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Experimental Analysis and Modeling of Z-pinned Joints under Pull-out, Shear and Flexure Loadings

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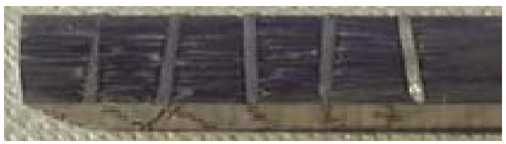
Overview

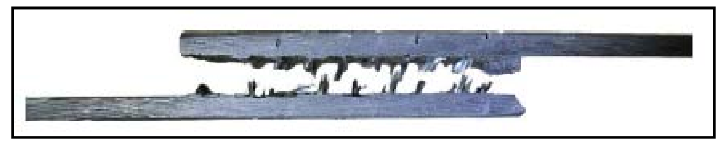
- Introduction
- Pinned T and L joints
- Experimental
- Modeling
- Conclusion

Z-pinning technology

- Z-pinning in literature:
  - Main research goal: *Increase delamination strength of laminates*
  - Most widespread manufacturing technique: *Z-fiber®*



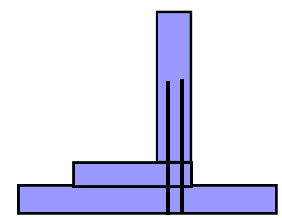
Laminate reinforced with z- pinning (z-fiber®)



Z-pinned « Lap-joint »

- Present work
  - Low-cost laminates joint by z-pinning (ALCAS program)

- ***Twisted carbon pins***
- ***Ø = 0.75mm***
- ***L=40mm***



  - Research goal: *provide physical understanding and mechanical modeling of pinned joints*

Overview

- Introduction
- **Pinned T and L joints**
- Experimental
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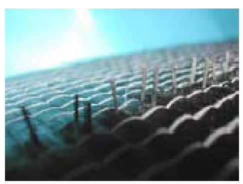
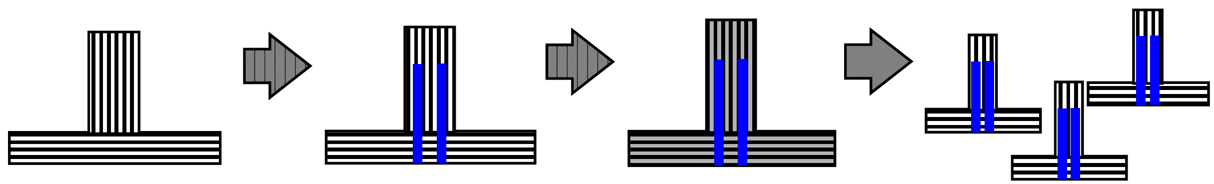
- Conclusion

Pinned T and L joints

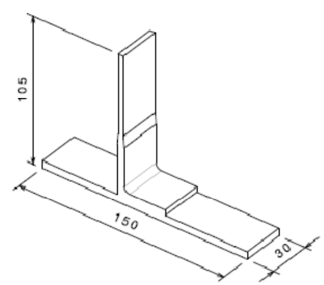
- Joints investigated:
  - Skin/stiffener joint: typical in aircraft structures
- Manufacturing:
  - (EADS IW + Dassault Aviation) [1]





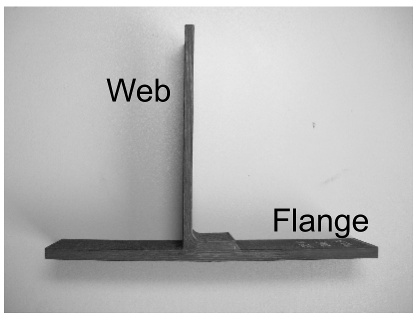
a) Ply lay-up b) Pin insertion (vibrating needle) c) RTM d) Coupons

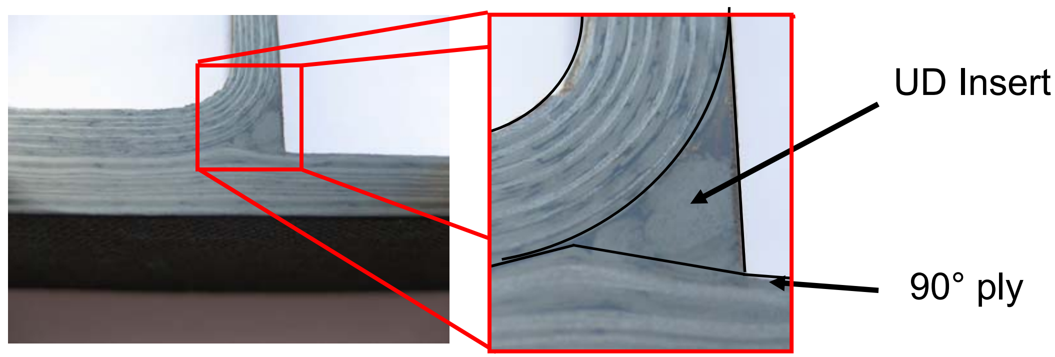
- 3 configurations tested:
  - Non-pinned L-joint
  - Pinned L-joint
  - Pinned T-joint



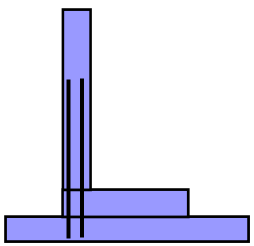
[1] Lefebure P. Experimental Assembly of dry Carbon Preforms By a Z pinning technology. *SAMPE Europe Technical Conference*. SETEC 01/06

