DIMEAS - Mechanics and Aerospace Engineering Departments
«Innovative Electric and Hybrid Vehicles»
Research Group

Modelling and testing of Thermoplastic composite parts integrating process simulation

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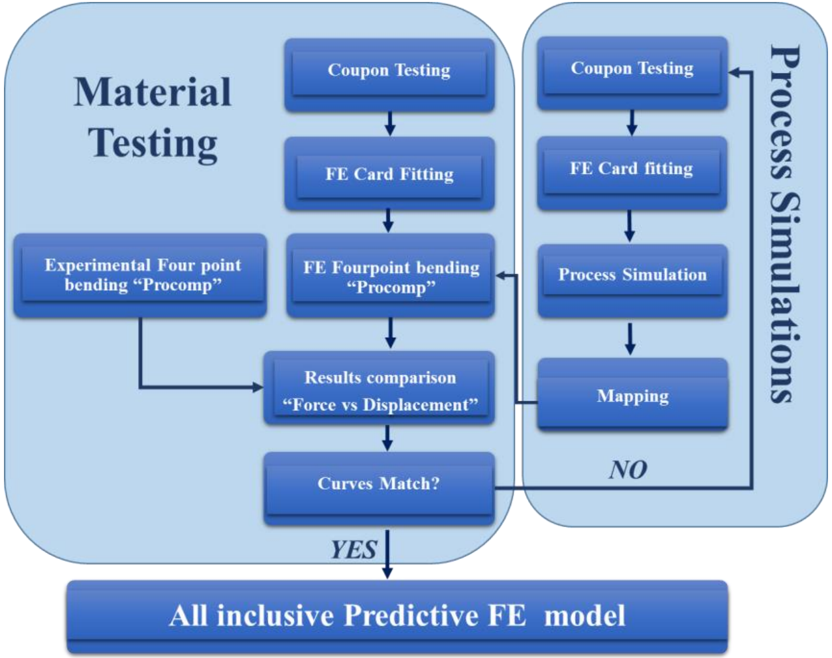
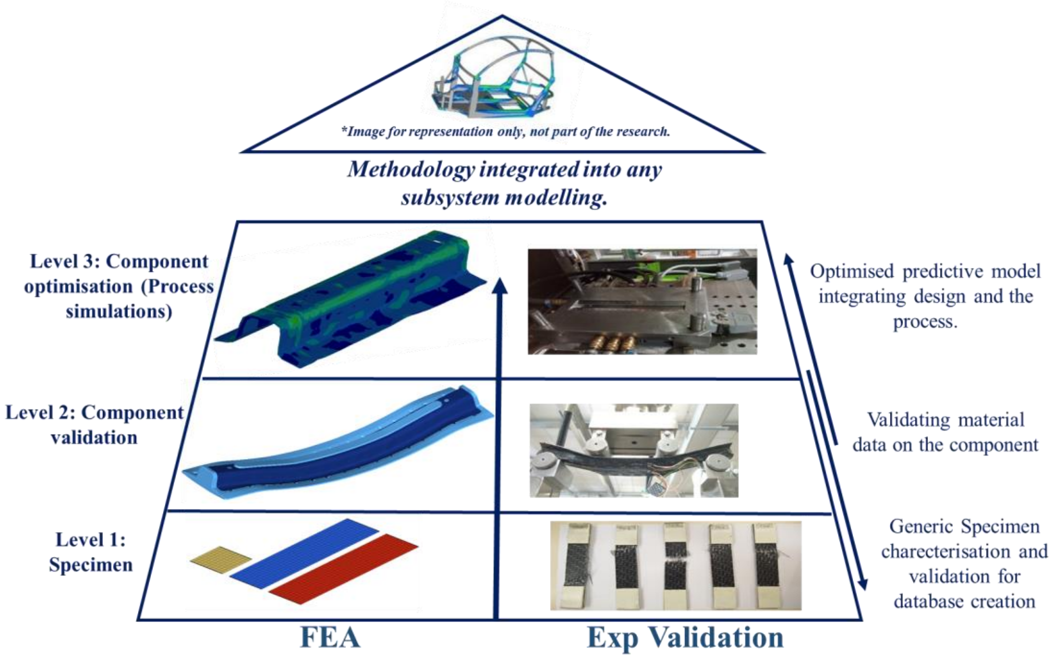
PhD Research Activity





Level 1: Material FEA and Experimental tests

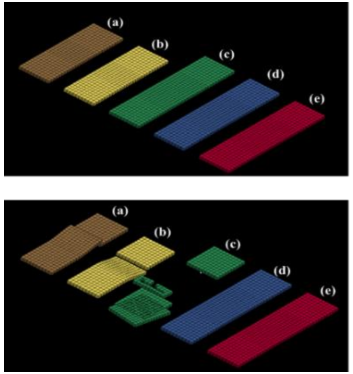
5 Specimens tested for each behaviour

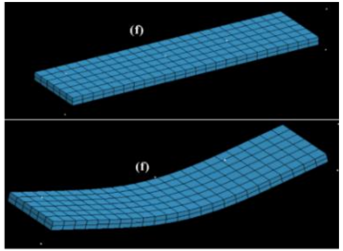
a: Tensile Test
ASTM D 3039

b: Compression Test
ISO14126:1999

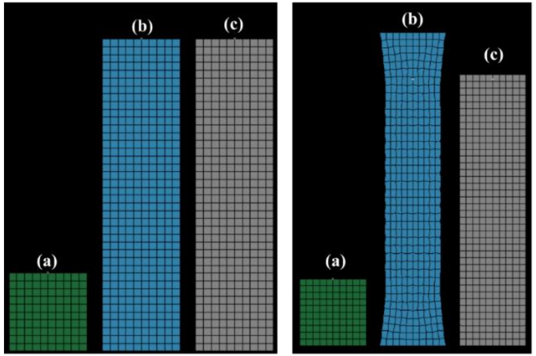
c: Bending Test
ISO 14125:1998

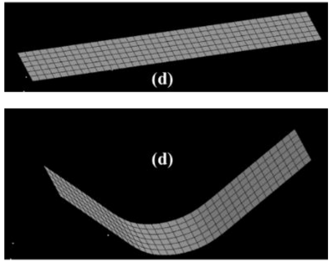
d: Shear Test
ISO 14129: 1997





(a) Compression 0° test
(b) Compression 90° test
(c) Shear test
(d) Tensile 0° test
(e) Tensile 90° test
(f) Flexion test validation

