Short Beam Strength Tests on Woven Composite Specimens

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Introduction

- **Context**

CRIAQ project aimed at identifying material parmeters for Progressive Damage and Failure analysis of woven composite composite under tensile, compressive, **shear**, bending and impact loading

- Material supplied by **Aerospace industrial** partners
- Testing, Analysis and Identification performed by U**niversity partners** - →**M3C Ulaval :**
  - Apply Testing process standard for UD composites to woven composite materials, observe the difference
  - Develop material model and associated material parameters
  - Implement material behavior using user material within ABAQUS
  - Validate models results against experimental results using standard specimens (3PB, OCT, SBS, drop tower LVI, HVI, etc.)
  - Try to apply invere identification process for predictive model parameters

Introduction

- Laboratory M3C Ulaval :

  - Modelling material behavior using **user's material subroutine** with ABAQUS
  - Testing woven composite materials for model parameters
  - Compare model and experimental results
  - **Inverse Modeling**: Try to obtain a model to replicate the same material behavior

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Introduction: Timeline for some tests

Tests		A13	W14	S14	A14	W15	S15	A15	W16	S16	A16	W17
Part 1: Characterization tests												
1.1 Quasi-static, low and high strain rate., out-of-plane + in-plane compression		X	X	X	x	x						
1.2 Fracture tests for delamination behaviour		X	X	X	X							
1.3 Cyclic loading for plasticity		X	X	X								
Part 2: Validation tests												
2.1 Low velocity impact on flat panel (hemispherical impactor) 2.1.1 Postmortem C-scan analysis				X	X	X	X	X	X			
2.2 Three-points bending tests on coupons 2.1 Short Beam Shear Test				X	X				x	x	x	
2.3 OverHeight Compact Ternsile tests							X	X	x	x	x	x
Part 3: Bird impact, Hail Impact, Crash tests			X	X	X	X				x	x	x

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Material tested

- Woven composite material :
  - Carbon fibers (woven pattern)
  - Polymer epoxy matrix
  - Fabrication in autoclave in this case
  - 28 plies material, layup [0,90]14s
  - Material used for aerospace structures

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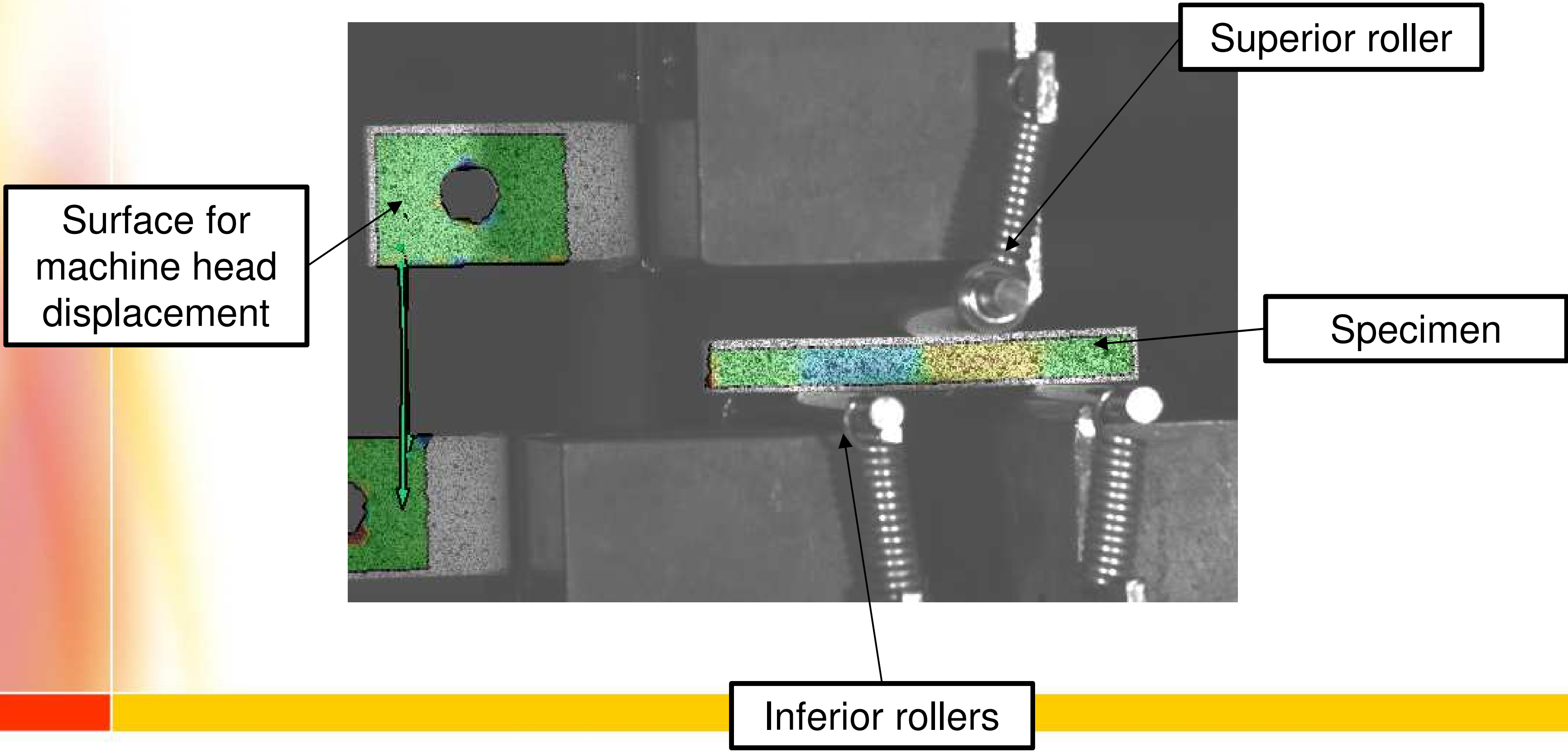
Testing and results: focus SBS