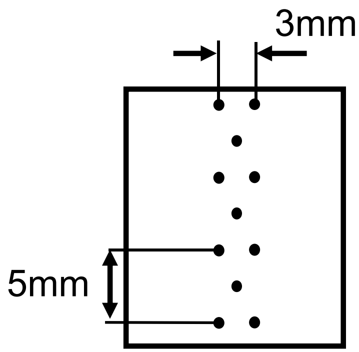
- Non-pinned L-joint:
  - Web:
    - Thickness: 3.8mm
    - Material: NCF PRIFORM HTS 450 $[[90^\circ/+45^\circ/-45^\circ]_n]_s$
  - Flange:
    - Thickness: 5.3mm
    - Material: Uniwave PRIFORM IMS 200, quasi-isotropic sequence

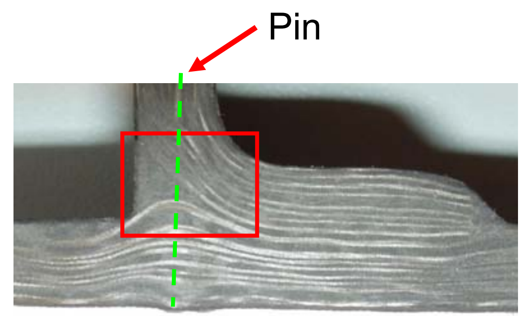


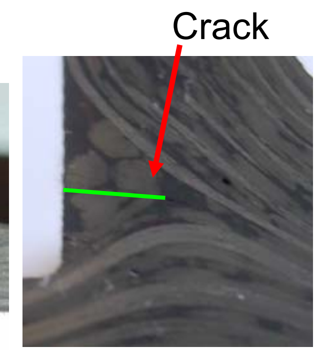


- Pinned L-joint:
  - Web / Flange jointed by carbon pins (18 pins/coupon)
  - Same materials as non-pinned L-joint
  - Pins produce increase in web thickness and waviness on flange plies
  - Cracks have been detected over the UD insert region

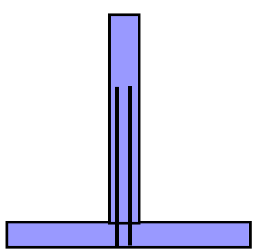








- Pinned T-joint:
  - No web foot: Web / Flange ONLY joint by carbon pins (18 pins/coupon)

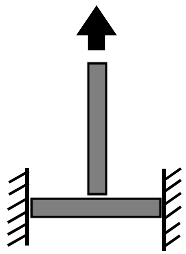


Overview

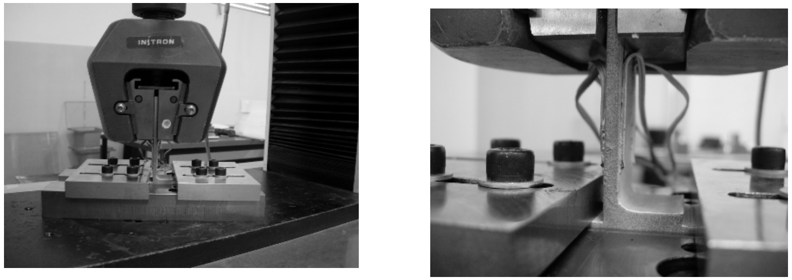
- Introduction
- Pinned T and L joints
- **Experimental analysis**
- Joint modeling
- Conclusion

