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Thickness influence on a structural methacrylate adhesive behavior

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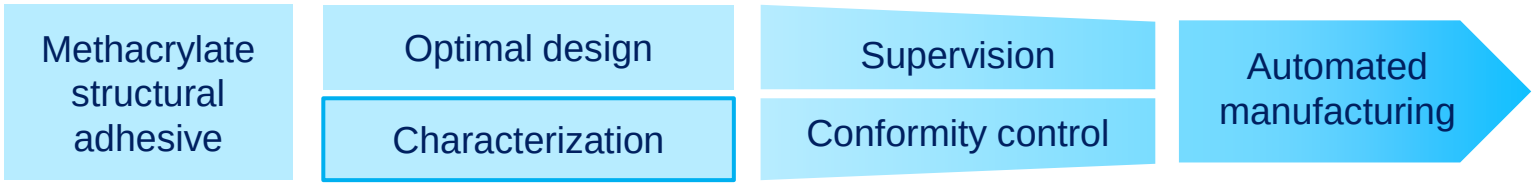
Context

- ***Global project***

To develop an adhesive bond manufacturing process which ensure its reliability through supervision and numerical simulation of the part life cycle



- ***Scientific problematic***
  - Characterization approaches for the evaluation and modeling of adhesive thickness influence on adhesive bond failure behavior

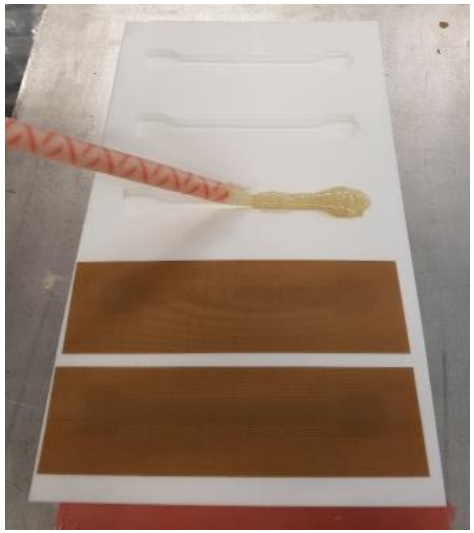
Content

- ***Context***
- ***Experimental studies***
  - Bulk adhesive tests
  - Arcan tests
  - DCB tests
- ***Numerical modeling of a DCB test***
- ***Comparison between experimental and numerical test results***
- ***Conclusions and perspectives***

Bulk adhesive manufacturing

- ***Adhesive specification***
  - Methacrylate structural adhesive SAF30MIB (Bostik)
  - Bi composants thermoplastic adhesive in paste
  - Polymerization at room temperature for 24h

Cured specimen

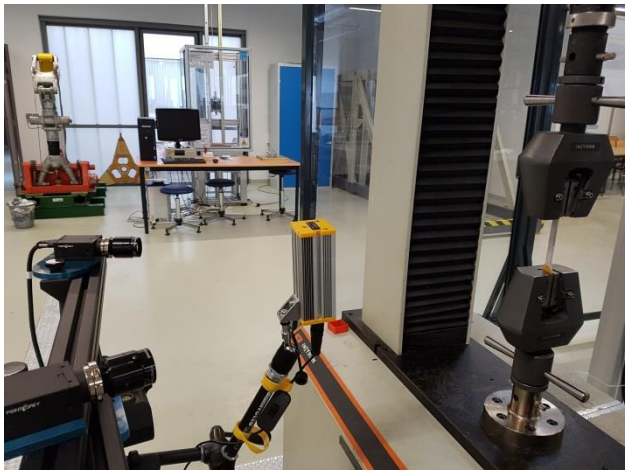


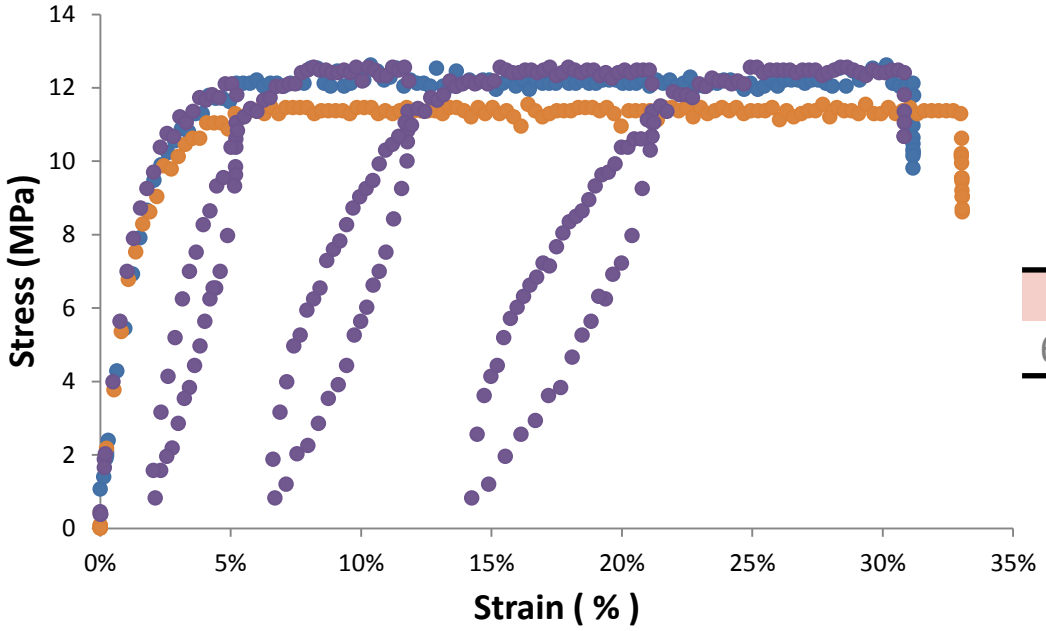
Bulk specimen manufacturing

- ***Manufacturing protocol***
  - PTFE mould
  - Specimen's size 150x10x4mm [NF ISO 527-2]
  - Recovered by a polypropylene film ⟶ Inhibited by oxygen

Bulk adhesive tensile tests

- ***Test condition***
  - Monotonic test on an Instron 100kN
  - Speed rate : 5mm/min
  - Measurements made by 3D digital image correlation (DIC)

