foam (upper half) of preform collapses allowing z-pins to penetrate the laminate.
Z-pin Ultrasonic Insertion

In plane waviness  Misalignment, splitting and crimping  Post-cure debonding

- Z-pinning introduces several defects in the laminate
- The Z-pin/laminate interface is weak to allow pull-out

T-Joint Example

- Z-pinning does not increase the ultimate strength
- Z-pinning does not influence the damage initiation
- Z-pinning compromises the stiffness
- Z-pinning increases the “apparent” toughness
T-joint Example

- The failure mode does not change, but the delamination growth in the base flange is more progressive
- The crack in the web grows faster than that in the base flange

Design for Damage Tolerance

- Stiffness vs. Toughness trade-off

![Diagram showing structural weight vs. structural stiffness with Feasible Design Region and various delamination and pinning conditions.](image)

- Single pin testing – mixed-mode
- Analytical Modelling of Z-pin Bridging Laws
- Coupon tests for Z-pin arrays
- Micro-scale FE models – inc. process variation
- Z-pin interaction with “features” (e.g. ply drops, free edges)
- Meso-scale cohesive interface element model
- Modelling of complex cases – e.g. multiple delaminations
- Component Testing
- Z-pin Design and Quality Guidelines

Legend:
- Green: Experimental testing
- Pink: Analytical modelling
- Blue: Finite element analysis
FE curve vs. Experimental curve

- FE calibrated via a parametric study
Semi-Analytical Bridging Laws

- Derived assuming that the Z-pin behaves as a beam embedded in an elastic foundation
- Validation based on Mixed-Mode Testing – 0.28 mm diameter, 2% aerial density
Coupon-Level Modelling

- Semi-analytical bridging laws implemented in user-defined interface element
- Good agreement with experimental test

Model example: pin diameter 0.28 mm, pinned area 2%

Experimental results from Cartie’s PhD thesis (2000), Cranfield University, p.75
Summary & Conclusions

- Z-pinned components have often been developed following a “trial and error” approach, largely based on experimental characterization.

- The design of Z-pinned structures requires a multi-scale approach.

- Scaling-up from coupon level to structural level is computationally expensive.

- There is still a significant lack of understanding regarding Z-pin behaviour at high strain rates (high velocity impacts).
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