Experimental analysis

- 3 Static loadings (I):
  - Pull-out

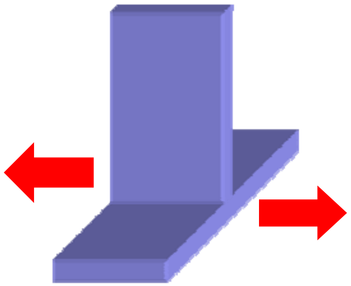


Pull-out test principle

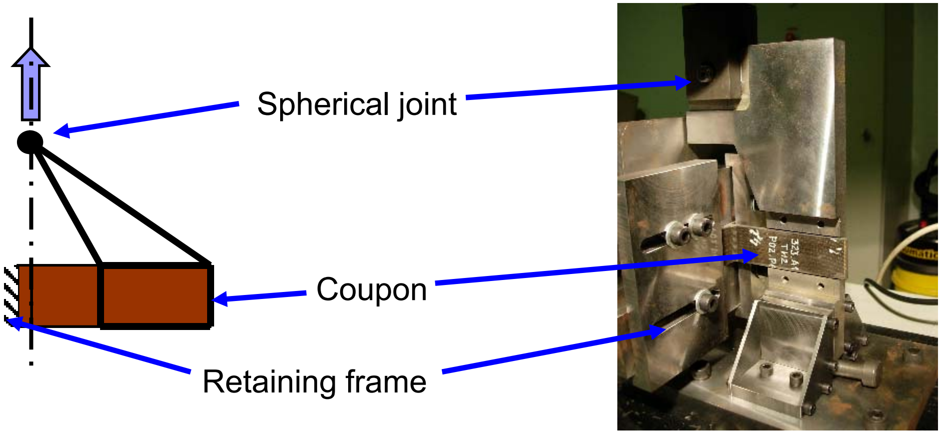


Pull-out experimental fixture

  - Shear

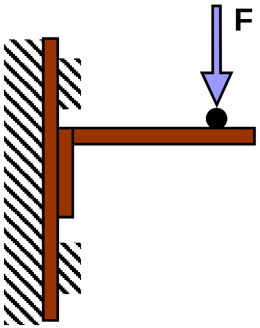


Shear test principle

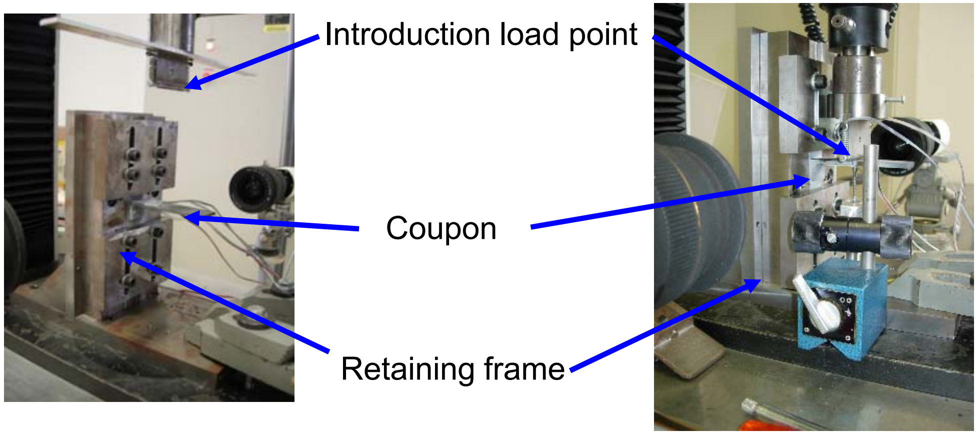


Shear experimental fixture

- 3 Static loadings (II):
  - Flexure



Flexure test principle

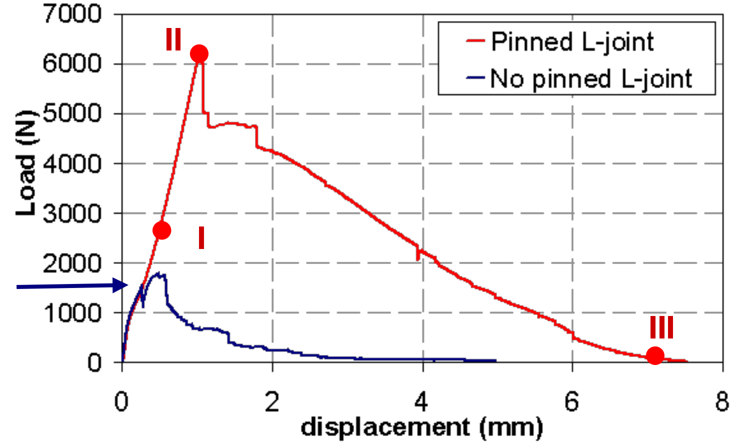


- Parameters to analyze:
  - Loads:
    - Limit load (1st failure load)
    - Ultimate load
  - Pin behavior

⟺ Application on aircraft structures

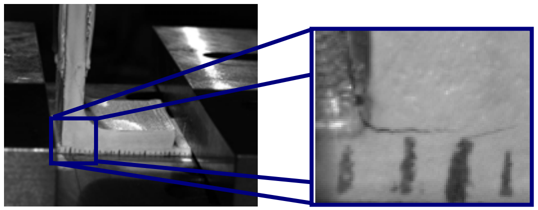
Pull-out test results

- L-joints :

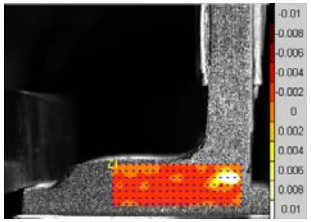


  - Non-pinned L-joint:
    - Failure by interface delamination (A)

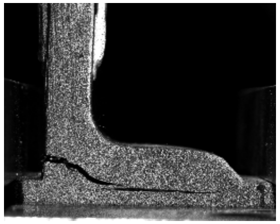
A



  - Pinned L-joint
    - Crack opening (I)
    - Pins debond from flange (II)
    - Pins slip from flange (III)



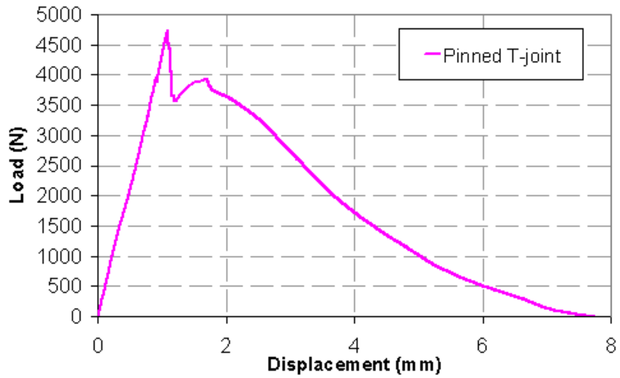
I



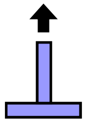
II

III

- T-joints :

