POLITECNICO DI TORINO

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

In partnership with:

proplast
PLASTICS INNOVATION POLE

BeOnD

Structural analysis of thermoplastic composite components integrating process simulation mapping with ENVYO.

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

CARELLO Massimiliana
(*Assistant Professor*)

2 Post-Doc

3 PhD Students

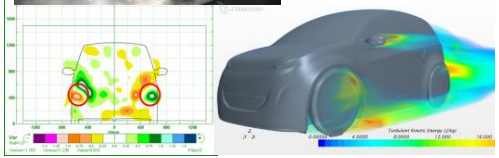
2 Researchers Fellowship

5 Scholarships

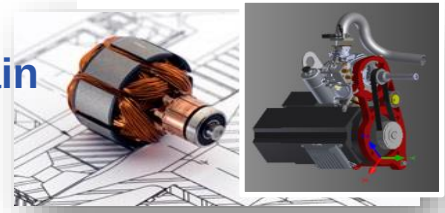
10 Students/year (Thesis)

15 Students/year (Internship)

Aerodynamics

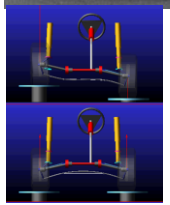


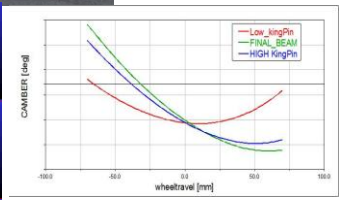
Mechatronic & Hybrid Powertrain



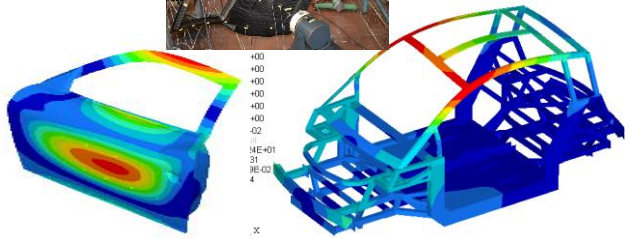
«Innovative Electric and Hybrid Vehicles»

Vehicle Dynamics

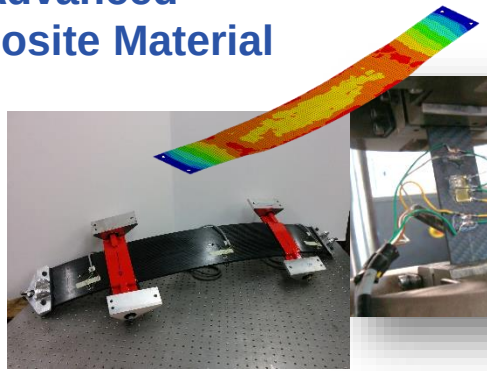




NVH



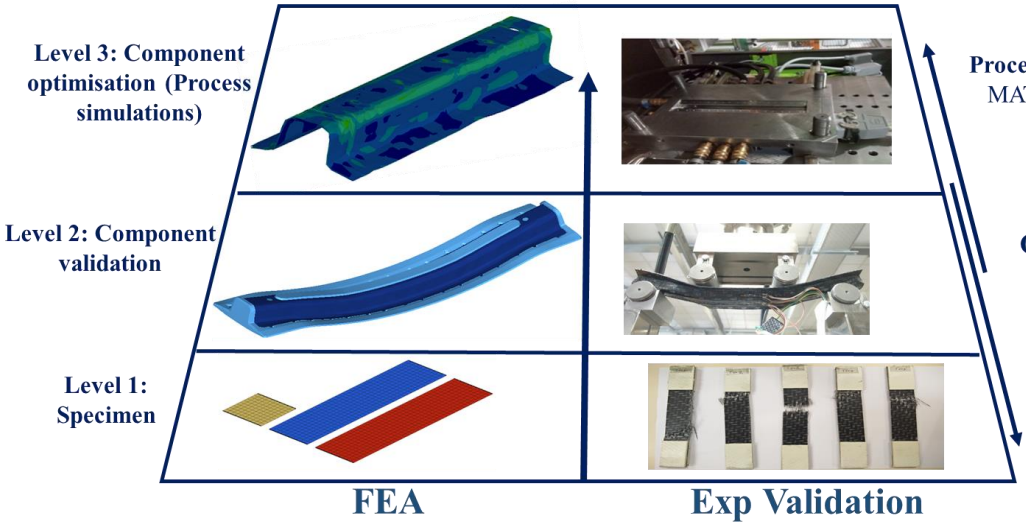
Advanced Composite Material



Comprehensive composite modelling with LS-DYNA

**Image for representation only, not part of the research.*

Methodology integrated into any subsystem modelling.