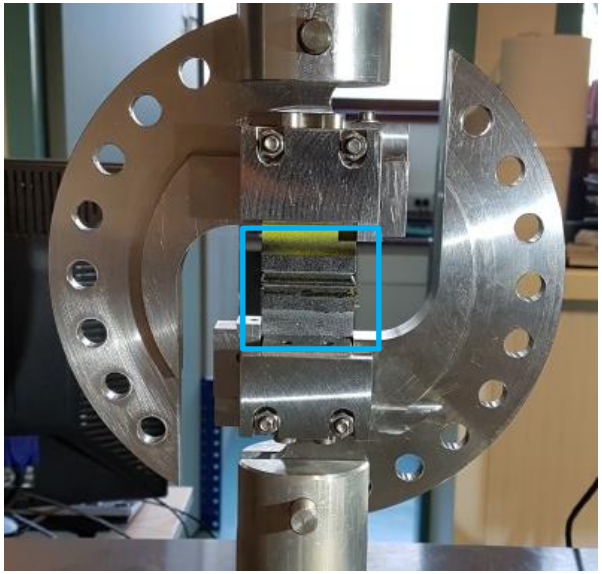




E (MPa)	υ (-)	Smax (MPa)
614 (±143)	0.37 (±0,02)	11.8 (±1,6)

ARCAN specimen manufacturing

- ***Specimen specifications***
  - Massive adherends
    - **Round beaks** [Cognard2005]
  - Bonded surface :
    - 21x40mm
  - Surface preparation :
    - degreasing with isopropanol
  - Calibrated thicknesses :
    - **0.2mm and 1mm**
  - Excess adhesive removed with a cylindrical spatula



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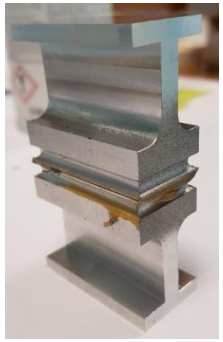

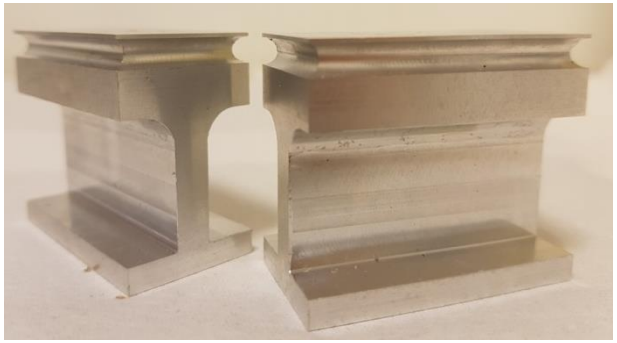

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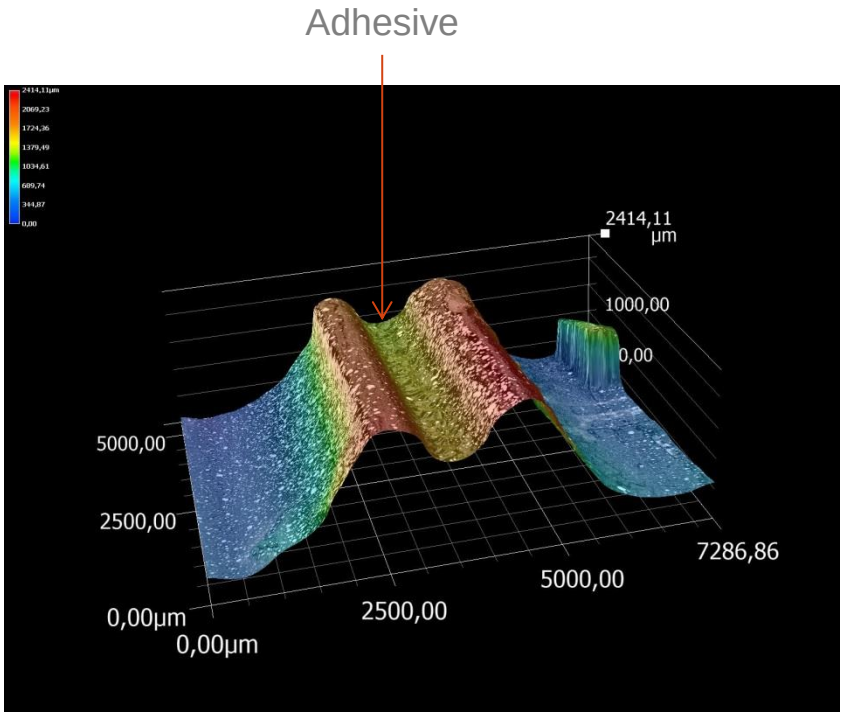
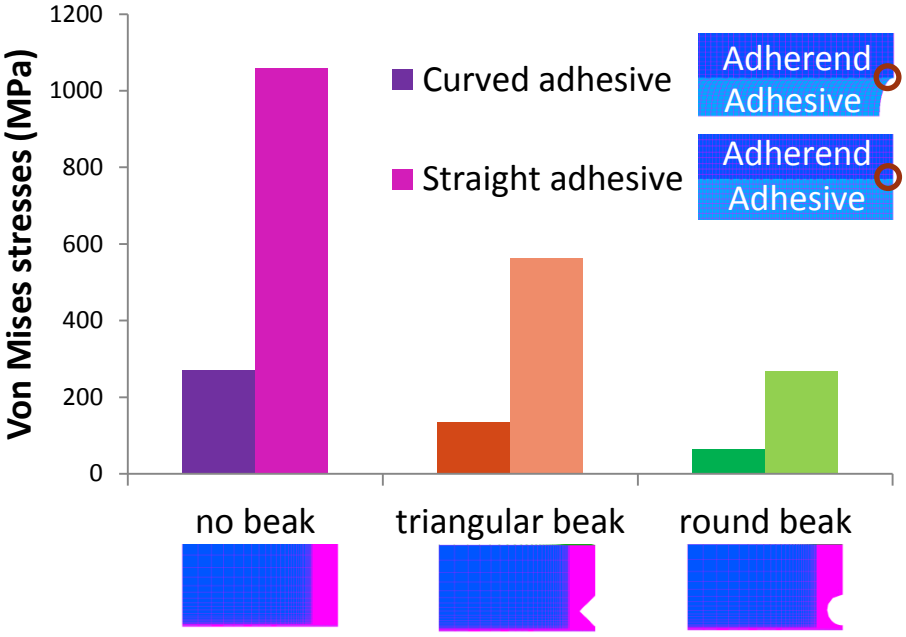
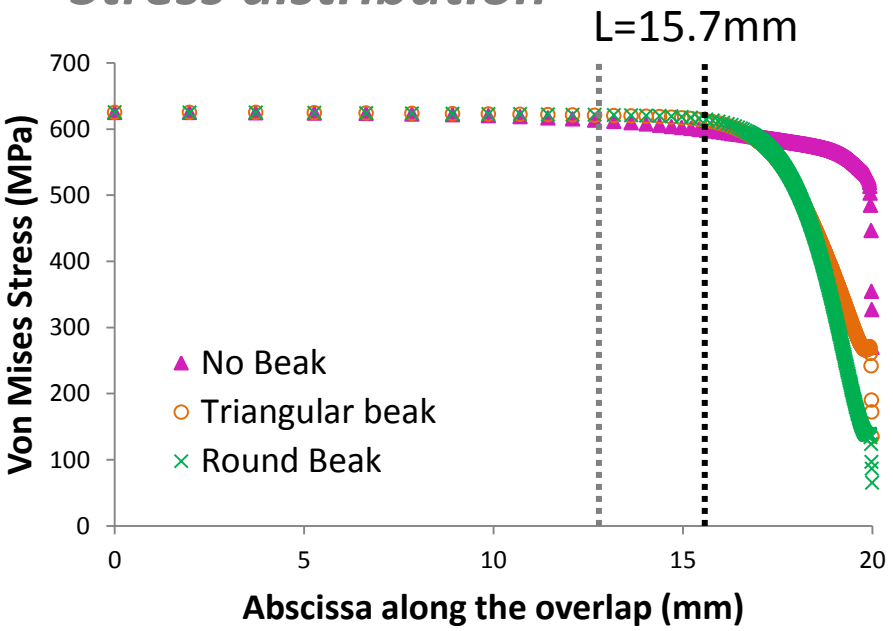