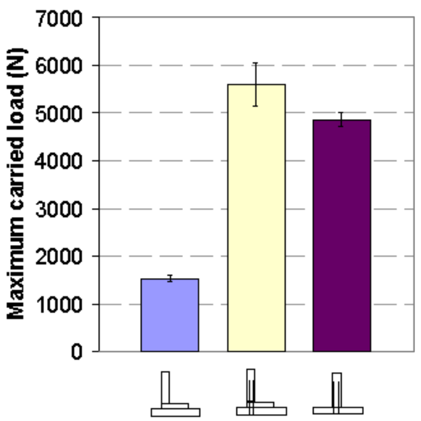


Web and pins after pull-out test



  - Failure: Pins debond from flange + residual friction

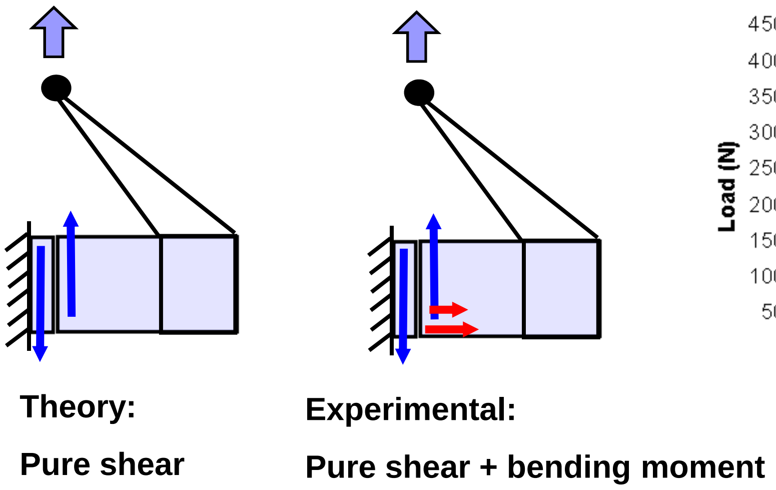
- Maximum carried load comparison

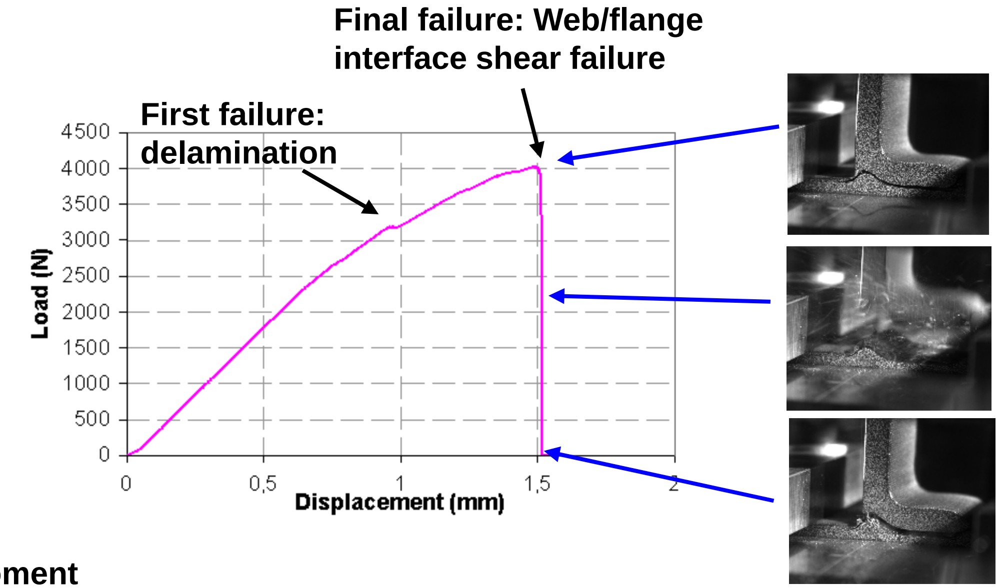


  - Pinned L-joints and T-joints strength +260% and +215% higher than Non-pinned L-joint
  - Pinned joints: same failure mode in L and T- joints (pins debond from flange)

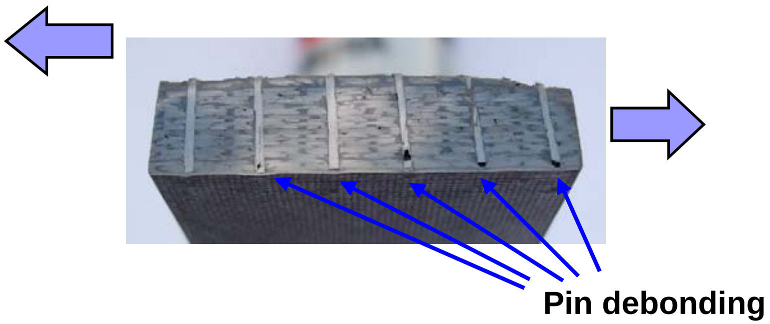
Shear test results

- Joints shear behavior:

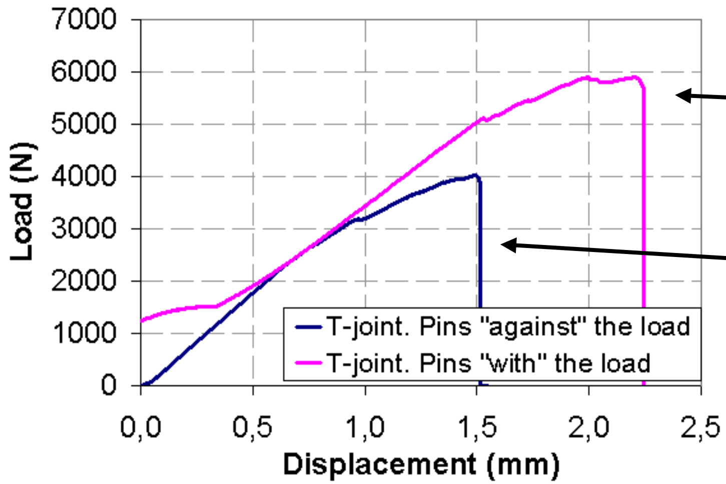


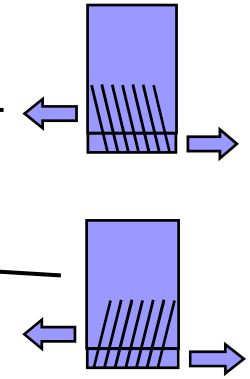


- Pins behavior: pin debonding from flange + shear failure

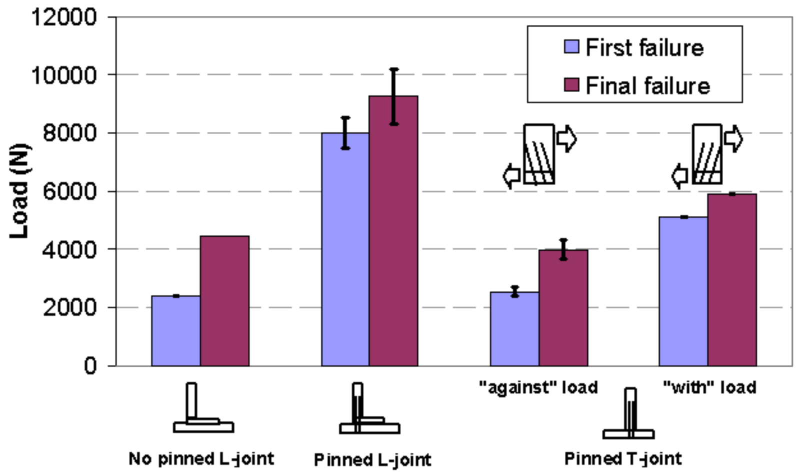


- Pins orientation dependence of pinned T-joint :



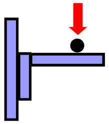


- Joint strength comparison

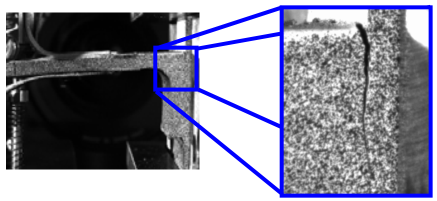


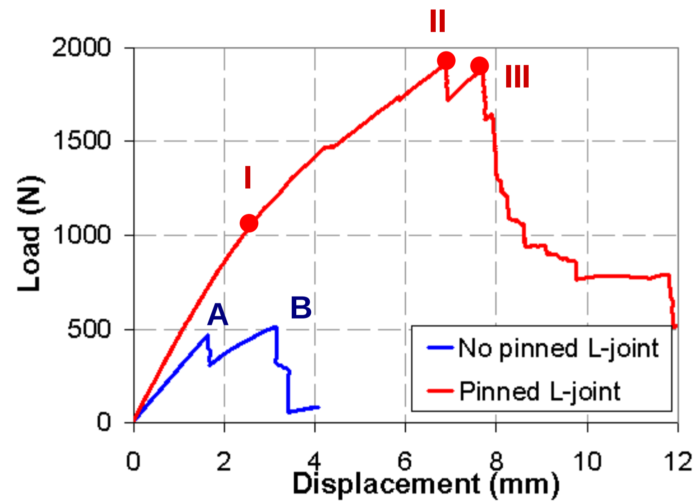
- L-joints: Pins increase both first failure and final failure load
- T-joints :Strong strength dependence on pins orientation. +48% if oriented “with” load
- Specimen sudden failure by shear at the web/flange interface ➔ Test bench OK

Flexure test results

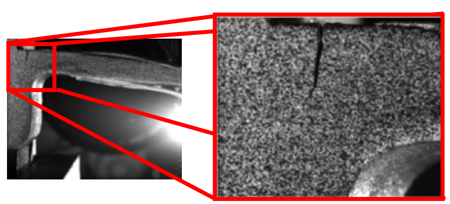


- L-joint behavior:
  - Non-pinned L-joint:
    - 1st failure: web/flange delamination (A)

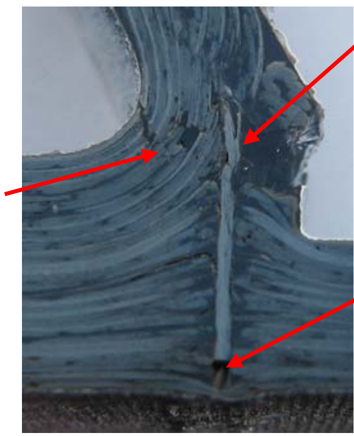




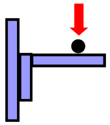
    - Final failure : crack propagation (B)
  - Pinned L-joint :
    - Crack opening while pin debonding from flange (I)



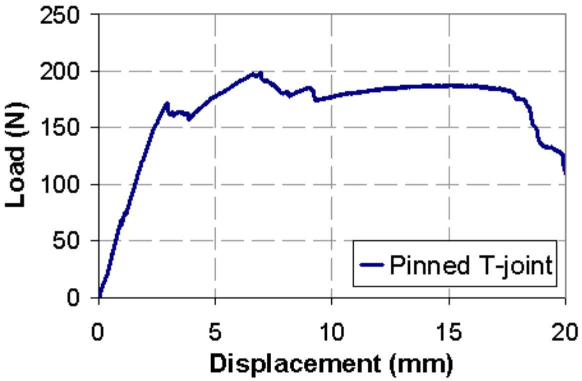
    - Web delamination at the curved area (II)
    - Web plies compression failure (III)