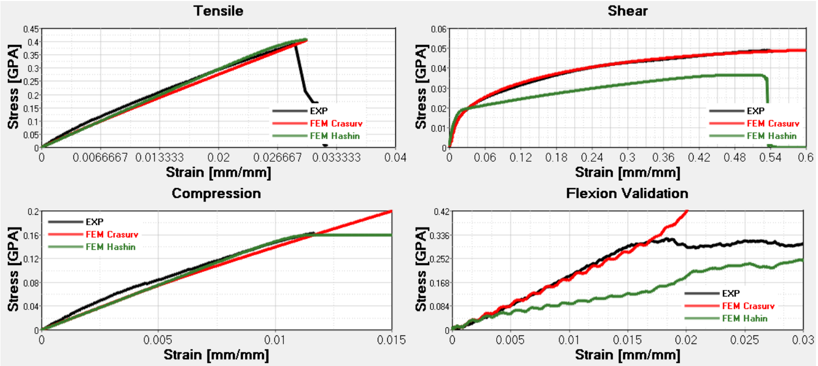




(a) Compression test
(b) Shear test
(c) Tensile test
(d) Flexion test validation

FE material specimens: solid and shell models

Level 2: Card fitting & component testing



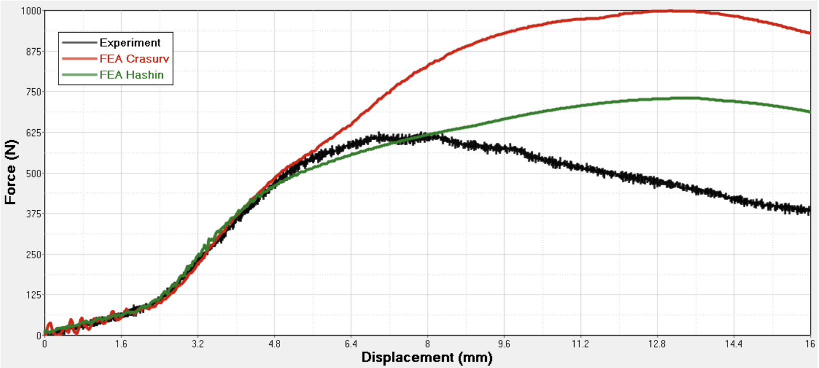
Specimens Material Card

CRASURV (modified Tsai-Wu Formulation)

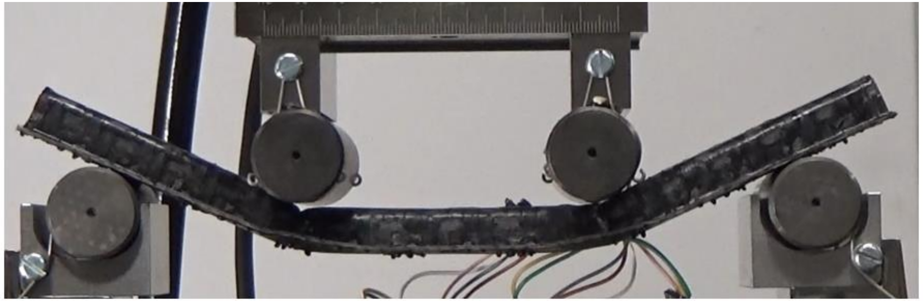
- *Orthotropic plasticity hardening Based on Tsai-Wu*
- *Quadratic, interactive stress-based criterion*
- *Failure criteria not directly associated with failure modes.*
- *Do not take into account different damage mechanisms leading to failure*

Hashin failure criteria

- *Failure criteria associated with failure modes.*
- *Considers non-homogenious character of composites leading to failure.*
- *Considers fibre fracture, transverse matrix cracking and shear matrix cracking.*

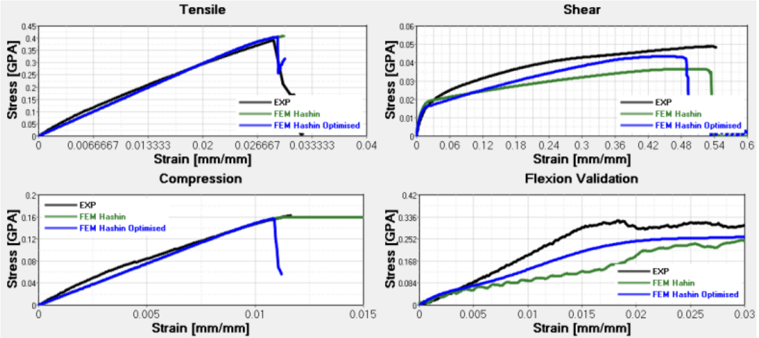


Component Force vs. Displacement Curves



Four-point bending experimental test on component

Level 2: Card fitting optimisation & Component testing

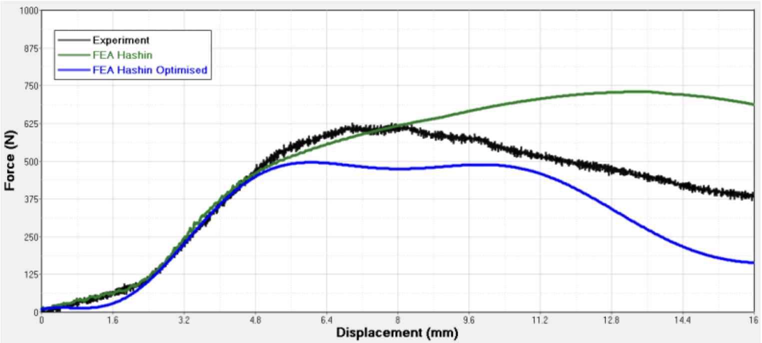


Specimens Material Card

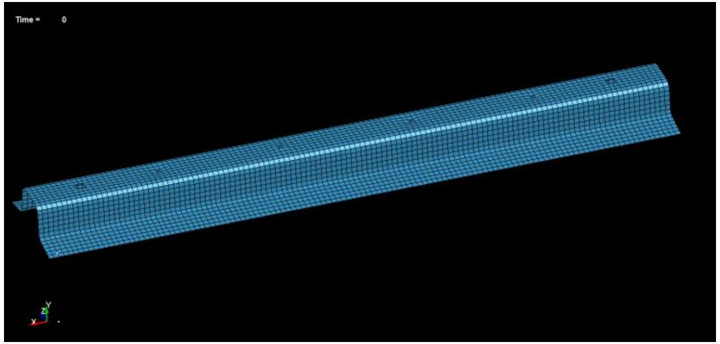
Hashin: Optimised

- *Optmisation considerations for Hashin for better results match.*
- *Different failure modes identified and implemented for optimum fit.*
- *Shear strength increased slightly for a better fit which is validated with the flexion curve.*

Overall for a better composite fit a polynomial criterions such as CRASURV (Tsai-Wu) can be safely discarded for Hashin as detailed, where the composite failure can be distinguished induvidually.