validation of specimen geometry – FE model

- ***Stress at the edge***



- ***Stress distribution***

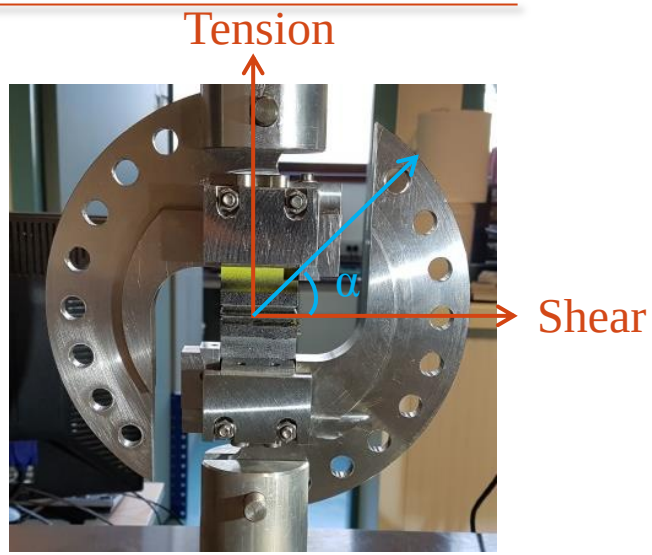


- Advantages of **curved adhesive**
  - Decrease stress concentration

- Advantages of **round beaks**
  - Decrease edge's stress concentration
  - Increase length where stress is constant

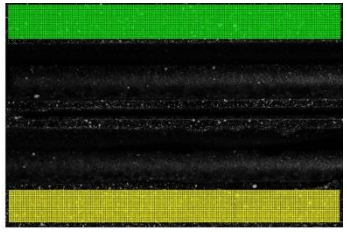
ARCAN tests

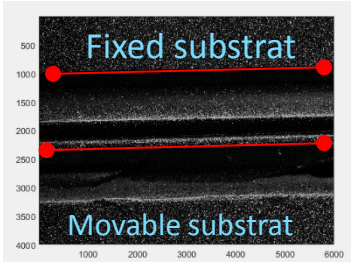
- ***Test conditions***
  - Modified Arcan on Zwick 10kN
  - Digital image correlation on the adherends
  - Speed rate for t = 0.2mm: 0.1mm/min
  - Speed rate for t = 1mm: 0.2mm/min
  - Loadings : tension, shear and tension-shear
- ***Matlab analysis***