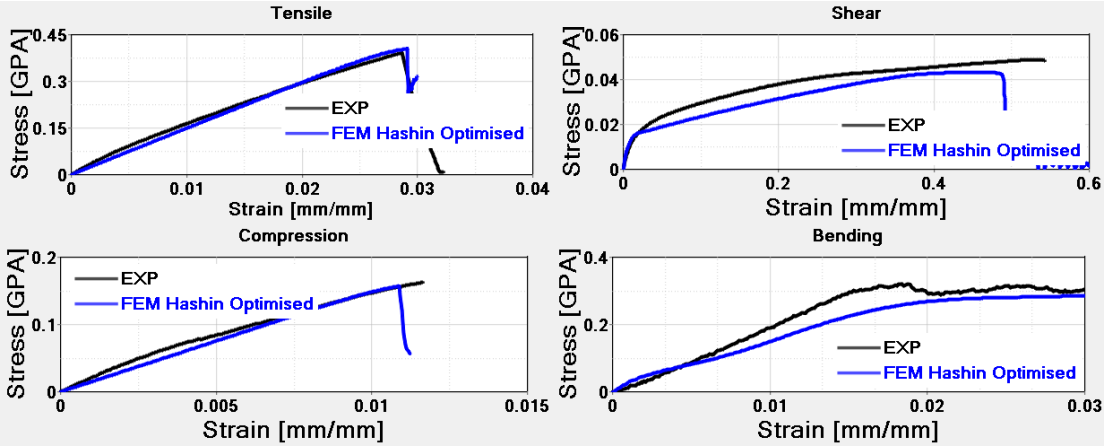
Process simulation and Mapping
MAT_249: Process simulations
ENVYO: Mapping

Quasistatic and dynamic testing

Specimen charecterisation and Fitting
MAT_157, MAT_215 :Short Fibre
MAT_058, MAT_158, MAT_261, MAT_262: Continuous Fibre