- ASTM D2344 standard used to get shear properties in the out-of-plane direction
- Specimen dimensions slightly modified to get more accurate results (based on experience)

  5.7 mm X 5.7 mm X 40 mm
- Superior roller : 6.35 mm
- Inferior roller : 3.175 mm
- Distance between rollers : 22.8 mm (4 x thickness)
- Standard setup from ASTM D2344
- Parameters identified in this test : maximum shear stress and strain and elastic shear modulus:
- Use virtual fields methods

Testing and results : ARAMIS set up



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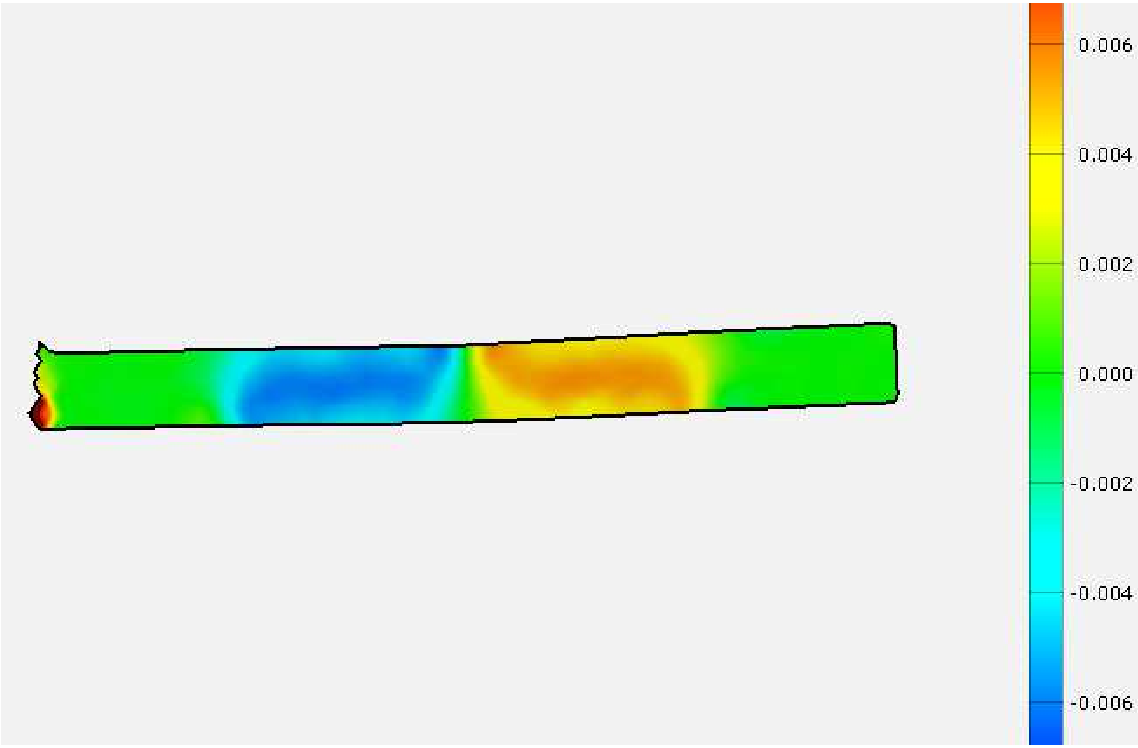
Testing and results: ARAMIS DIC