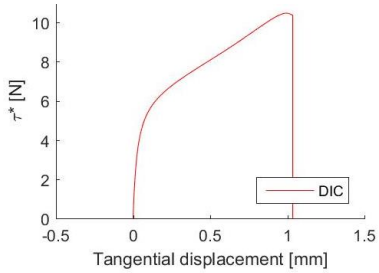


Arcan experimental set-up

DIC analysis → Image correction → Results

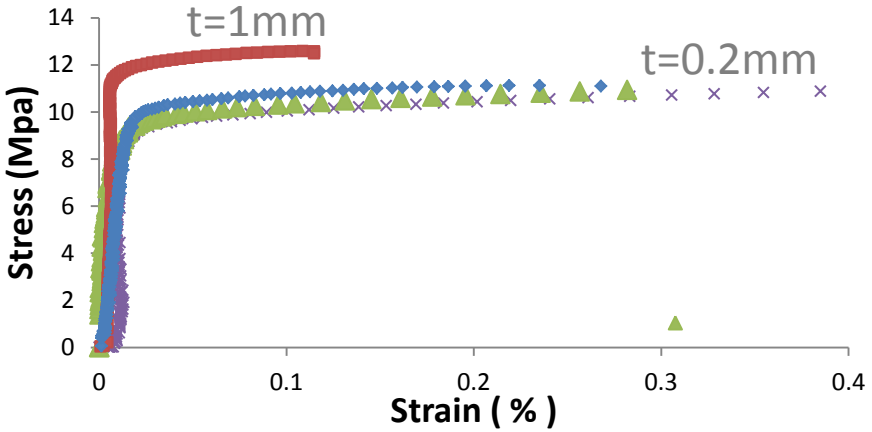


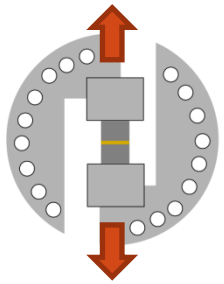




ARCAN Results

- *Tension: α=0°*



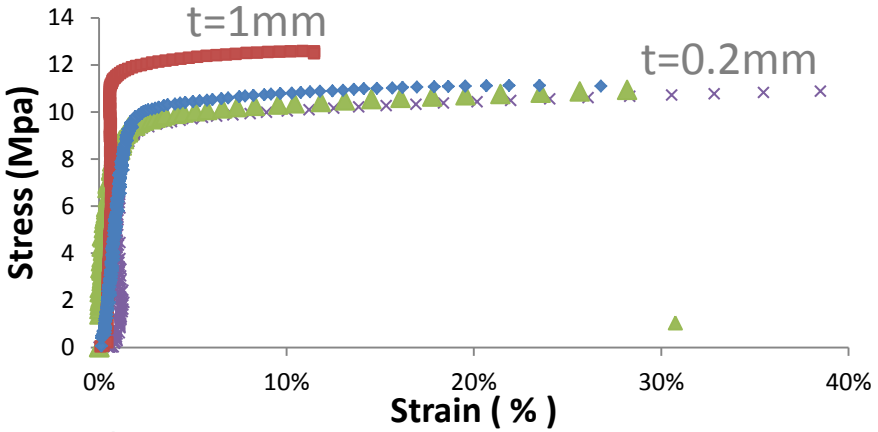


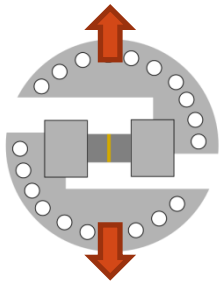
Tension

t (mm)	Yt (MPa)	Smax (MPa)
0.253(±0.06)	1650(±850)	10.56 (±0,24)
0.796 (±0.04)	1750 (unk.)	13.07 (±0,14)

ARCAN Results

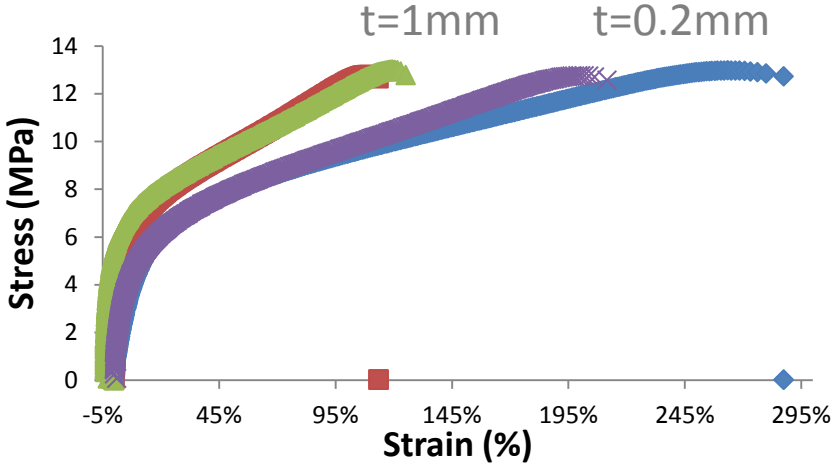
- *Tension: α=0°*





Tension-shear

- *Shear α=90°*

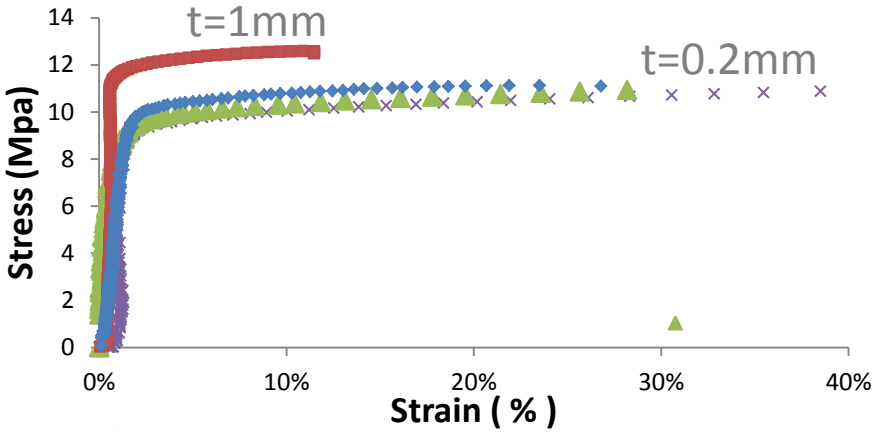


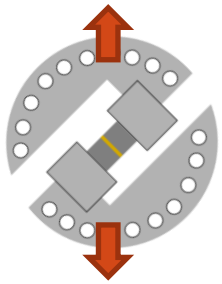
t (mm)	Smax (MPa)	εr (%)
0.183(±0.01)	12,51 (±0,11)	250 (±54)
0.765 (±0.21)	13.21 (±0,10)	119(±8)