doi:10.1016/j.compositesa.2017.06.007

Initial Specimen characterisation and curve fitting with MAT_058 & MAT_158

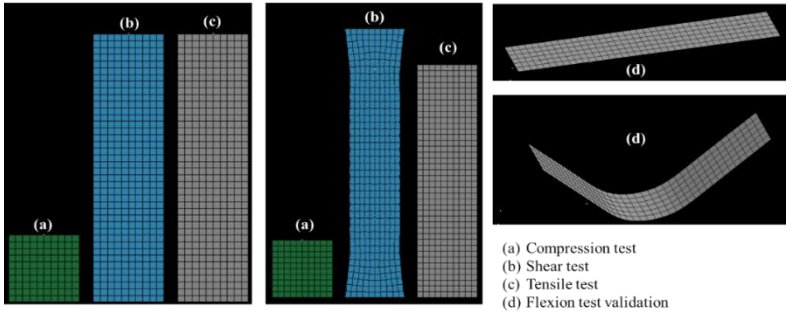


a: Tensile Test
ASTM D 3039

b: Compression Test
ISO14126:1999

c: Bending Test
ISO 14125:1998

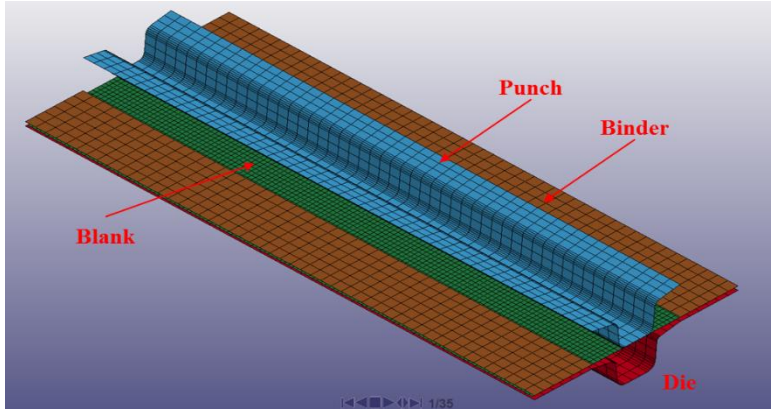
d: Shear Test
ISO 14129: 1997



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

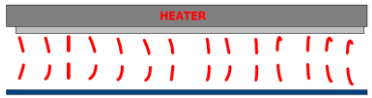
doi:10.1016/j.compositesa.2017.06.007

Process Simulations with MAT_249

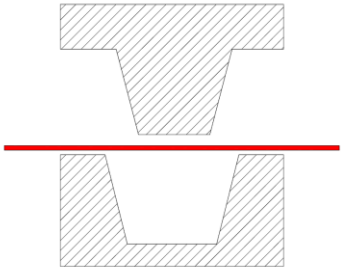


Process simulation Setup

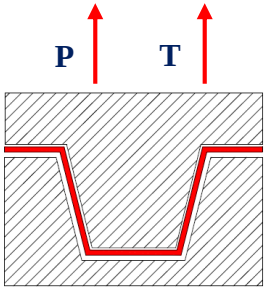
- *Process simulation setup to simulate the thermoforming of thermoplastic composite laminate forming.*
- *Material model of blank at forming temperature: additive split between* ***isotropic, elasto-plastic matrix and anisotropic hyper-elastic fibers.***
- *Process paramters required for process simulation:*
  - *Tensile modulus and the associated tensile curve.*
  - *Shear modulus and the associated shear curve.*
  - *Resin parameters at forming temperature.*
  - *Bending modulus. (no direct input)*
  - *Frictional coefficients (dynamic and static).*



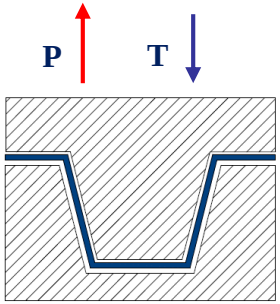
Heating to Process Temp



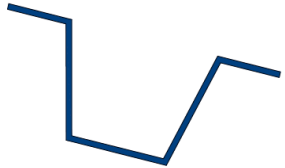
Forming setup



Heating

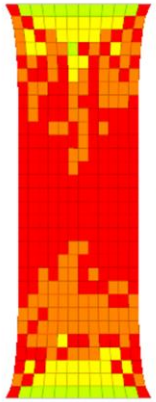


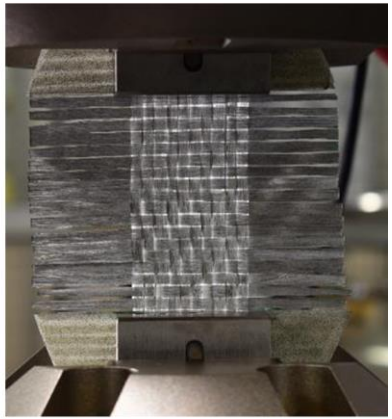
Cooling

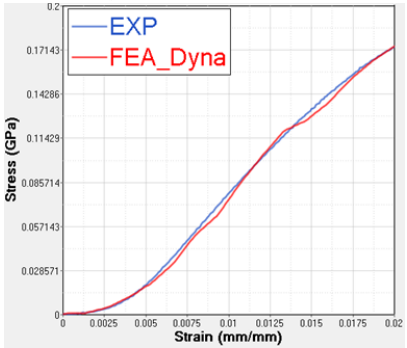


Final Product

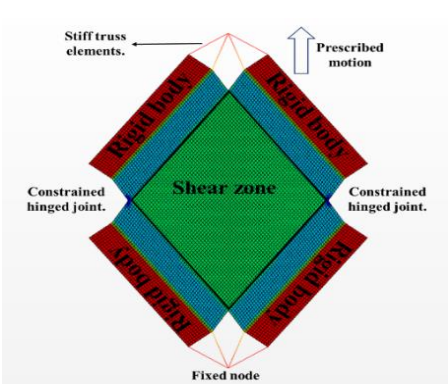
Primary Charecterisation and Curve fitting for Mat:249