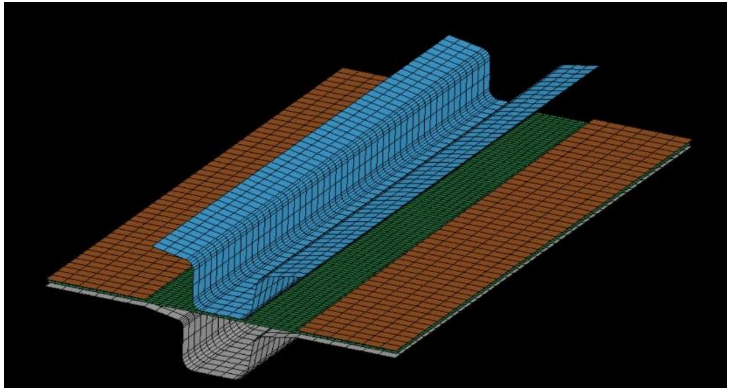


Component Force vs. Displacement Curves



Four-point bending FEA on component

LEVEL 3: Process Simulations and mapping

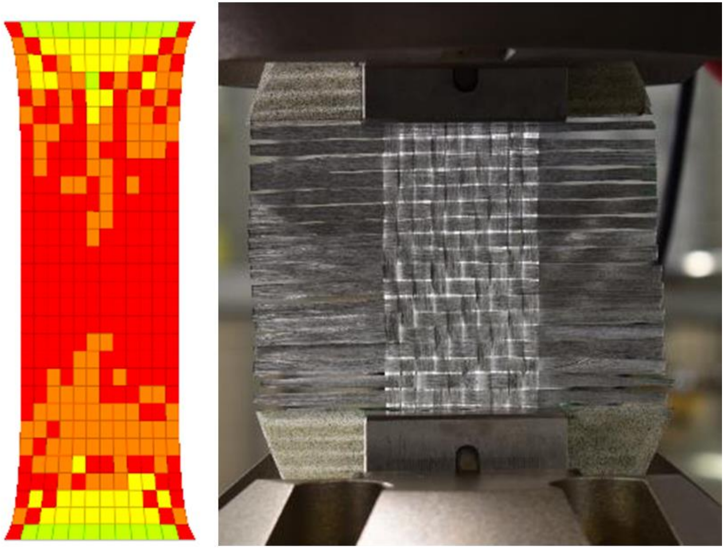


Process simulation Setup

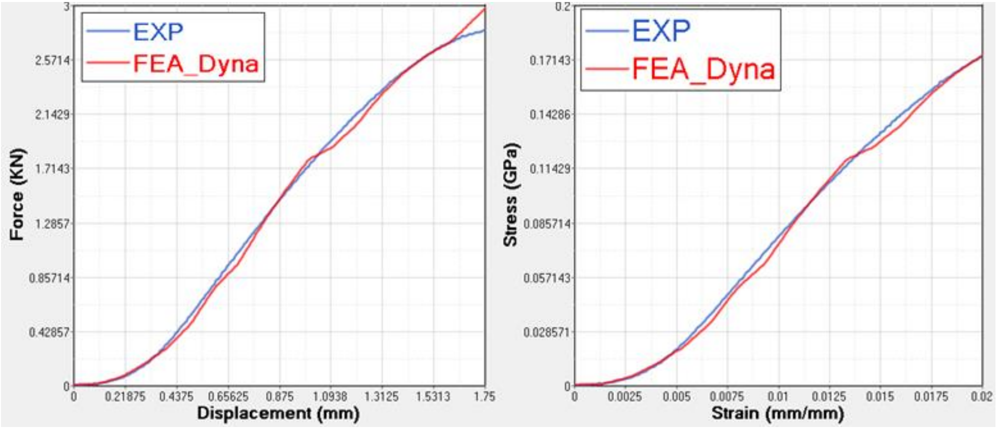
- *Process simulation setup to simulate the thermoforming of composite laminate*
- *Material model of blank at forming temperature: additive split between* ***isotropic, elasto-plastic matrix and anisotropic hyper-elastic fibers.***
- *Process paramters required for process simulation:*
  - *Tensile modulus and the associated tensile curve.*
  - *Shear modulus and the associated shear curve.*
  - *Resin parameters at forming temperature.*
  - *Bending modulus.*
  - *Frictional coefficients (dynamic and static).*

Tensile Tests on Fabric material

- *5 specimens tested.*
- *Tensile test done for fabric material (not for laminate).*
- *Tensile test results assumed to be the same for both dry fabric and laminate at melting temperature.*

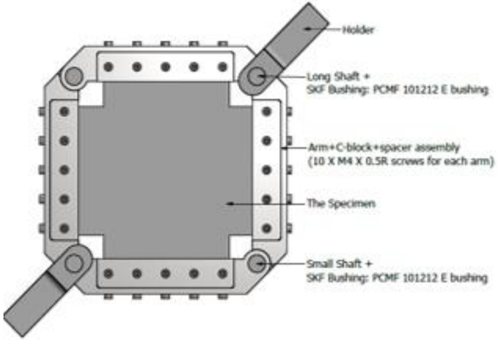


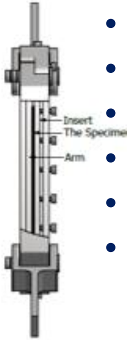
Simulation and Tensile tests (ASTM D5035)