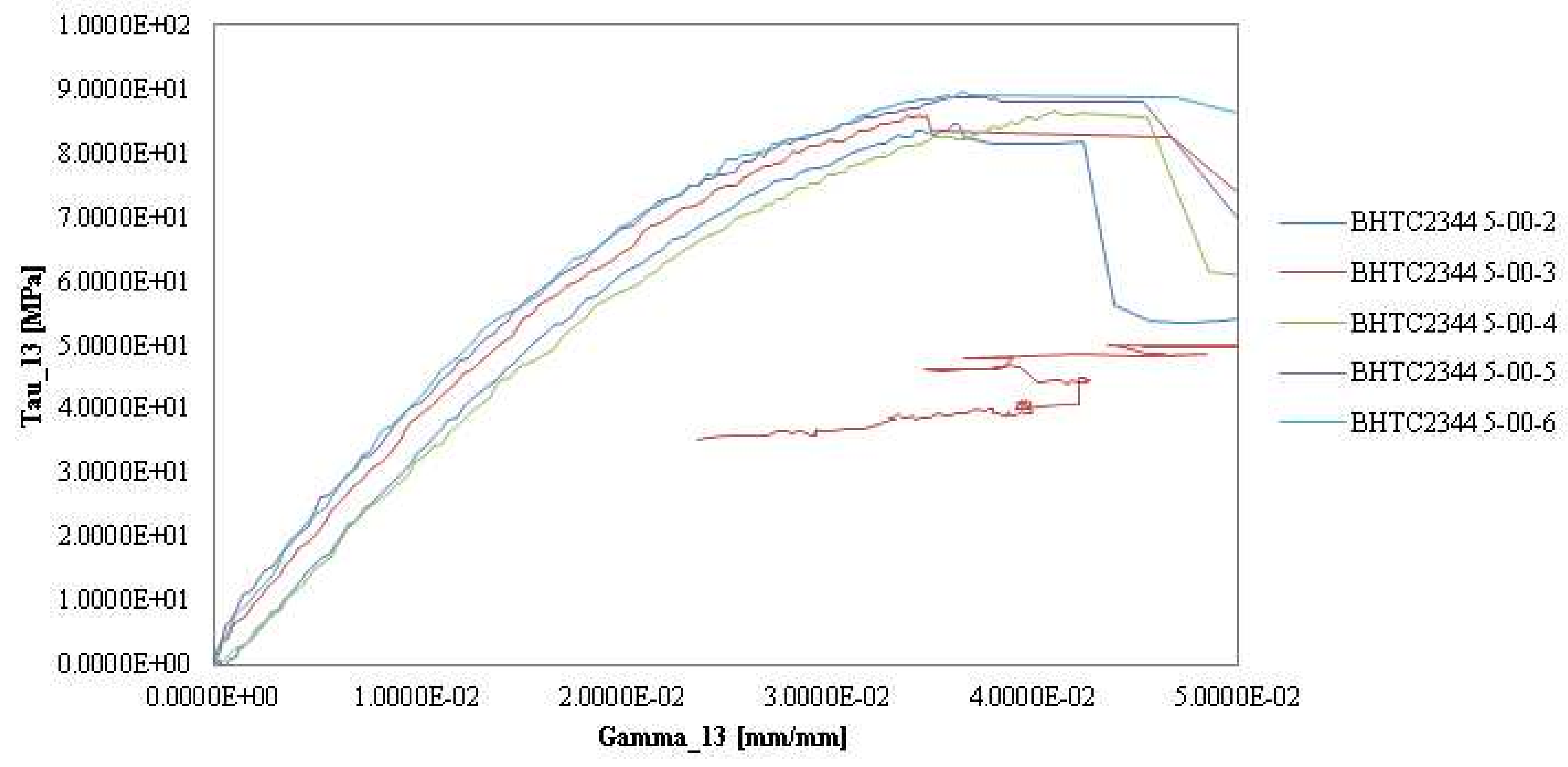
- Experimental results (epsilon 13)