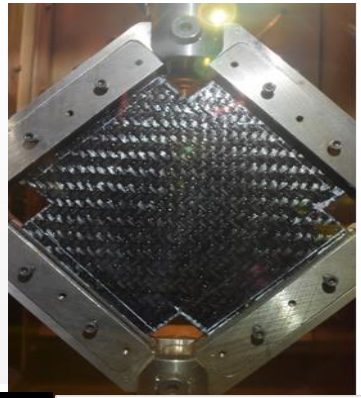


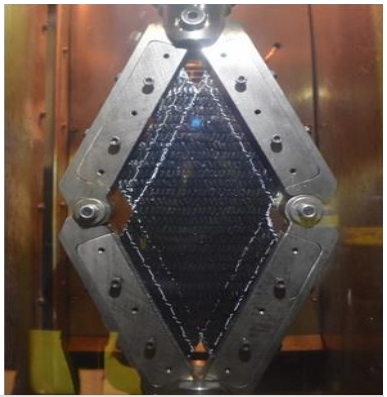


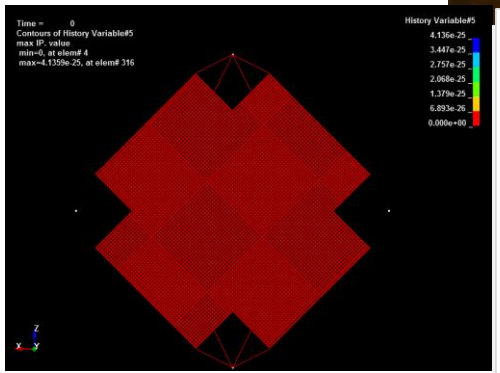


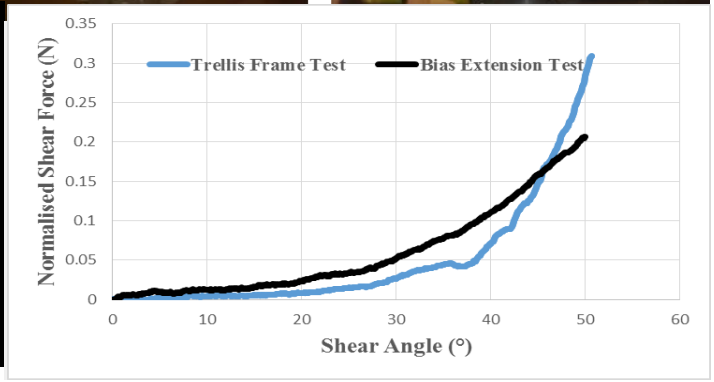
Tensile tests (ASTM D5035)





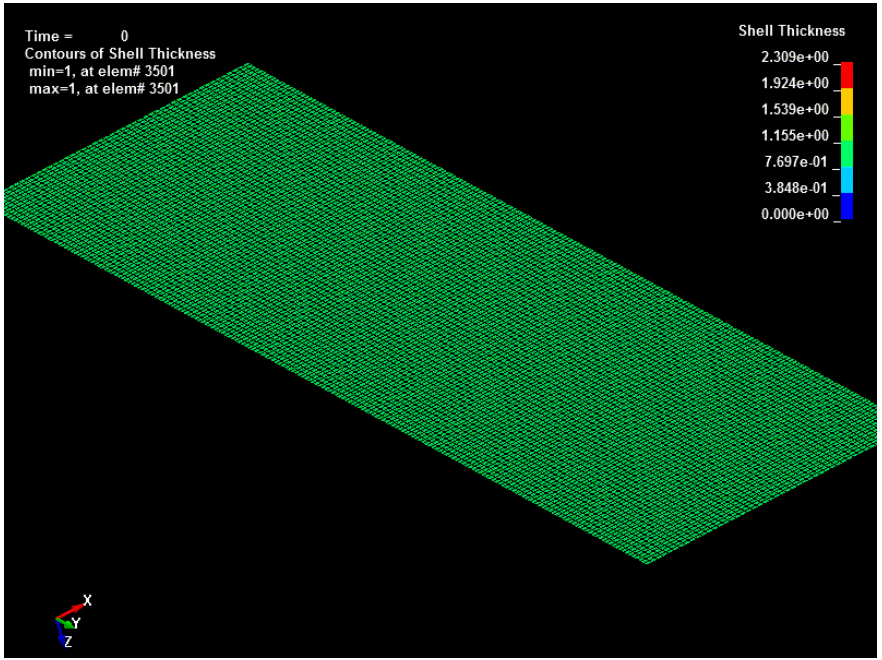






Shear tests and validations

Thermoforming simulations with MAT_249.