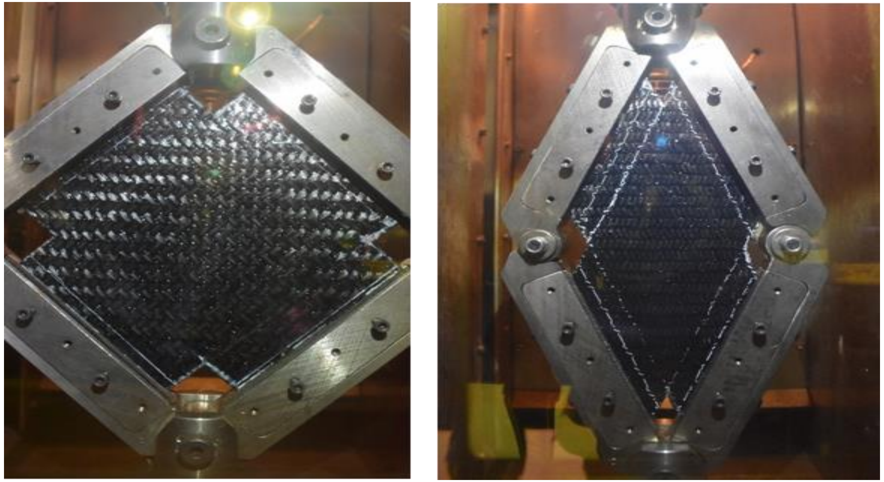
Tensile curve fitting

Shear Tests: Trellis Frame

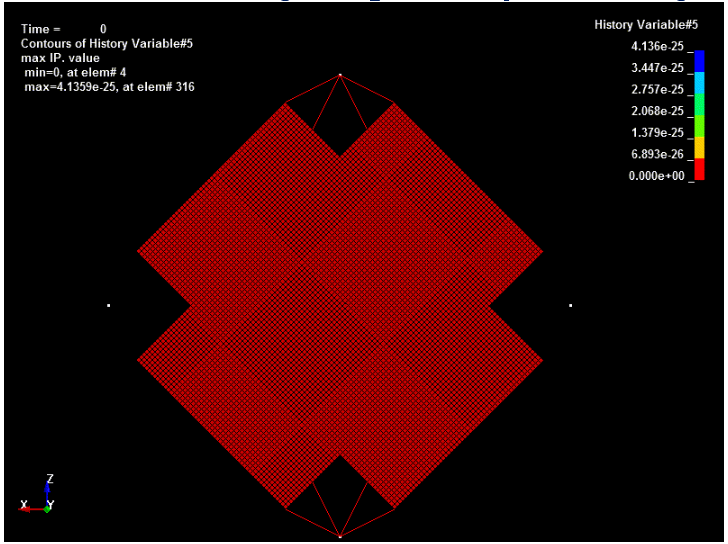




- *Shear induced on a fabric using support on all four sides.*
- *5 specimens tested.*
- *Done on both fabric material and laminate.*
- *Fabric testing: pure shear properties*
- *Laminate: fabric shear properties + resin properties*
- *Difficult level: Complications involved in avoiding compressive forces along the edge on the specimen.*



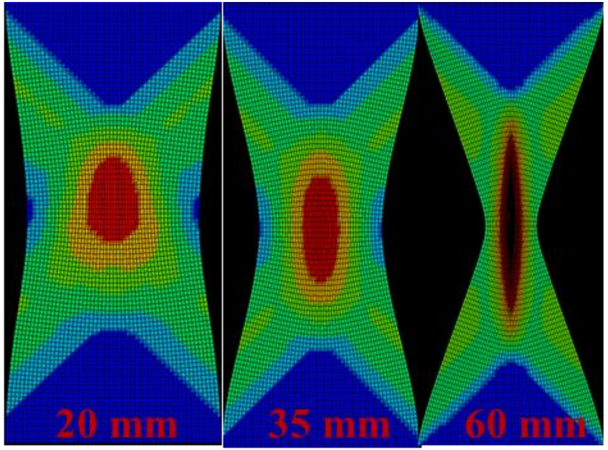
Trellis Frame Laminate in thermal chamber



Trellis Frame FEA

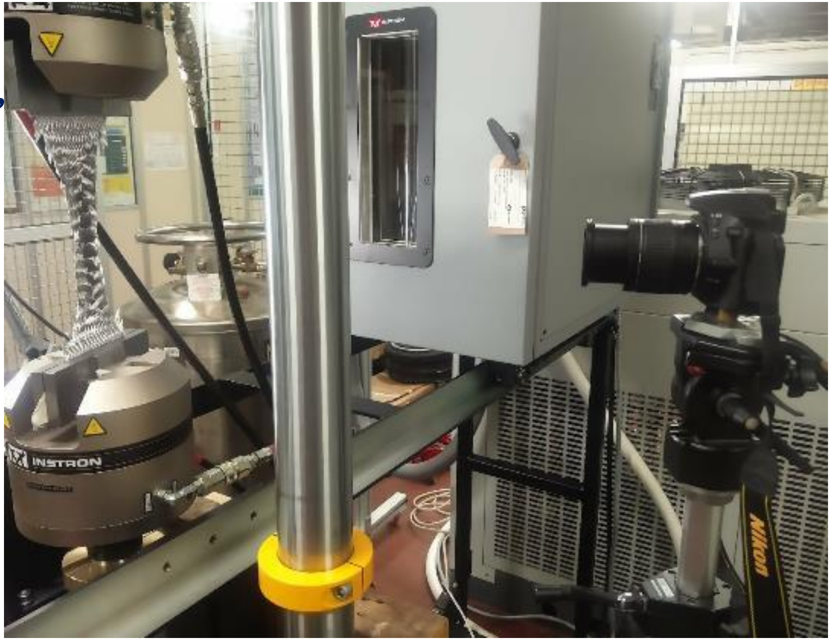
Shear Tests: Bias Extension

- *Modified tensile fixture.*
- *5 specimens tested.*
- *Inducing shear on it at the centre of a specimen oriented at 45°*
- *Tested only for fabric material (not suited for laminate).*
- *Difficult level: Complications involved in material handling, test is material dependant.*