Testing and results

- Experimental results (epsilon 13) on the neutral axis
- Some discontinuities because of the camera noise

Testing and results: (transverse shear stress vs shear strain curves-→ plasticity or Ramberg-Osgood model can be used)



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Testing and results

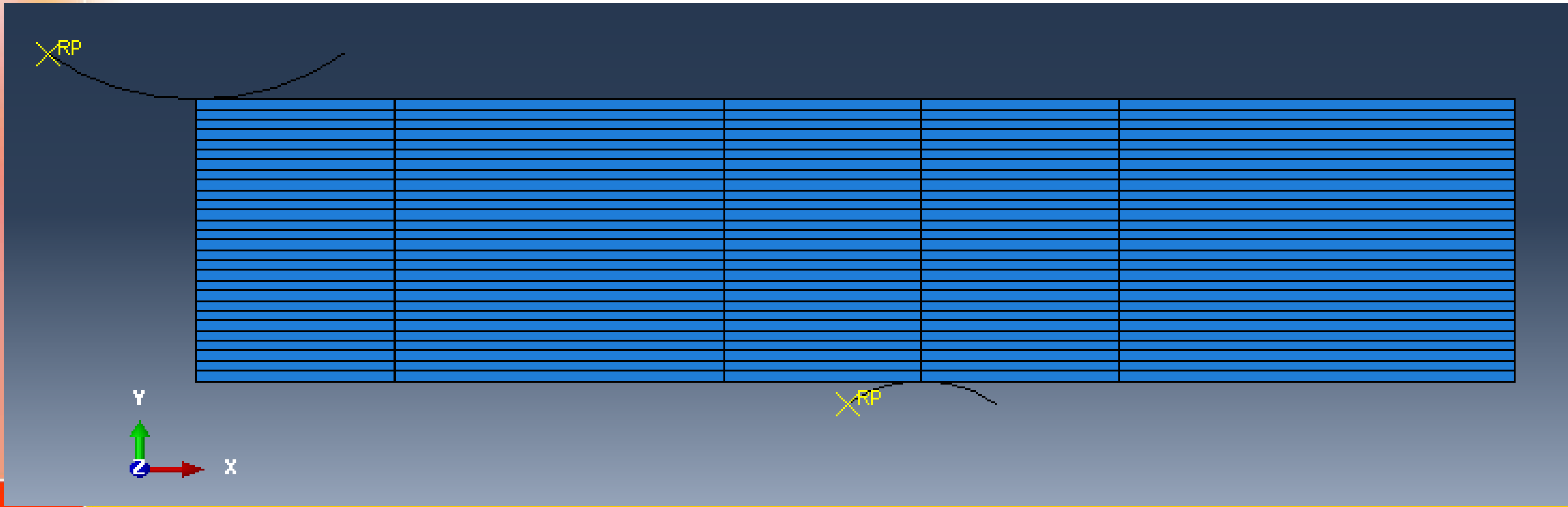
Specimen	Ultimate Shear Strength 13 [MPa]	Ultimate Shear Strain (gamma_13) [%]	Elastic Shear Modulus [GPa]
2	84.47	3.61	3.40
3	85.86	3.45	3.59
4	86.38	4.11	3.27
5	88.73	3.69	3.73
6	89.50	3.67	3.95
Mean Value	87.00	3.70	3.59
Std	2.07	0.244	0.268
CV %	2.39%	6.60%	7.48%

Finite element modelling

- User material **3D-ULavalPLyFabric**-(improved MAT162 from LS-DYNA) implemented in ABAQUS
- 40 material parameter for an explicit analysis
- Parameters from testing and from a mathematical formulation
- Mass scaling used for a faster analysis
- C3D8R solid elements
- Mesh refined near contact surfaces
- Elastic model used for parameter identification, more effective but can also be used with a VUMAT

Finite element modelling

- Geometry : quarter of a specimen with boundary conditions for efficient calculations
- Rigid rollers with reference points for load and displacement measurements



Finite element modelling

- Boundary conditions and loads :
  - Superior roller : displacement of 1 mm in the y direction
  - Inferior roller : encastré
  - Symmetry in the x and y directions to reduce calculations