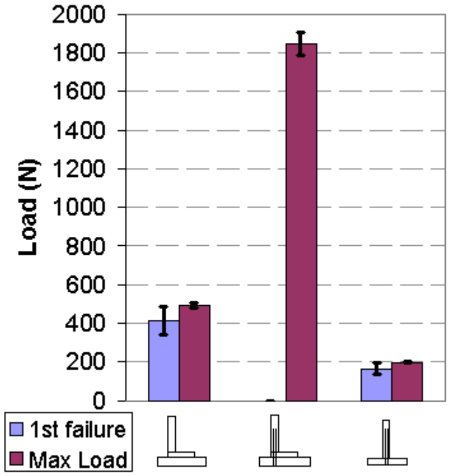
Pinned L-joint post-mortem analysis



T-joint behavior:



Strength comparison



- Pins increase strongly maximum carried load level on L-joints but difficult to establish 1st failure level
- T-joint strength much lower than L-joint due to their architecture (low bending stiffness at web base)

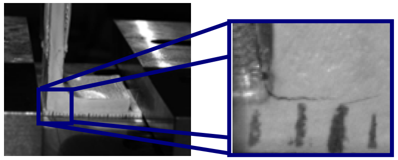
Overview

- Introduction
- Pinned T and L joints
- Experimental analysis
- **Joint modeling**
- Conclusion

Modeling introduction

- Phenomena to be modeled:
  - Origin of cracks at the web/flange interface in pinned joints

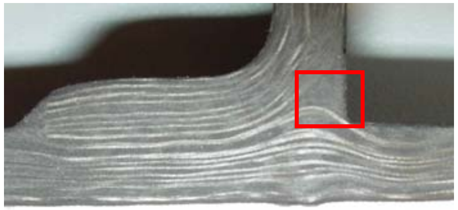
  - Mechanical behavior
    - Non-pinned joints: 1st failure criteria under Pull-Out and Flexure

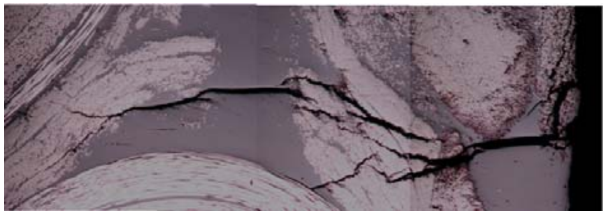


    - Pinned joints:
      - Pin modeling
      - Test simulation (Pull-Out / Shear/ Flexure)
        - For predicting strength
        - To estimate limit load

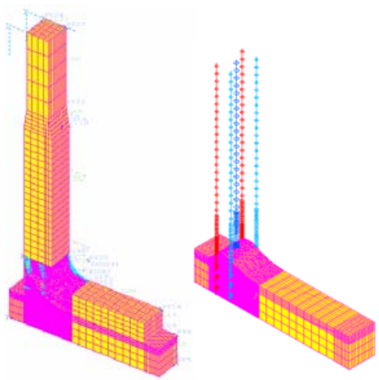
Thermal loading on pinned joints

- Specimens observations:
  - Cracks at the rich resin regions around pins at the web/flange interface

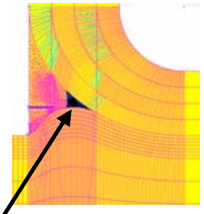




- Model:
  - Thermal loading after curing cycle: (ΔT=-155°C)

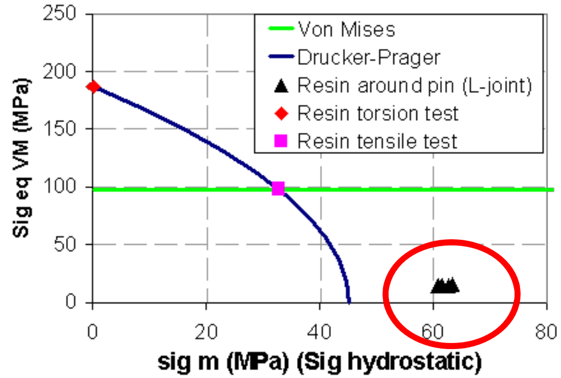


- Results
  - Triaxial stress state over resin region : hydrostatic tensile stress
  - Failure predicted using Drucker-Prager criterion