t=1mm

ARCAN Results

- *Tension: α=0°*





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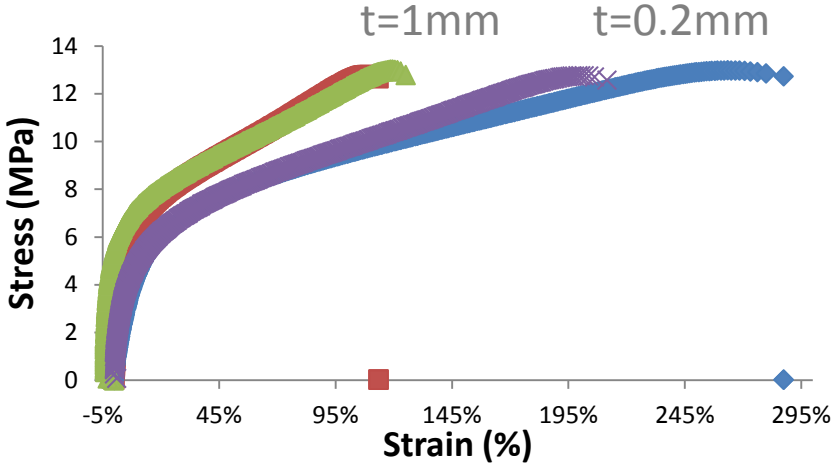
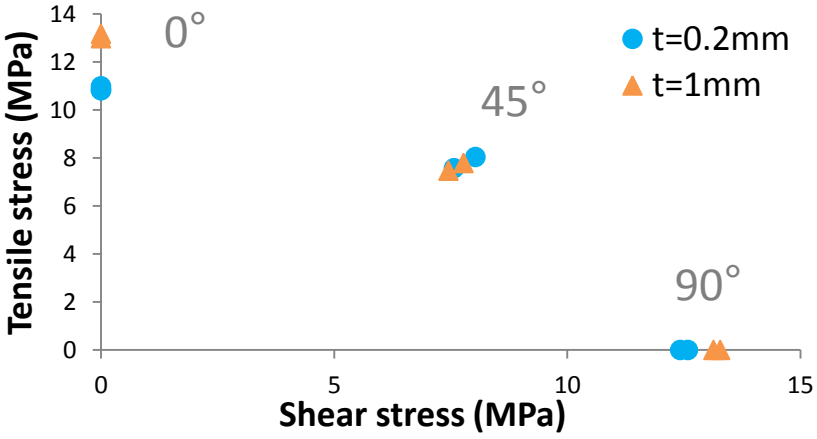


- *Failure envelope*

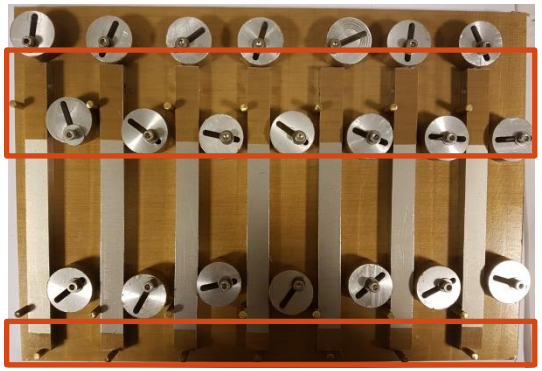


t=1mm

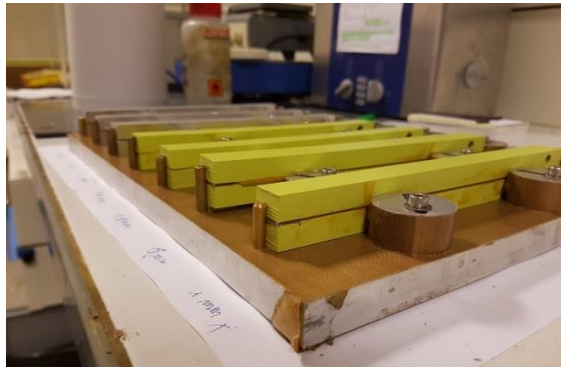
DCB specimen manufacturing

- ***Specimen specification***
  - Adherends' size : **195x15x10mm**
  - Overlap length : **145mm**
  - Initial crack : **35mm**
  - Calibrated thickness :
    - **0.2mm and 1mm**

PTFE film



DCB adherends with PTFE film for thickness calibration



DCB specimen assembly tool

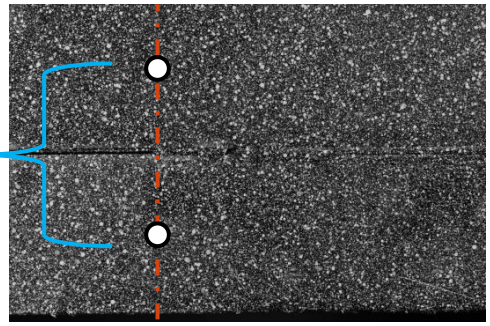
DCB tests

- ***Test conditions***
  - On a Zwick 10kN
  - Speed rate: 2mm/min
  - Digital image correlation on both sides
  - Cohesive failure