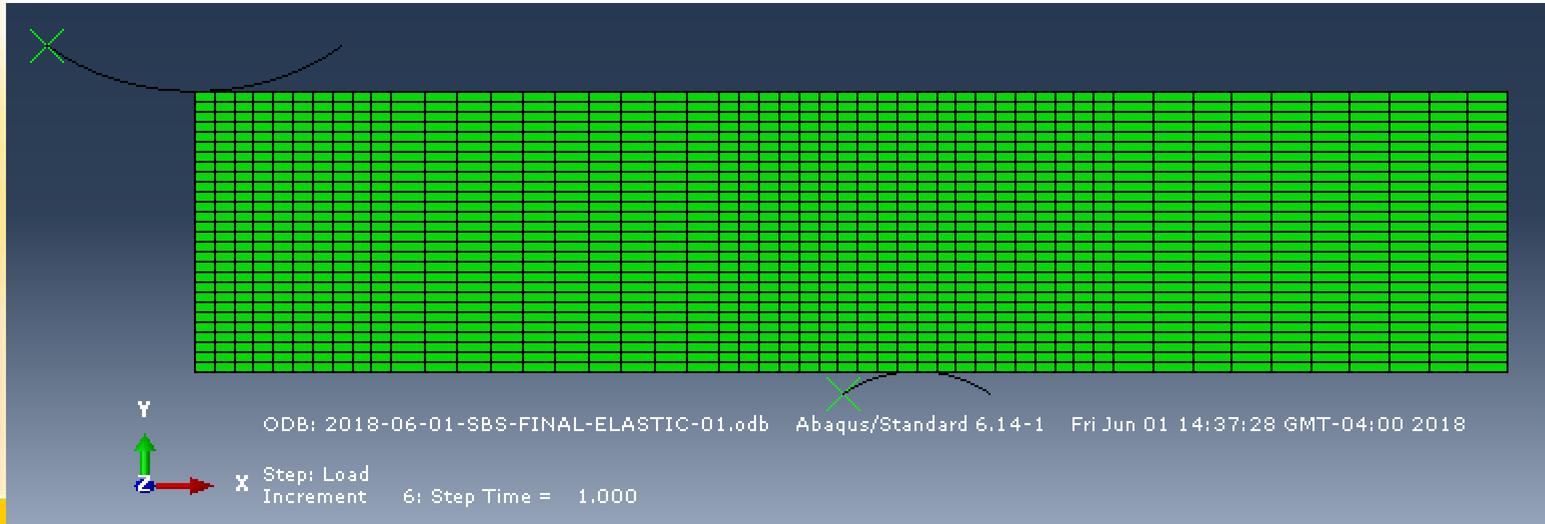
Finite element modelling

- Model interactions

  - Slight friction on rollers and hard contact with the specimen
  - Cohesive surfaces between plies
  - Gf Parameters obtained from experimental testing (Beckelynck, 2016)
  - More effective than cohesive elements
  - Can be used to get delamination when the material fails

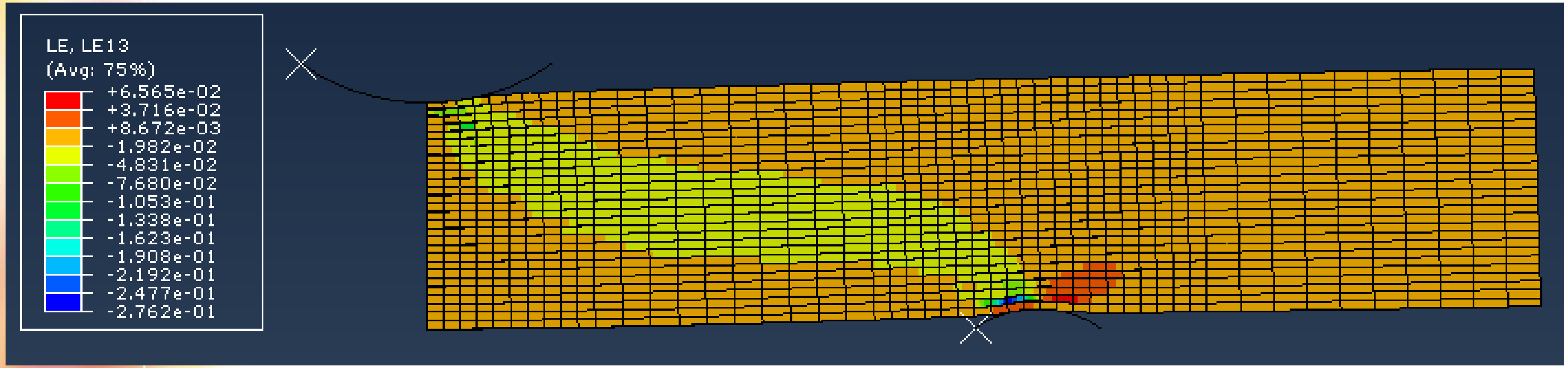
Meshing

- 10 elements per partition
- Finer mesh near rollers
- Elements seem homogeneous, reduce stress concentration