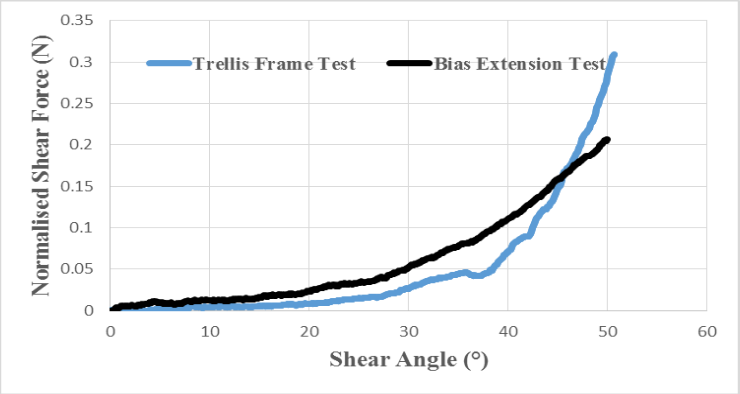
Displacement at various instances: FEA


Bias Specimen

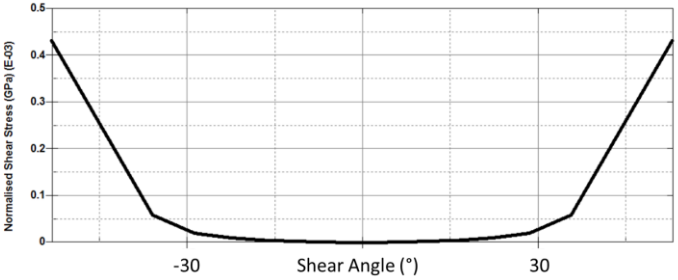


Bias extension test setup

Shear Tests: result validation



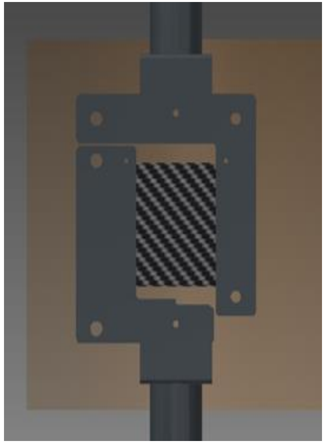
Shear force vs. shear angle



Normalized shear stress vs. shear angle for FE Input

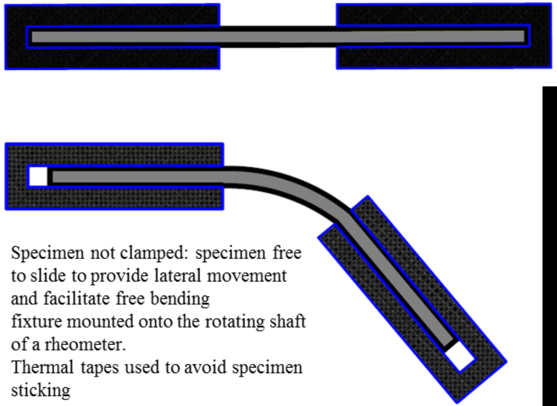
- *Shear properties validated by comparing the shear results from Trellis and Bias extension test.*
- *Shear force normalised.*
- *Shear angle obtained by Digital image correlation and the pattern validated mathematically.*
- *Done as there is no standard for both the tests and this is the best way for validation*

Bending Test: Custom dynamic bending testing fixture

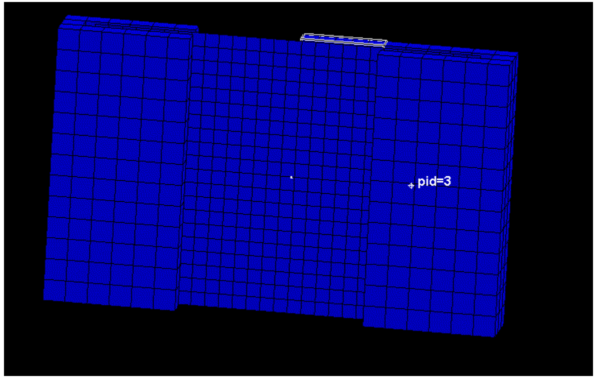


- *Custom made components for bending tests.*
- *5 specimens tested.*
- *Validating the bending behaviour of composite at forming temperature. (traditional bending tests impractical at forming temperature).*
- *"Integration point position variation method" for determining the ideal bending stiffness.*

Development and testing of the bending fixture



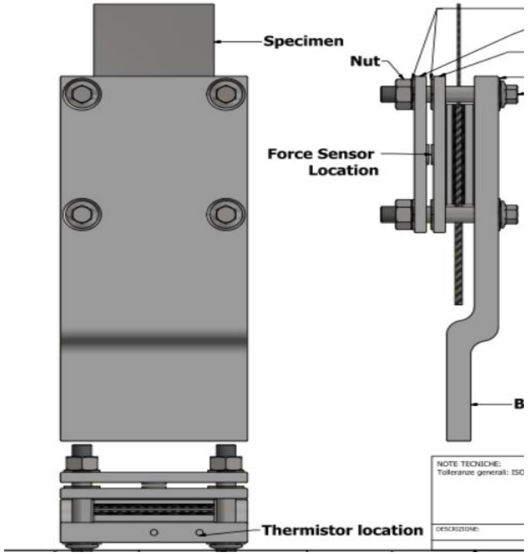
- Specimen not clamped: specimen free to slide to provide lateral movement and facilitate free bending
- fixture mounted onto the rotating shaft of a rheometer.
- Thermal tapes used to avoid specimen sticking

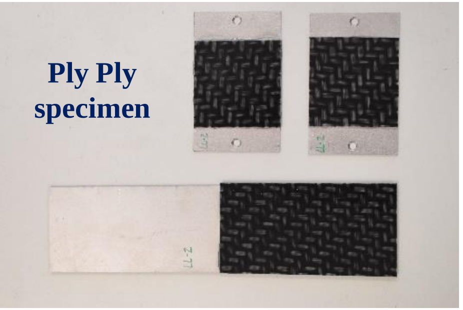


Bending Fixture FEA

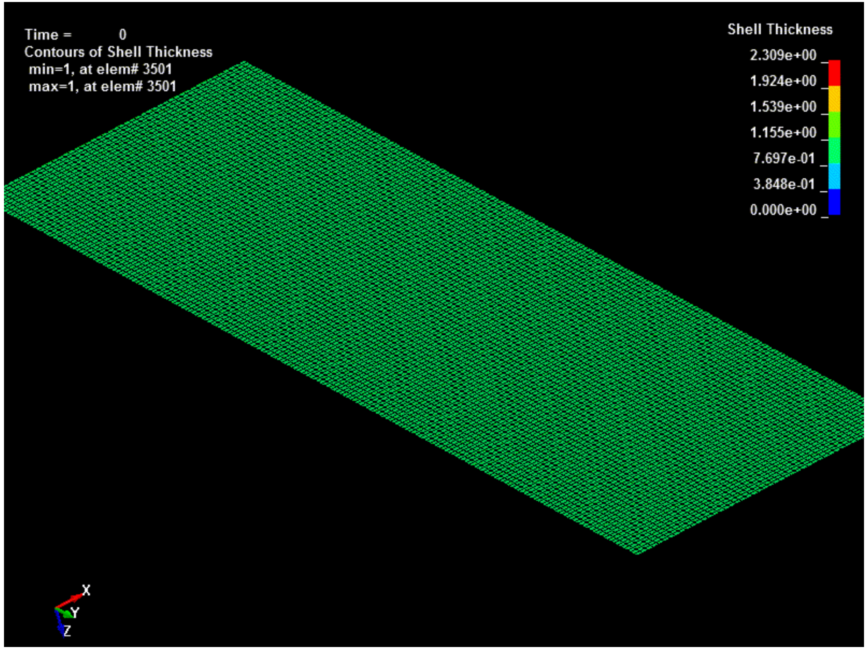
Friction tests: Custom Ply-Ply and Tool-Ply Tests

- ***Custom made components for friction tests***
- ***5 specimens tested.***
- ***To obtain frictional coefficients (Static and dynamic) for***
  - *Between tool and ply*
  - *Between ply and ply*
- ***Using a high temperature piezoelectric force sensor***
- ***Easy to implement in any testing machine inside a thermal chamber for testing.***