DCB experimental set-up

Crack tip

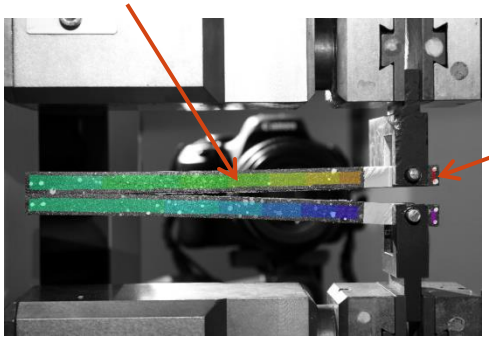
Openning measurement



initial crack tip taken up close

Adherend displacement

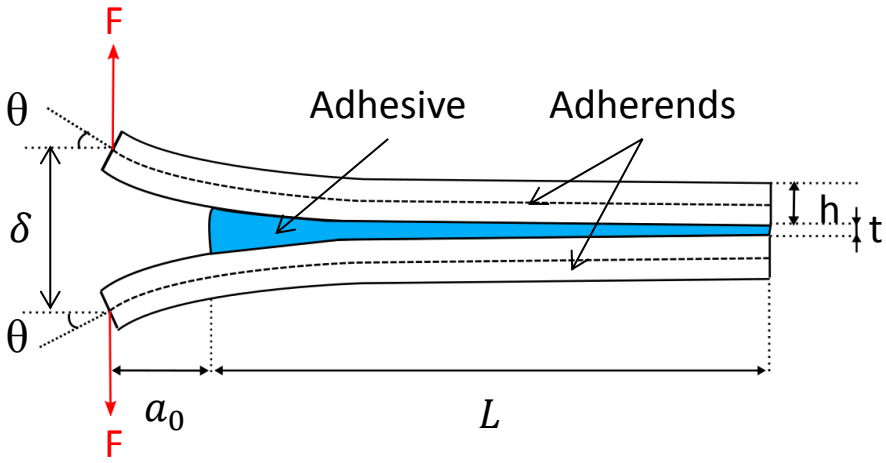
Adherend rotation



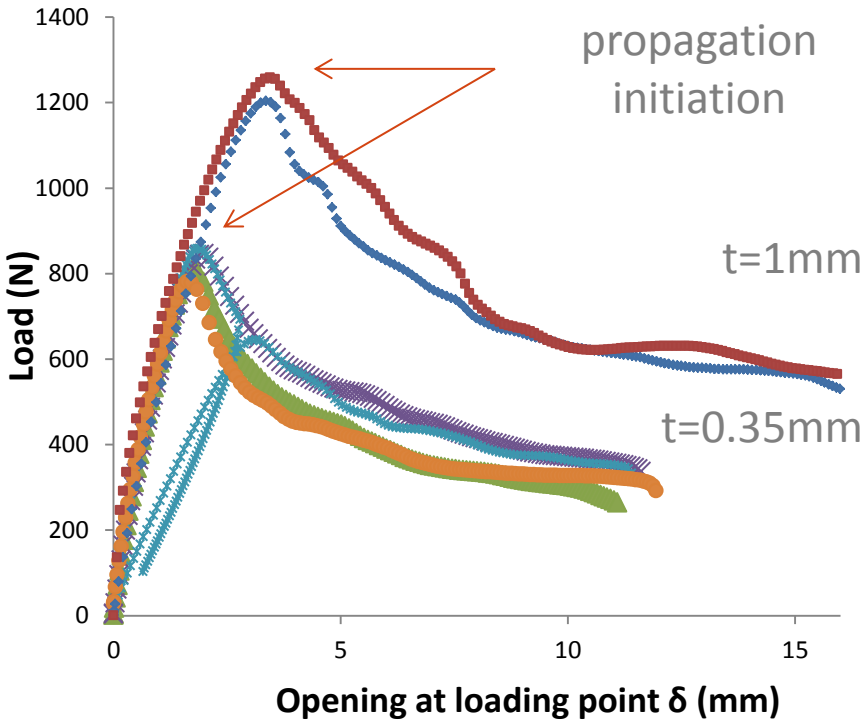
Full DCB specimen

DCB results

- ***Load displacement curves***
  - Hypothesis :
    - No plastic strain in adherends
    - Adhesive behavior not time dependent



Schematic representation of a DCB test

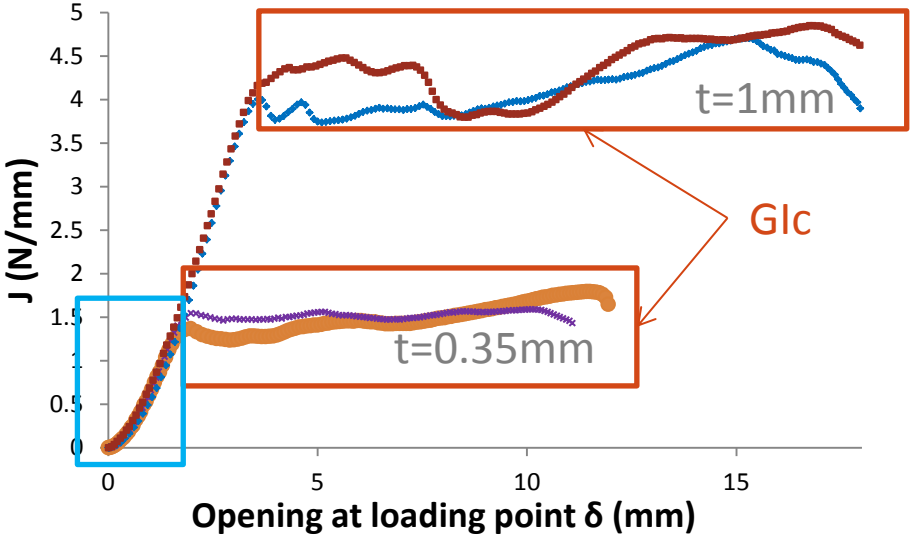


- Comments:
  - Modulus not thickness-dependent
  - Crack propagation thickness-dependent

DCB results

- ***Energy release rate***
  - J integral computation

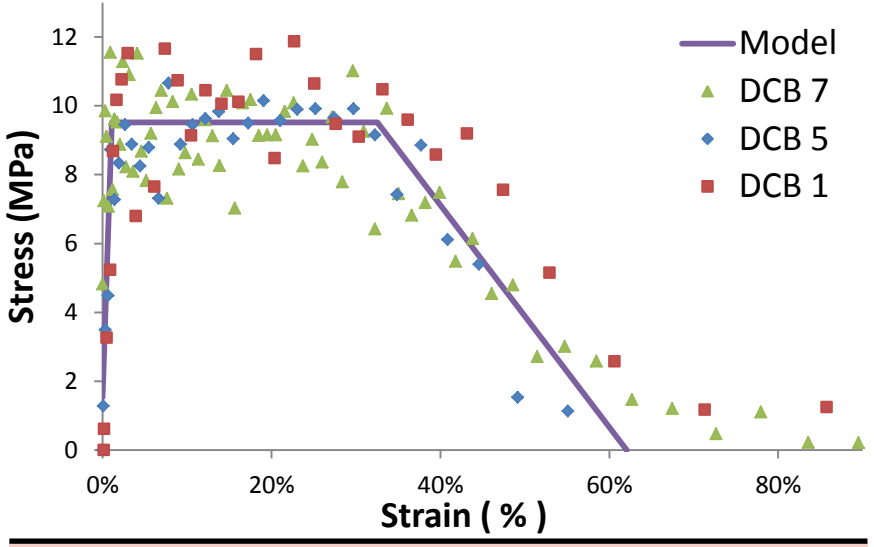
$$J = \frac{2F\theta}{b}$$ [Andersson2004]



t (mm)	GIc (J/m²)
0.35 (±0,06)	1730 (±347)
1.31 (unk.)	4270 (±180)