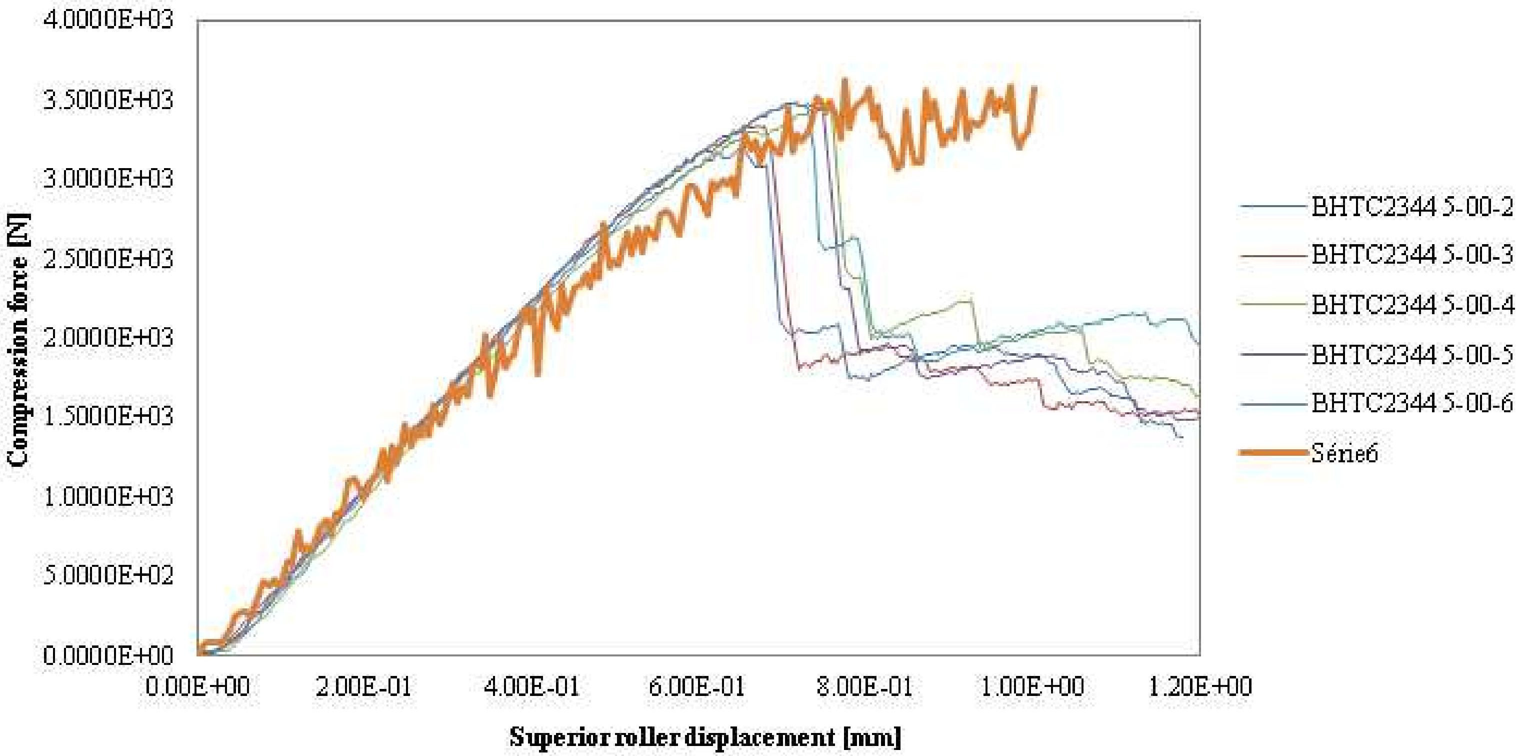
FEA results

- With a user material 3D-ULAVAL-PLYFABRIC model162
- Shear strain distribution (gamma 13)