LEVEL 3: Thermoforming simulations

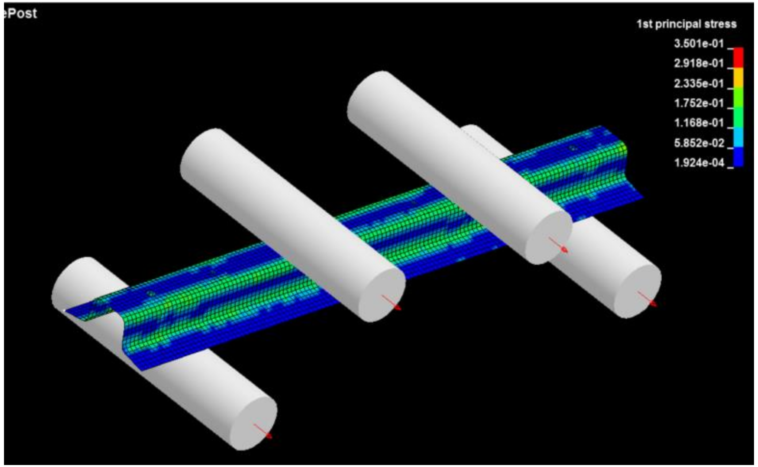


Process simulation conducted to identify:

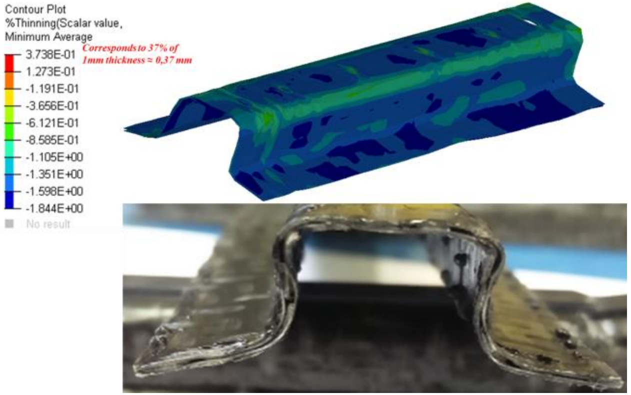
- *Geometric non-linearities*
  - *Residual stresses and strains*
  - *Fabric orientation change*
  - *Thickness change*
  - *Buckling.*
- *Boundary non-linearities*
  - *Frictional wear from contact between tool and ply*

LEVEL 3: Thermoforming results Mapping

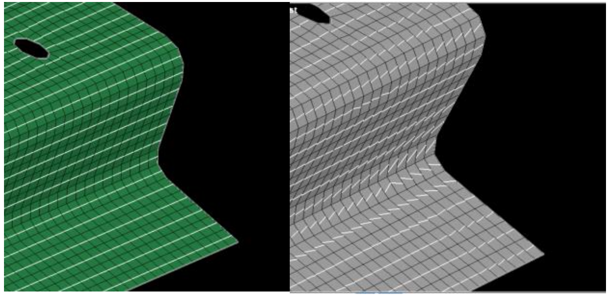
Mapping
Transfer of the required process simulation data to the crash model for further structural analysis



Mapped residual stresses

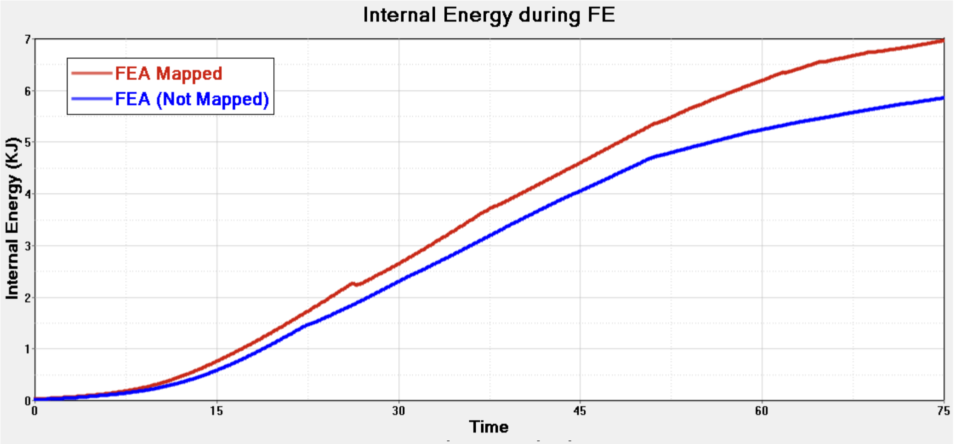


Thickness variation comparison



Element Direction: Before and after Mapping

LEVEL 3: Component four point bending curves comparison after mapping



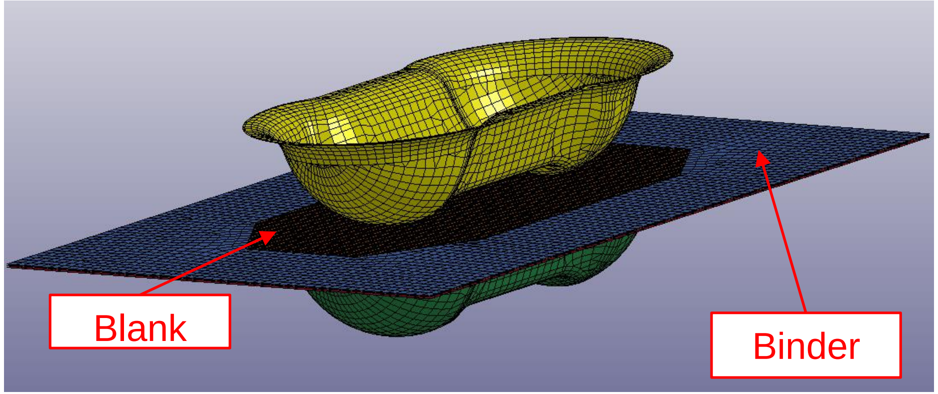
The two main reasons for variation in result after mapping:

- ***Fibre orientation change***
- ***Presence of residual stresses***
    - ***Micro-mechanical level***
    - ***Macro-mechanical level***
    - ***Global level***