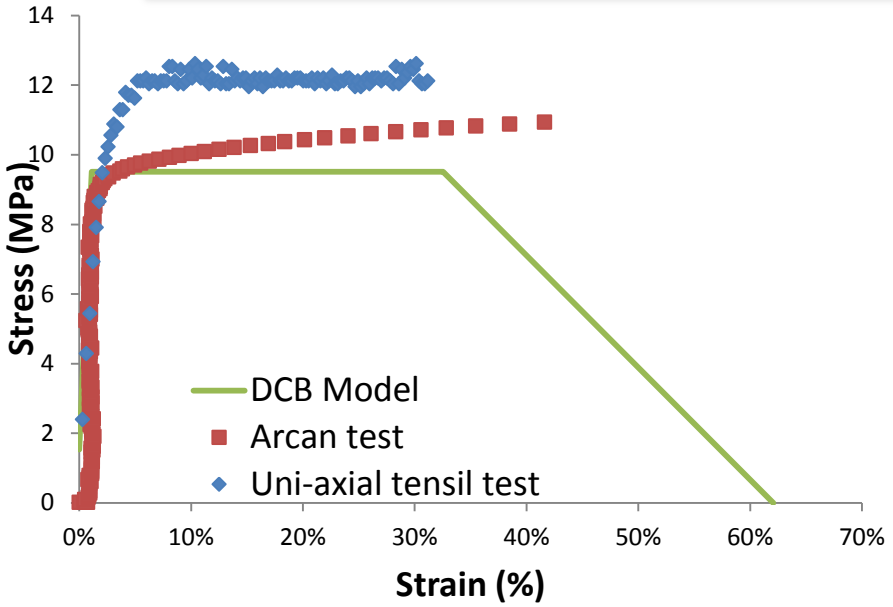
- ***Traction-separation law***
  - Stress computation for t=0.2mm

$$\sigma = \frac{dJ}{d\delta}$$



t (mm)	Yt (MPa)	Smax (MPa)	GIc (J/m²)	ε_p (%)
0.35 (±0,06)	762 (±162)	9.4 (±1,3)	1691 (±99)	82 (±19)

Strain-stress curves comparison



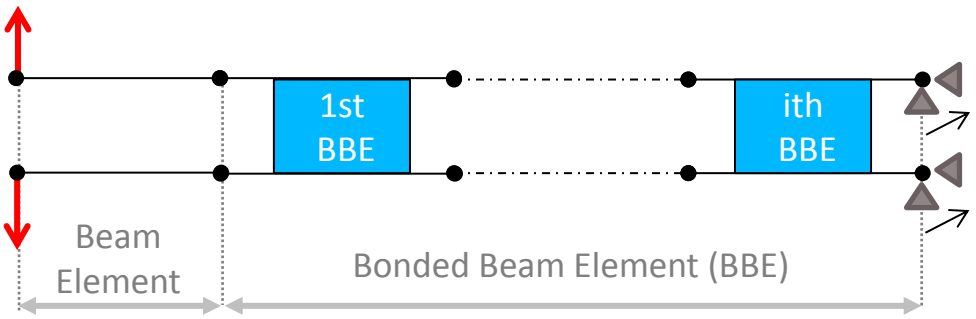
Test	t (mm)	Yt (MPa)	Smax (MPa)	A (MPa)
Tensile	3,96 (±1.6)	614 (±143)	11.8 (±1,6)	3.93 (±0.12)
DCB	0.35 (±0,06)	762 (±162)	9.4 (±1,3)	4.83 (±0.8)
ARCAN	0.253 (±0.06)	1650 (±850)	10.56 (±0,24)	2.57 (±1.8)

- ***Comments***
- 3 kind of tests with different stress state
- All tests have similar tendencies
- Modulus of the linear part are similar for DCB an tensile test
- Arcan tests have a significantly higher Modulus
- DCB and ARCAN tests have a similar plastic plateau
- Softening part only measurable during DCB test

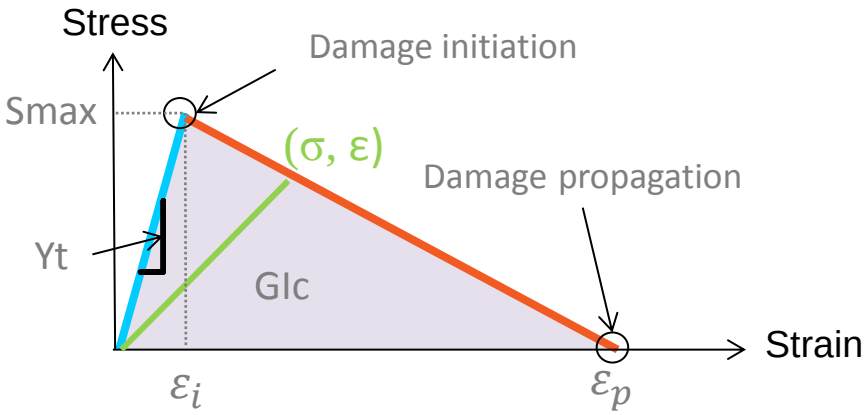
Which experimental results should be used for the numerical modeling of the adhesive failure behavior ?

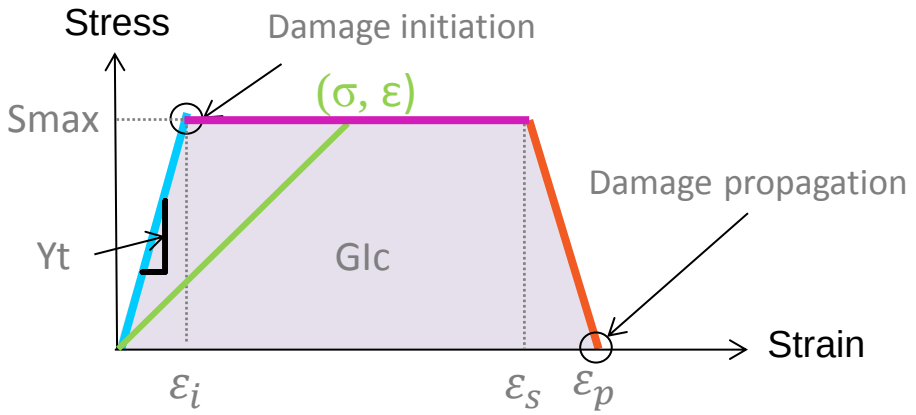
DCB models

- ***Macro element*** *[Lelias2015]*
  - 1D Implemented in scilab
  - 200 BBE in overlap length