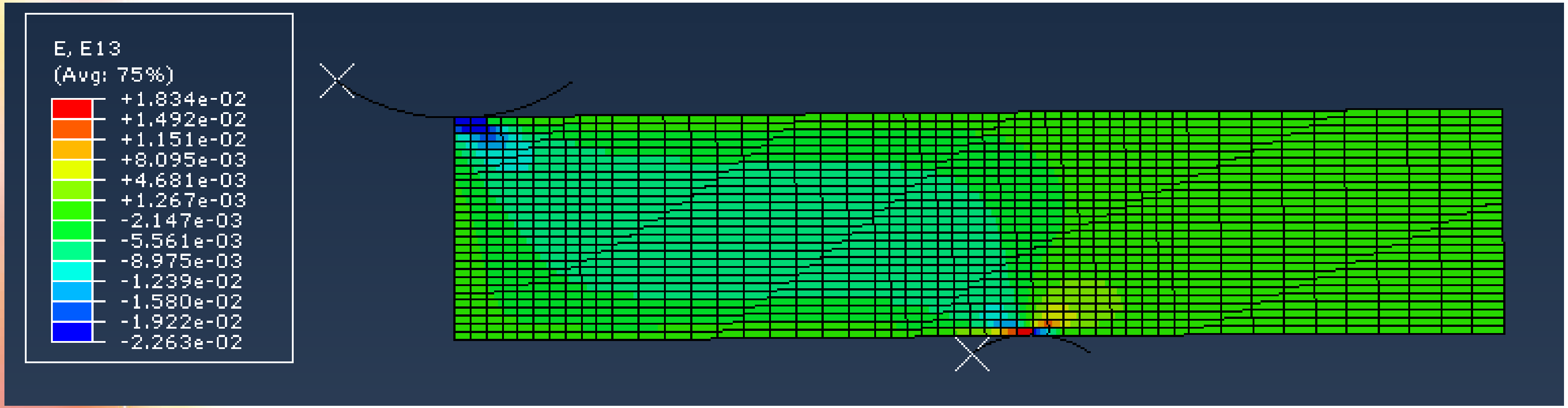
FEA results

- With a user material 3D-ULAVAL-PLY-FABRIC model162 (force-displacement)
- Slope and damage seem good, but delamination value should create a drop



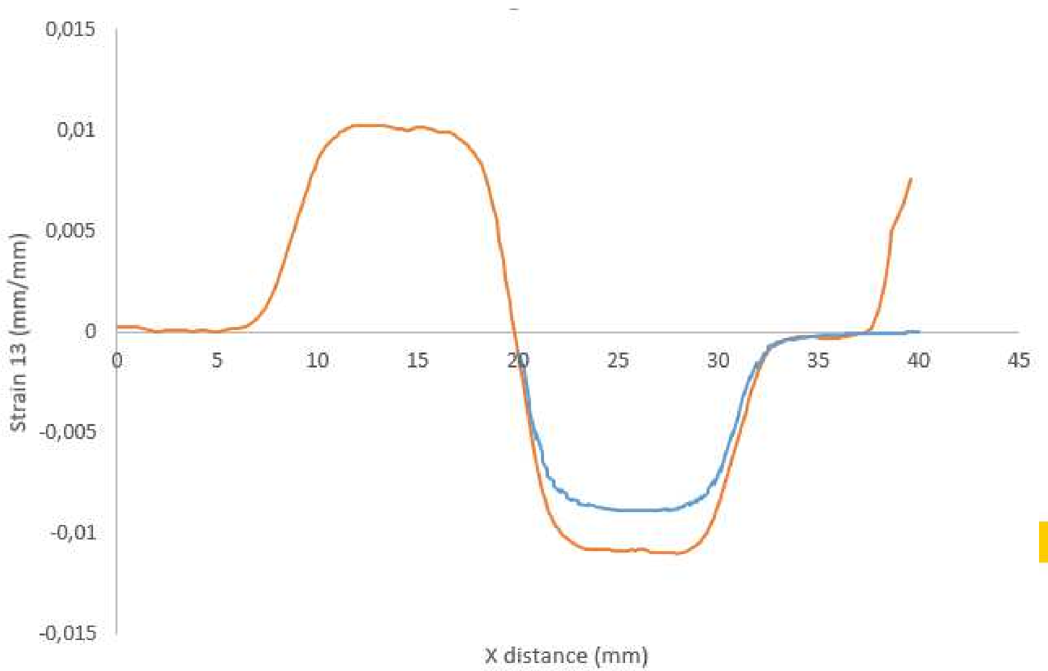
FEA results

- Assuming an elastic material behaviour



FEA results

- With an elastic material, results in blue color compared with experimental data
- Some differences between the standard and the model