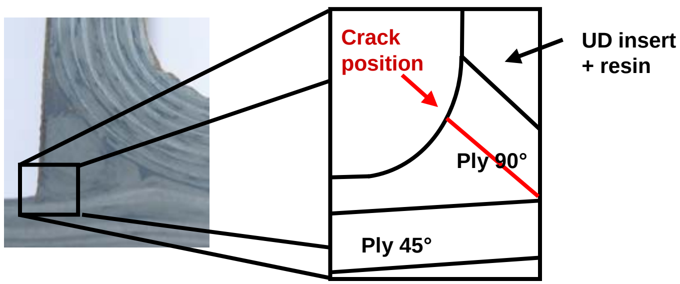
UD insert

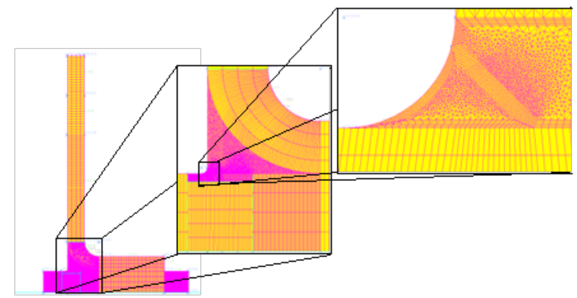
Rich resin region



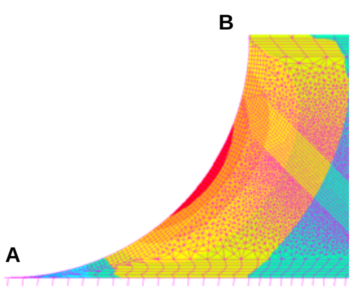
Non-pinned joints modeling

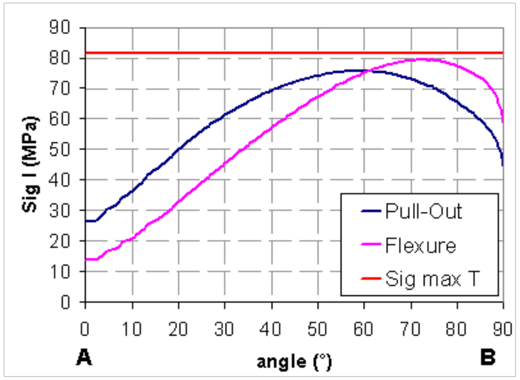
- 2D FE model for pull-out and flexure simulation:
  - Model: High detail resolution of the coupons geometry





  - Stress state at the 1st failure load level :
    - High stress concentration (pure tensile) : Criterion on $\sigma_{t\,max}$ of ply 90°

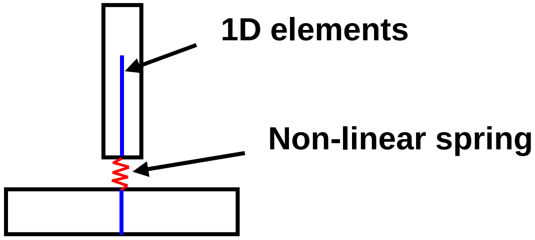




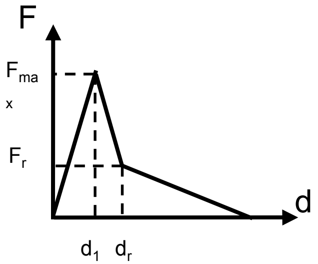
- Model 1st failure load level prediction:
  +7% pull-out
  +1% flexure
- Criterion OK
- Key factor: high detail resolution

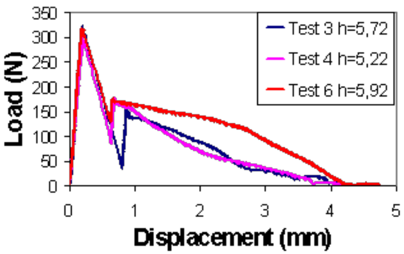
Pinned joints under mechanical loadings

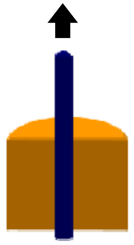
- Pin modeling:
  - 1D elements (beams) into laminates
  - Non-linear springs at the interface (pull-out and shear)



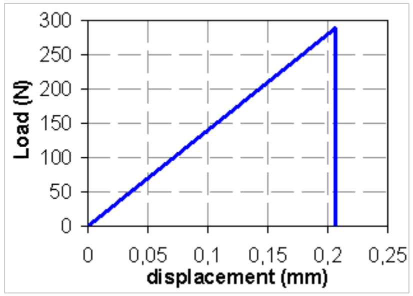
- Pin behavior
  - Tensile (pull-out) : based on single pin pull-out test bonded in net resin [2]

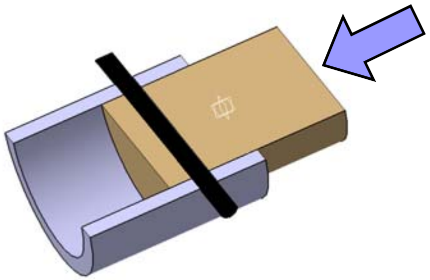






  - Shear: pin characterization in shear

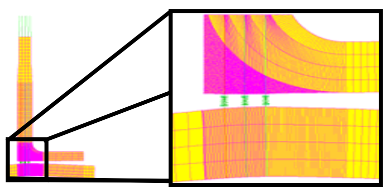


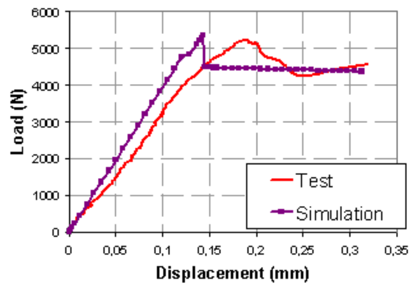


[2] Toral Vazquez J, Castanié B, Barrau JJ, Didierjean S, *Experimental analysis and modeling of Z-pinned joints under pull-out loading* Proceedings of ECCM13, 2008

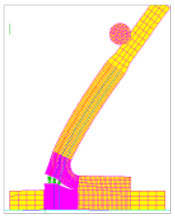
L-joint under pull-out and flexure loading

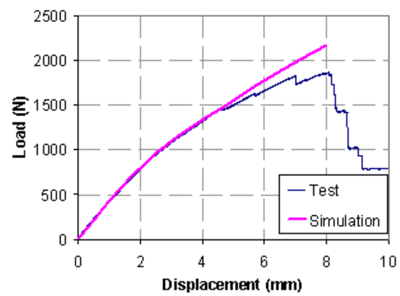
- Joint model:
  - 2D model
  - Pull-out :only pin behavior at the web/flange interface (no resin layer)
  - Flexure: crack through 10mm at the interface (cracks already present on the joints)
- Pull out:
  - Predicted strength 5% lower than experimental strength