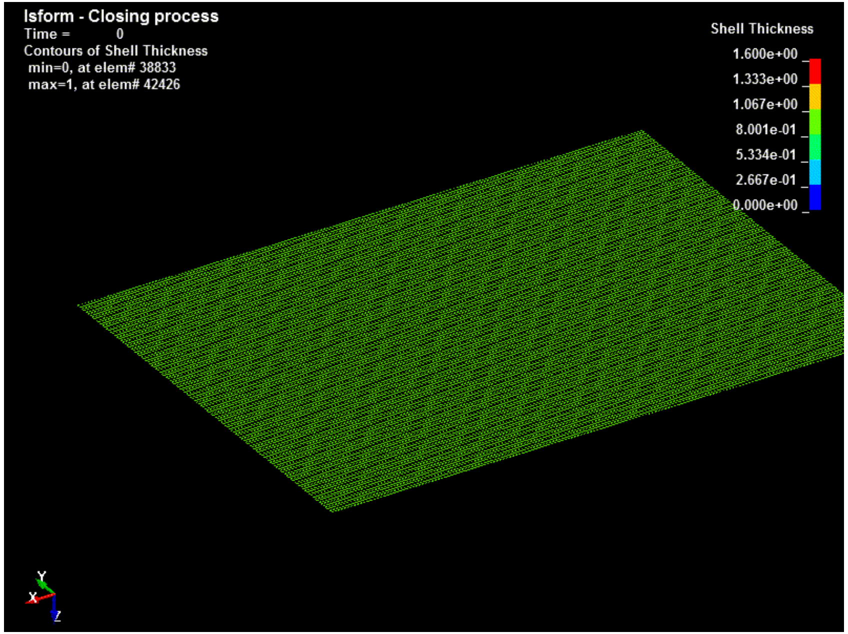
Conclusions

- *The component failure strength increases slightly after mapping*
- *Due to the thickness change and the presence of compressive residual stresses which strenghtens and tolerates the applied force a bit longer*

Thermoforming Methodology Validation: a Doubledome case



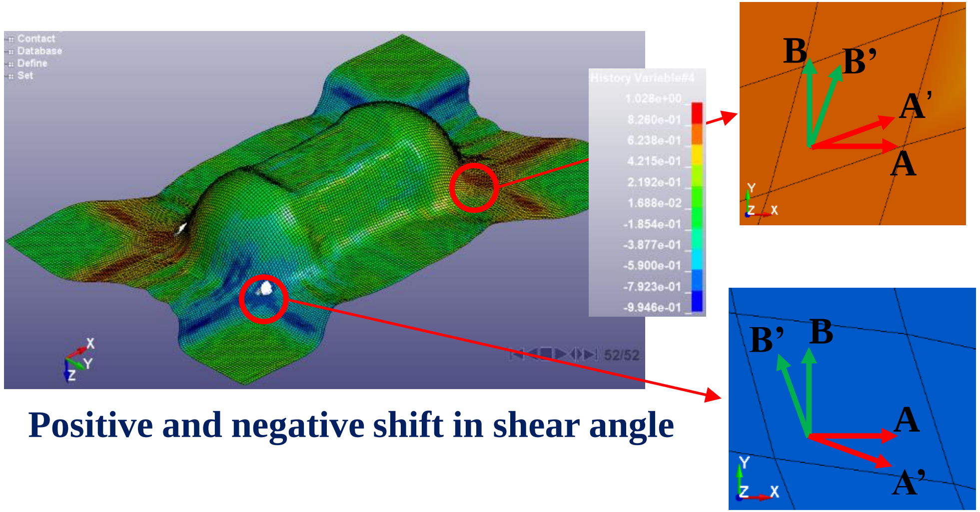
Thermoforming doubledome setup



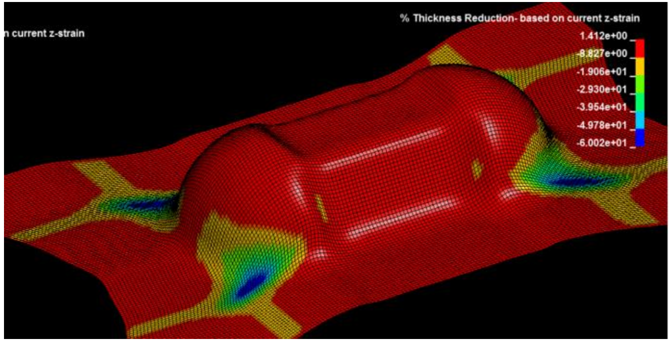
Thermoforming doubledome simulation

- *Done specifically to validate the methodology*
- *Shows the importance of including the process simulation results in load and crash FEA*

Influence of process simulation Results: a Doubledome case

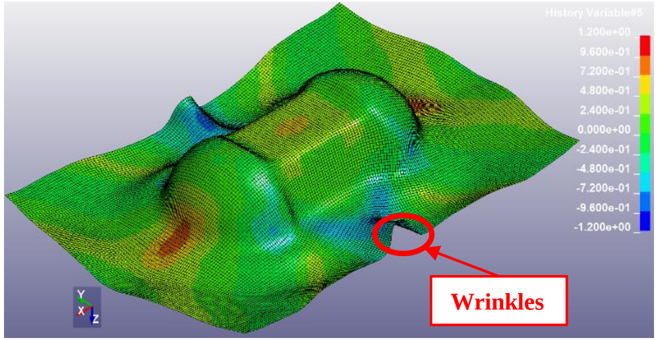


Positive and negative shift in shear angle



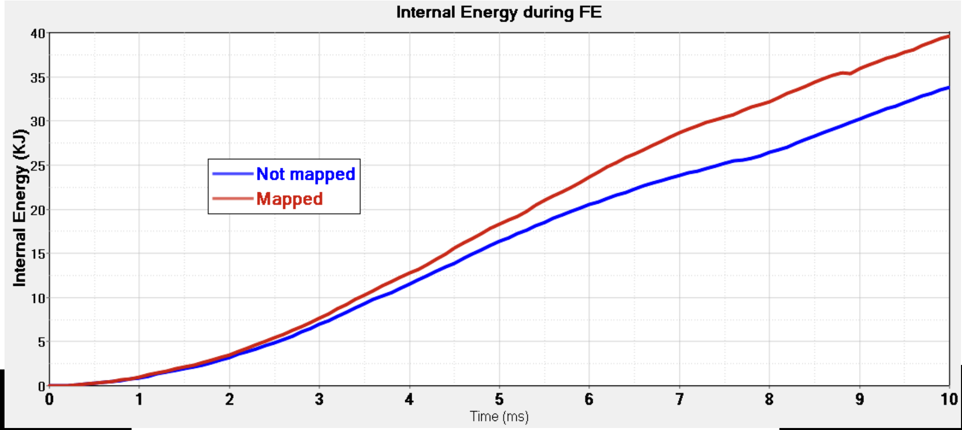
% thickness reduction on the blank after forming