Process simulation conducted to identify:

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

Mapping with ENVYO

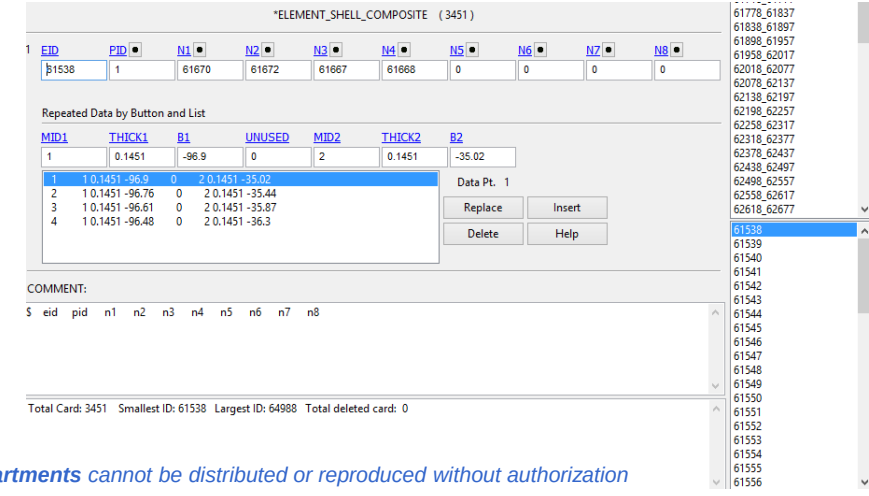
```
$#-------------------------------------------------
$# Main mapping definition
$#-----------------------------
ENVYO=SHELL-SHELL
$#-----------------------------
$# Activate transformation
$#-----------------------------
TRANSFORMATION=YES
TRAFO_OPTION=ICP
NodalPair#1=5684 57379
NodalPair#2=36860 57721
NodalPair#3=31477 44165
NodalPair#4=3912 47500
NodalPair#5=4028 45888
NodalPair#6=31717 45882
WriteTransformedMesh=YES
$#-----------------------------
$# In- and output meshes
$#-----------------------------
SourceFile=dynain
TargetFile=model.k
MappingResult=model_mapped_ICP.key
OrientationFile=HISV
TransformedMeshFile=trafo_ICP.k
$#-----------------------------
$# Target - PIDs
$#-----------------------------
NumTargetPids=1
TargetPid#1=1
$#-----------------------------
$# Mapping-Options
$#-----------------------------
ALGORITHM=ClosestPoint
SORT=BUCKET
REPEAT=YES
Shell_Option=Composite
```

```
$#-----------------------------
$# Source - PIDs
$#-----------------------------
NumSourcePIDs=1
SourcePid#1=1
$#--------------
NumFibers=2
FiberID#1=1
FiberID#2=2
CMPFLG=0
SourceMaterialModel=249
TargetThickness= 1
NumberOfTARInPlaneIPs=1
NumberOfTARLayers=4
ThroughThicknessAveraging=NO
NumberOfFiberBundles=2
FiberBundle#1:
Lay=1,IP=1,Fib=1
Lay=1,IP=2,Fib=1
Lay=1,IP=3,Fib=1
Lay=1,IP=4,Fib=1
FiberBundle#2:
Lay=1,IP=1,Fib=1
Lay=1,IP=2,Fib=1
Lay=1,IP=3,Fib=1
Lay=1,IP=4,Fib=1
MapStrain=NO
MapStress=NO
MapThickness=YES
$#-----------------------------
$# END-OF-FILE
$#-----------------------------
```