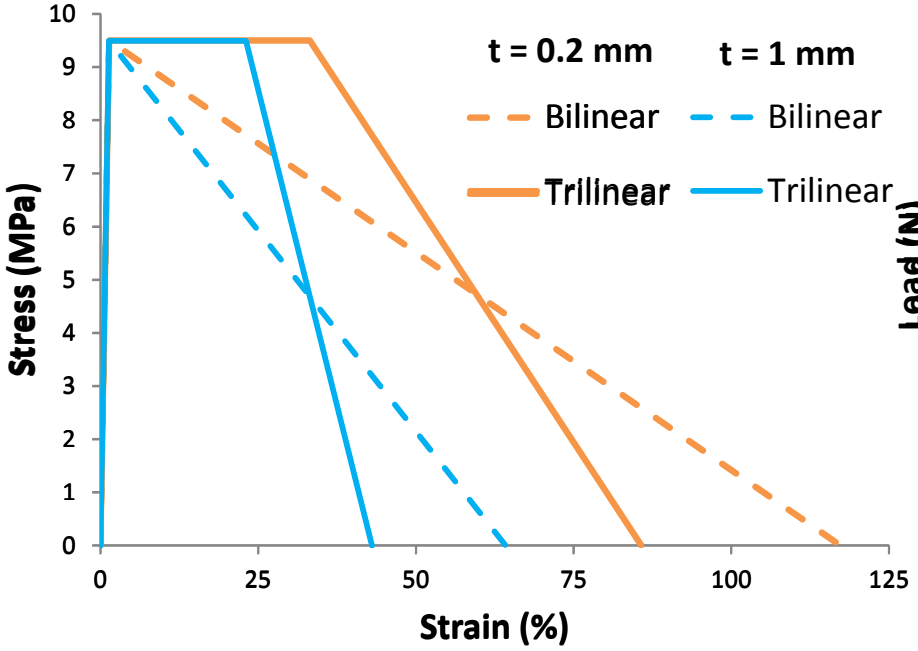
- ***Cohesive zone model***
  - Bilinear law as first approximation
  - Trapezoid law identified in DCB tests



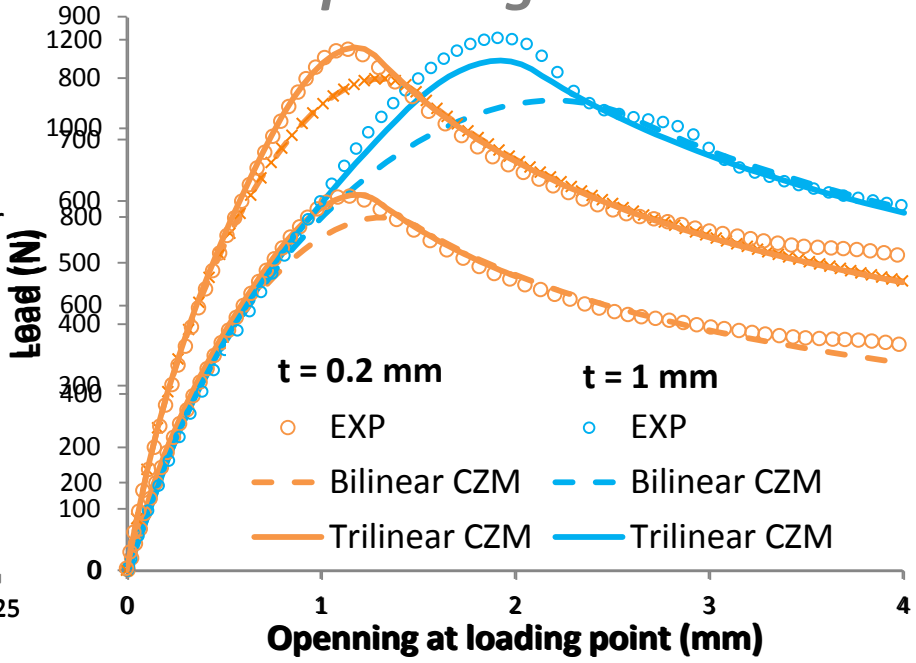


Numeric VS experimental

- ***Traction-separation law***



- ***Load-openning curves***



Adhesive thickness (mm)	Yt (MPa)	Smax (MPa)	GIc (J/m²)
0.35	710	9.5	1950
1.31	710	9.5	4000

- Propagation correctly predicted
- Stiffness correctly predicted
- Inverse method to find CZM for 1mm-bond

Conclusions & prospects

- ***Experimental results***
  - Characterization of the adhesive failure behavior
    - 3 differents tests : tensile on bulk adhesive, ARCAN and DCB
    - 2 thicknesses: 0.2mm and 1mm
    - Identifiaction of different stress-strain curves dependant on the stress state of the test
  - Adhesive thickness influence on the failure behavior ?
    - Increase of the energy release rate GIc
    - Increase of plastic plateau value
    - Increase of strain at failure in shear
- ***Numerical modeling***
  - Implementation of a bilinear and trilinear TS law in a ME model
  - TS law identified for 0.2mm-bond not directly usable for 1mm-bond
- ***Perspectives***
  - Experimental Identification of 1mm to 5mm-bond traction separation law
  - Sensivity study of CZM parameters
  - Implementation of a elasto-viscoplatic cohesive element

Thank you for your attention

www.institut-clement-ader.org

Toulouse, Albi, Tarbes

References

1. Norme, N.F EN ISO 527-2, *Plastiques-Détermination des propriétés en traction-Partie 2: Conditions d'essai des plastiques pour moulage et extrusion*, 2012
2. Cognard, J. Y.; Davies, P.; Gineste, B. & Sohier, L. *Development of an improved adhesive test method for composite assembly design*, Composites Science and Technology, 2005, 65, 359-368
3. Andersson, T. & Stigh, U. *The stress--elongation relation for an adhesive layer loaded in peel using equilibrium of energetic forces*, International Journal of Solids and Structures, 2004, 41, 413-434
4. Lelias, G.; Paroissien, E.; Lachaud, F.; Morlier, J.; Schwartz, S. & Gavoille, C. *An extended semi-analytical formulation for fast and reliable mode I/II stress analysis of adhesively bonded joints*, International Journal of Solids and Structures, Elsevier, 2015, 62, 18-38