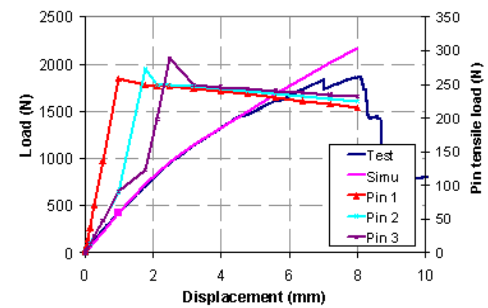




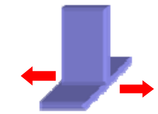
- Flexure:
  - Good agreement in load/displacement curve
  - Final failure not modeled:
    not pins failure but web failure
  - Model can estimate 1st failure load level



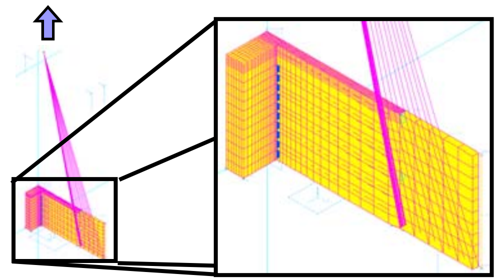




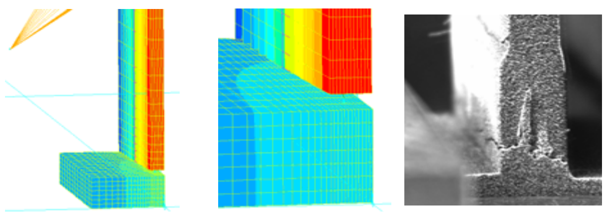
T-joint under shear loading

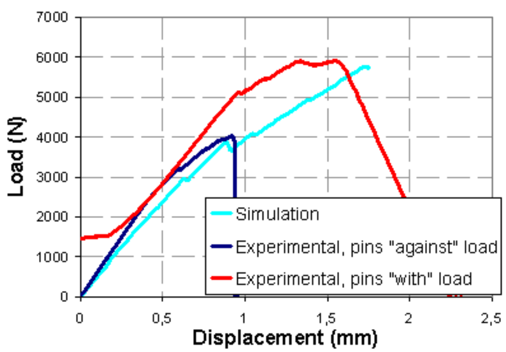


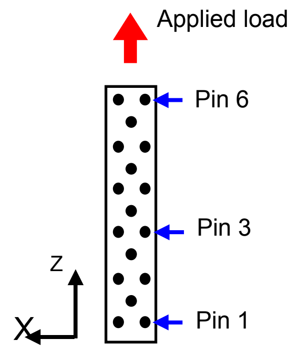
- Joint model:
  - 3D model
  - No resin layer at the interface
  - Contact between flange and web
  - Pins as no linear springs

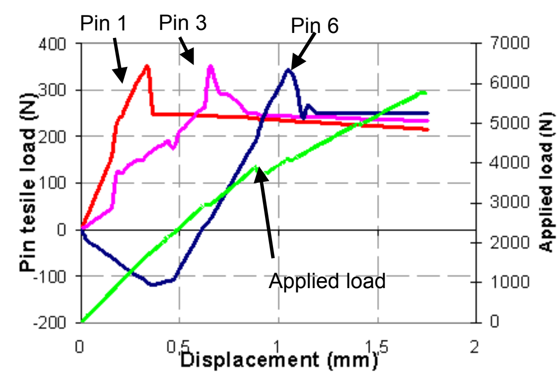


- Results:









  - Joint failure by pins debonding + shear failure
  - Joint strength predicted if pins under tensile load
  - Still misunderstanding of joints with pins “againts” load : IN PROGRESS

Overview

- Introduction
- Pinned T and L joints
- Experimental analysis
- Joint modeling
- **Conclusion**

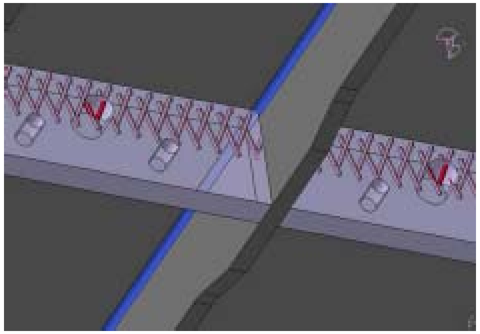
Conclusions

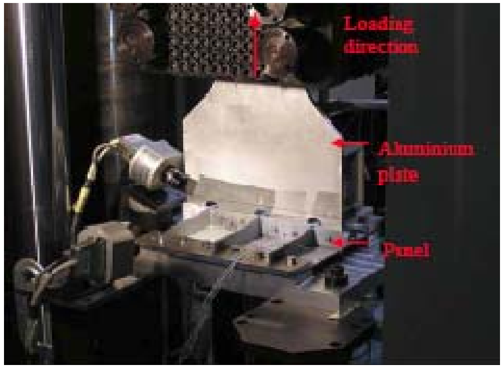
- Experimental analysis:
  - Pins increase pull-out and flexure strength (until +260%) in L-joints
  - Pinned T-joints +200% stronger than Non-pinned L-joints under pull-out
  - Pinned T-joint as resistant as Non-pinned L-joins in shear
  - Pins loaded mostly in tension even while joint under shear loading
- Modeling:
  - 1st failure criterion of Non-pinned joints
  - Thermal analysis showing cracks origin into rich resin regions
  - Mechanical modeling of pinned joints:
    - Good agreement under pull-out, flexure and shear loadings:
      - Helpful to provide joint behavior understanding
      - Able to predict joint strength in most of cases
    - Still progress to do in mixed-loadings

Future works

- Testing:
  - Fatigue loadings
  - Ageing

- Application in demonstrator





THANK YOU !!!

UE FP6 ALCAS project

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