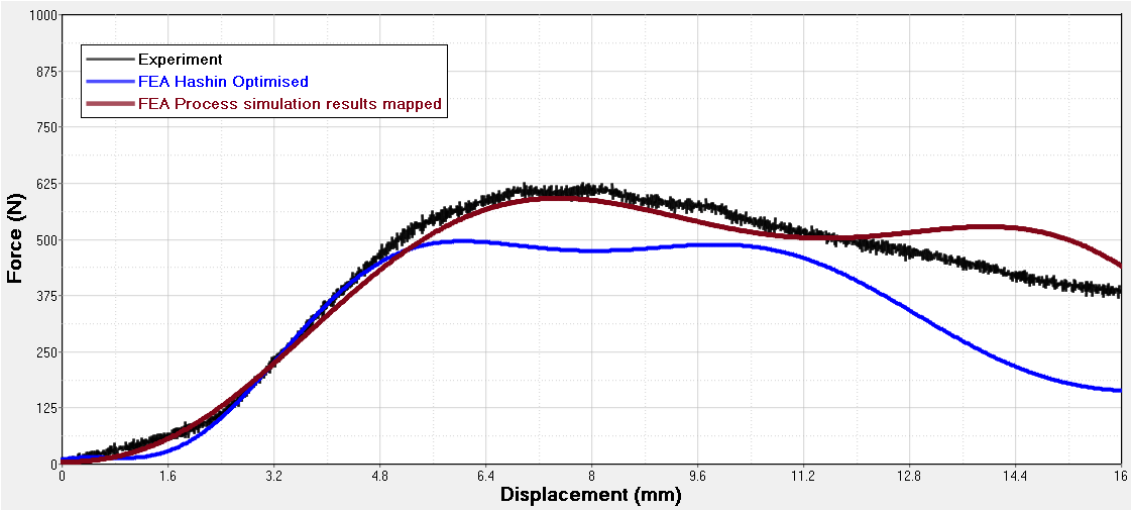
Linkage of multiple FE tools from different suppliers can be avoided when integrating ENVYO to LS-DYNA.

Mapped results *Shell- Shell*

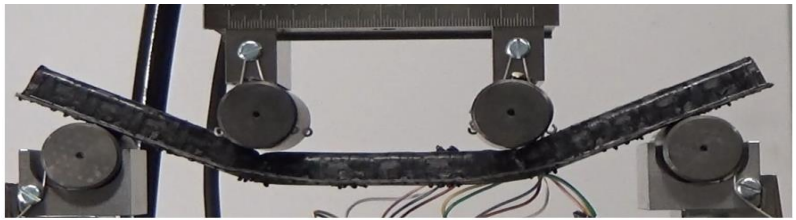
- *fiber oreintation*
- *Thickness*
- *Residual Stresses and strains*

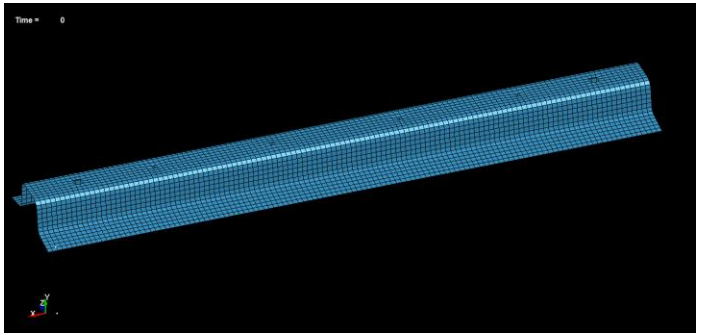


Component four point bending curves comparison after mapping: Case Study Procomp



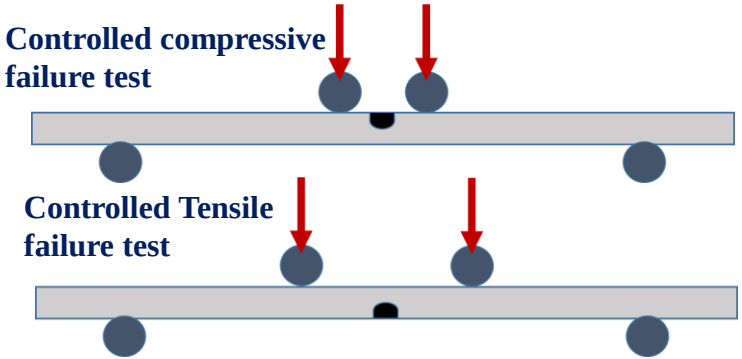
- *Initial trials shows the flexurual stiffness increases slightly after mapping.*
- *Similar initial pattern between mapped and not mapped, mapped curve converges to match the EXP curve.*
- *Stiffness variations due higher fabric density and fiber waviness weakening the interface after the thermoforming through fiber-matrix debonding and frictional processes creating compressive residual stresses.*
- *Fabric density, fiber volume fraction and fiber packing, dependant.*