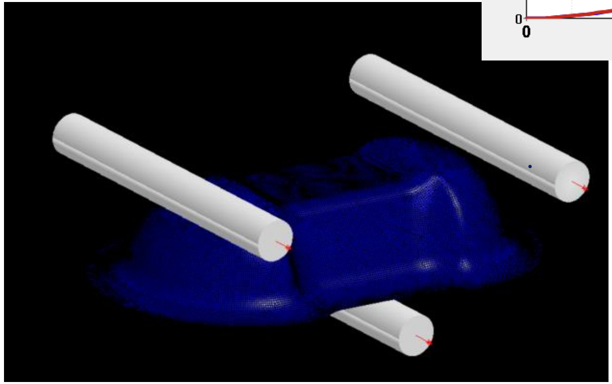
- *The figures displays the various anomalies occuring on the part, that affects the structural stiffness of the doubledome*
- *So it is very important, for an accurate predictive model, include the results from process simulations.*



Formation of wrinkles on the blank

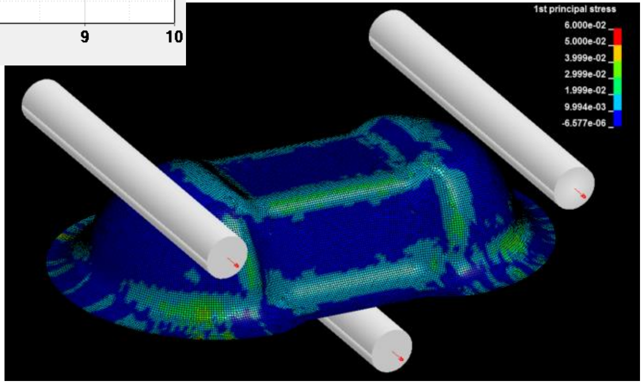
Doubledome Structural simulations: results comparison





Three point bending: no residual stress

- *The strength of the double dome increases slightly.*
- *Due to the thickness change and the presence of compressive residual stresses preventing brittle fracture as the initial crack is formed under compressive (negative tensile) stress.*



Three point bending: with residual stress and fabric direction mapped

Research Conclusions

- ***Composite failure criteria such as Tsai-wu or Crasurv which is not directly associated with failure modes didnot give good results for out of plane bending of the curved laminate.***

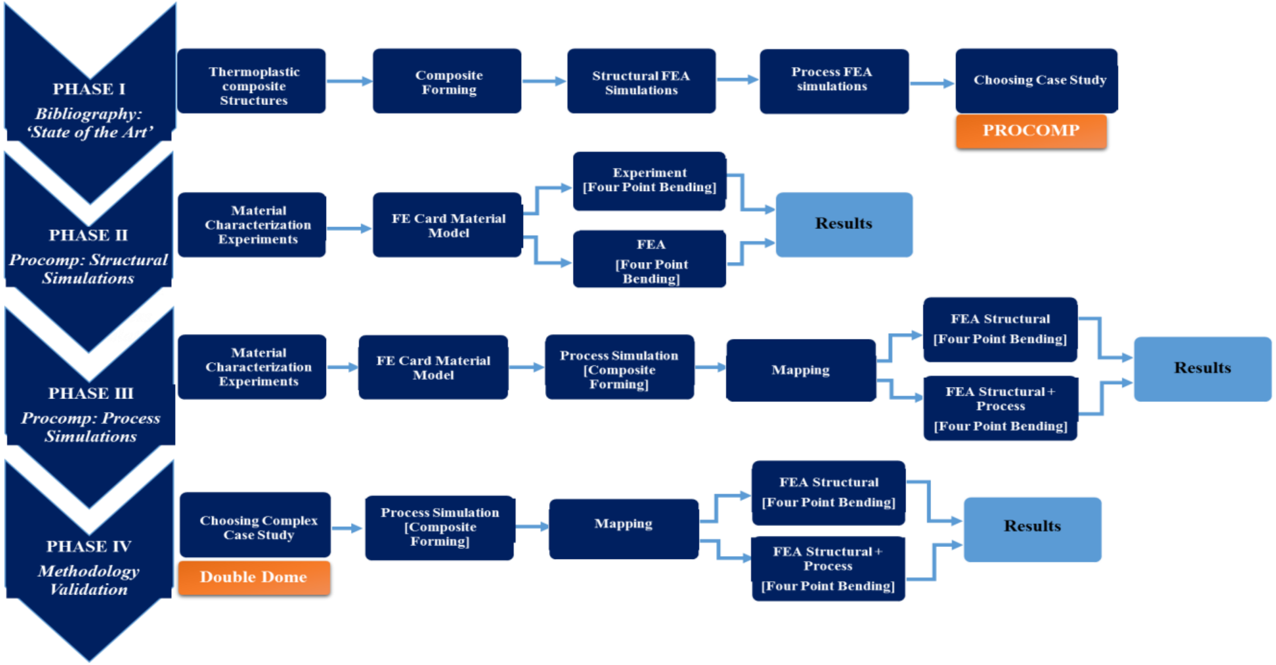
- ***Hashin criterion, a failure crtieria directly associated with failure modes gives acceptable results.***

- ***Successfull implementation of all the necessary tests for process simulations such as Tensile tests, Trellis frame, Bias test, Bending test and friction test.***

- ***Successfull mapping of the process simulation data on to the model gives a fairly accurate result for further four point bending FE tests, giving a good match with experimental curve.***

- ***The effect of residual stresses and fibre direction changing validated again with a more complex double dome model.***

Research in brief



Thank You

Lessons attended	Credit
Communication	1
Durability and Ageing of Organic Matrix Composites (OMC)	2
Multiscale structural mechanics	3
Probabilità applicata e processi stocastici	6
Progettazione di strutture meccaniche in materiale composito	6
Programmazione degli esperimenti industriali	5
Public speaking 1 & 2	3
Strumenti e applicazioni del systems engineering	6
Strumenti e tecnologie per lo sviluppo del prodotto	5
The redefinition of the International System of Units (SI)	3
Topics In Internet & Society Interdisciplinary Studies	4
Polymers and Polymer Matrix Composites in Harsh Environments	2
Lingua Italiana I Livello	3
Total Credits (Exceeded)	**49**

RESEARCH AND CONFERENCE PAPERS

1. Carello, M., Amirth, N., Airale, A.G. et al. Appl Compos Mater (2017). *Building Block Approach' for Structural Analysis of Thermoplastic Composite Components for Automotive Applications doi:10.1007/s10443-017-9592-x*
2. Carello, M.; Airale, A.G.; Ferraris, A.; Messana, A.; Amirth Jayasree, N. (2017) *From thermosetting to thermoplastic composite materials: automotive applications in structural components. In: Automotive Engineering Congress, Norimberga (Germany), 30-31 March 2017.*
3. N. Amirth Jayasree, A.G. Airale, A. Ferraris, A. Messana, L. Sisca, M. Carello. (2017). *Process analysis for structural optimisation of thermoplastic composite component using the building block approach. Composites Part B: Engineering. 126, 119-132.*