Inverse problem

- ASTM standard uses beam theory for the stress values
- A woven composite can differs from unidirectionnal material
- Using the digital image correlation system → Inverse problem
- Goal : Is it possible to Get the same results as the experimental results
- In our case, strain is used for the identification, other variables can be used as well

Parameter identification algorithm

1. Use a first approximation for properties (ASTM D2344)
2. Run FEA from the given properties
3. Compare experimental results and FEA results
4. Perform a nonlinear optimisation technique to define a parameter variation
5. Add the variation to the properties
6. Loop the steps 2 to 5 as long as the convergence parameter is not satisfied
7. Get the identified properties

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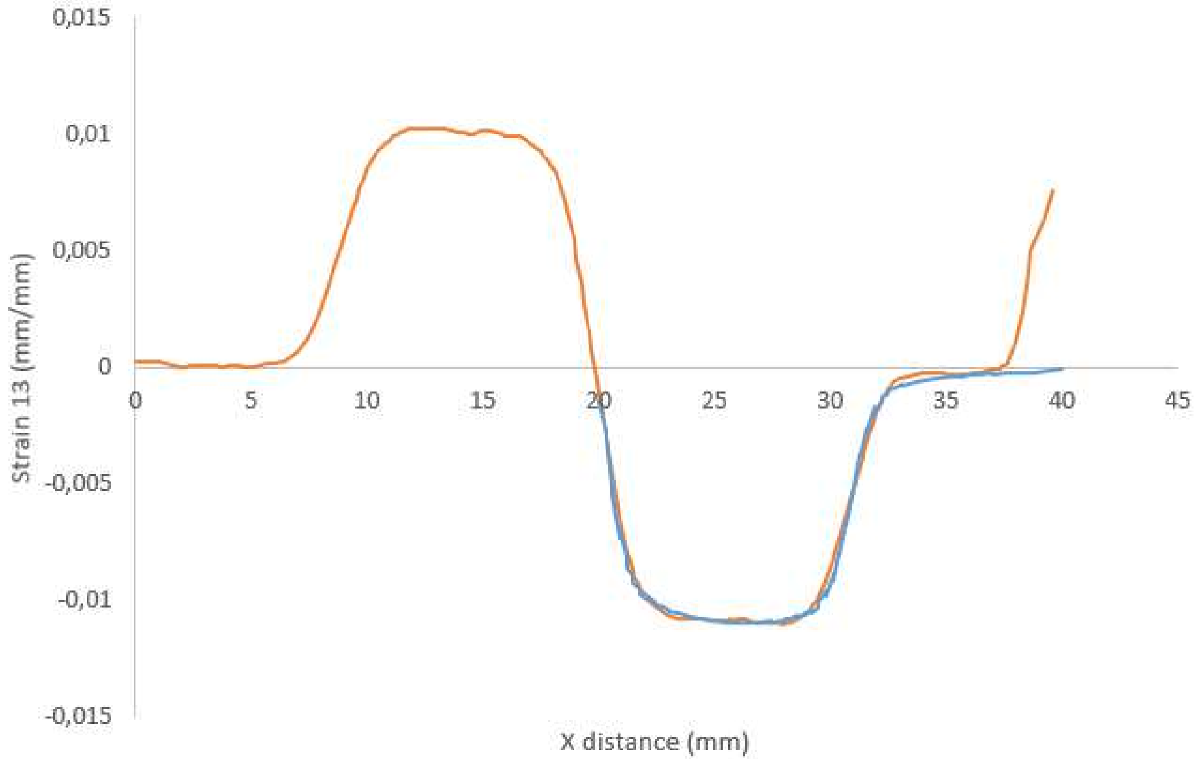
Results from identification

- Elastic modulus : 2.5 Gpa compared to 3.5 Gpa previously after using 3D-ULAVAL-PLY-FABRIC
- Strain distribution :



Conclusion

- Model developed to get the same material behavior with a finite element analysis
- Short beam strength test for shear parameters in the out-of-plane direction
- Difference between theory and experimental properties values
- Inverse identification to get the real values from the strain field
- FEA can estimate more accurately the experimental results
- Further work to improve modeling process

Thank you for your attention

Questions or comments?

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