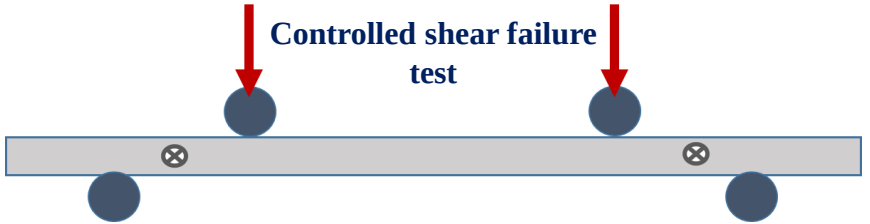




Current Conclusions on mapping

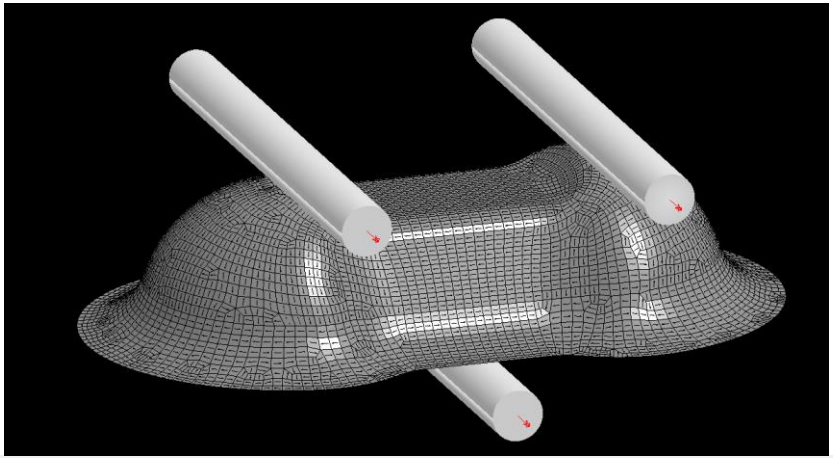
- *The orientation of the load applied needs to undergo controlled mechanical perfomance validation: controlled compressive, tensile and shear modulus to assure intended failure modes, which is set for future trials.*
- *Decreasing the density of the fabric, for futre trials.*
- *The initial trial showed a slight increase in stiffness of the composite fiber part after mapping, which maybe due to the higher density of the fabric and thickness variations due to fibre matrix debonding resulting in fiber waviness leading to compressive residual stresses. (Mapped with ENVYO.)*
- *Need to consider the laminate density change with respect to thickness variations, the feasibility needs to researched.!*
- *Stable mapping capability of residual stresses and strain with ENVYO for CFRP need to be addressed.*

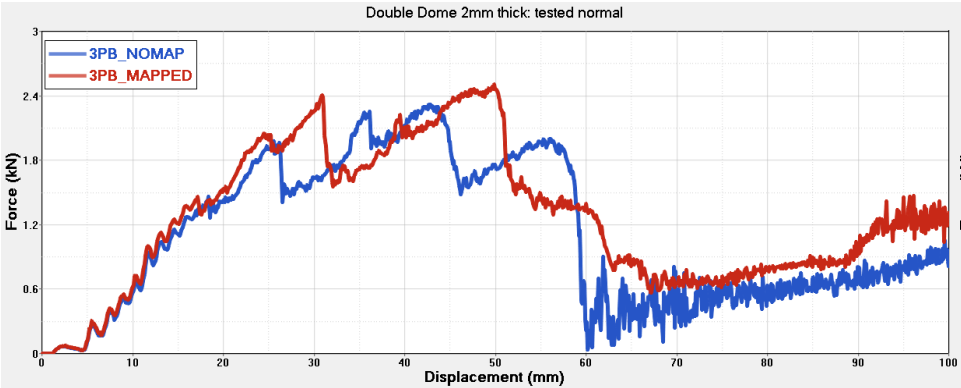


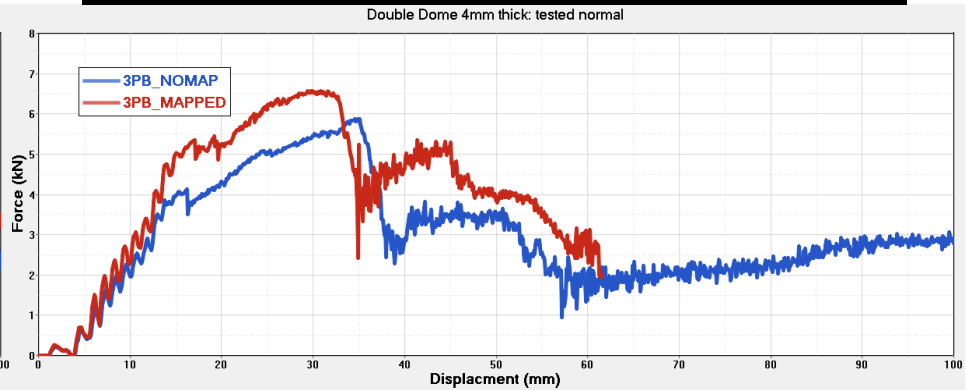


Ongoing Trials: Case Study DoubleDome

- *Currently only the fiber orientation change and thickness variations considered.*
- *Need to integrate residual stresses and strains.*
- *The parts with varying thickness (from 1mm to 6mm) are currently being made specifically for a sensibility study of mapping with ENVYO.*







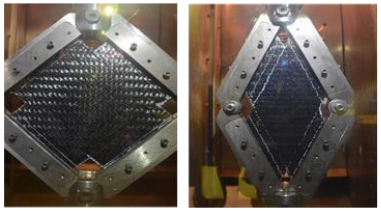
Current and prospective focus

Along with continuous feedback to LS-DYNA and ENVYO

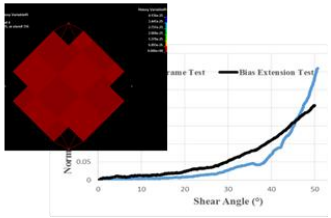
- ***Validate technology*** *on double dome case study and then on larger structural components, which includes forming with MAT_249 and mapping with ENVYO.*
- ***Short fiber reinforced polymer (SFRP) mapping*** *employing ENVYO to facilate simulation of overmolded composite structures in LS-DYNA and to gain confidence for multimaterial hybrid and overmolded composite structures.*
- ***Local denisty variations*** *of the laminate with respect to the thickness change need to addressed.*
- ***Local strain and stiffness comparison*** *employing 3D digital image correlation for future trials for automotive structural components.*

R&D Network in ITALY

*Politecnico di Torino, Proplast and BeonD are open to collaborate in **R&D program project** or in **industrial case studies** following and support our customer in the whole development process:*

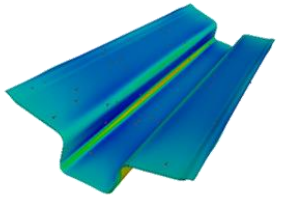


1) **Material Characterization** and Validation

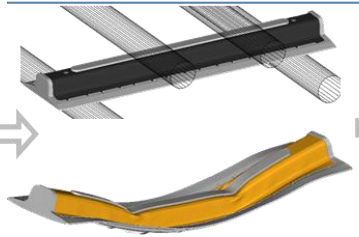


2) **Card Materials** Material Data Base

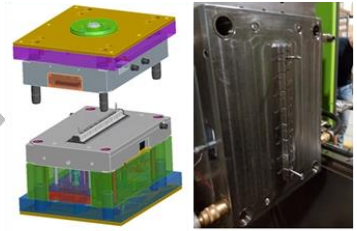
3) Shape choosing **CAD Design**



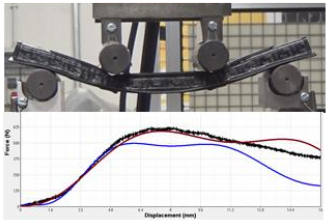
4) **FEM Analysis** PROCESS



5) **FEM Analysis** STRUCTURAL



6) **Prototyping** Manufacturing Parameters Definition



7) Exp Testing **+ Numerical Correlation**

Validate Tools

FEM PROCESS
FEM PRODUCT
CAD Design Constrain
Process Parameters

PRE and POST: *Hyperworks, Hypermesh, Ansa* **SOLVERS:** *Abaqus, Nastran, Optistruct, LS-Dyna, Radioss* **TECH:** *Compression Moulding + Overmoulding, Compression Moulding + Back-injection*

Thank you

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1. 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.*
2. Carello, M., Amirth, N., Airale, A.G, M. Monti & A. Romeo. Appl Compos Mater (2017). Building Block Approach' for Structural Analysis of Thermoplastic Composite Components for Automotive Applications
3. 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).*