automotive CAE GRAND CHALLENGE

Integrated Experimental Analysis, Modeling, and Validation of High-Performance UD CFRTP Lamina

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DatapointLabs

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Introducing DatapointLabs - Applus+ Group

Applus+ is a global leader in inspection, testing and certification. Driven by our passion for progress and technological development, we'll keep moving towards a more sustainable future alongside our customers; re-enforcing our mission and company motto: **Together beyond standards**.

26,000+
People in 2022

€2,058M
Revenue in 2023

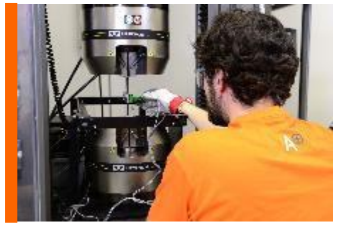
66
Countries in all continents

Accredited
By main international entities

Energy & Industry Division

€ 1,084.4M revenue

+16,000 personnel



Laboratories Division

€ 254.3M revenue

2,589 personnel

Automotive Division

€ 391.8M revenue

4,300 personnel

IDIADA Division

€ 331.5M revenue

3,158 personnel

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Introducing DatapointLabs - Expertise

Experience

- 27 years of experience in materials testing and characterization
- ISO 17025:2017 accredited, operating on an end-end digital platform
- NADCAP accredited [Aerospace / Defence] (Metallic/Non-Metallic Materials Testing)

Operations

- Testing 2000+ materials per year
- Standard 5-day turnaround
- Comprehensive one-stop testing capabilities
- Up to unique tests: all aspects of mechanical, thermal and rheological characterizations

Clientele

- Global R&D clientele of more than 1,800 companies in 49 countries
- Market leader in materials testing for CAE and simulation since 1995
- Recognized as an approved materials testing lab by leading OEMs

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Introducing DPL - Materials Testing for Product Development

TestCart

Comprehensive online catalog and order system for up to 200 unique tests characterizing physical, thermal and flow properties of materials for use in R&D and product development

metals, plastics, composites, rubber, foam, rubber, films

TestPaks®

Material testing and material parameter conversion to generate 179 material cards for 36 simulation (CAE) programs, including finite-element analysis, crash and drop-test simulations, injection-molding and other process simulations

CAETestBench™

Validate your simulation against a physical part, created and tested using a rigid protocol, which can be accurately replicated in your solver – probe simulation accuracy and quantify its ability to replicate the test

Validations range from simple tensile modes to more complex, multi-axial modes, impact and failure

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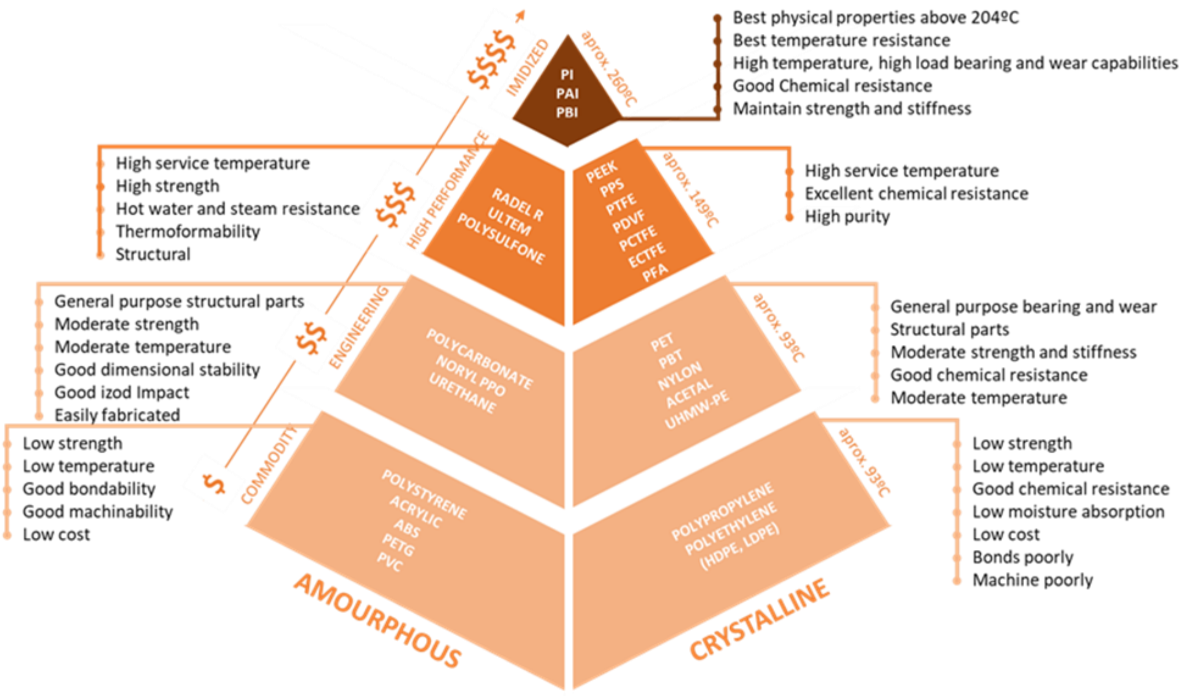
Background - Thermoplastic composite materials

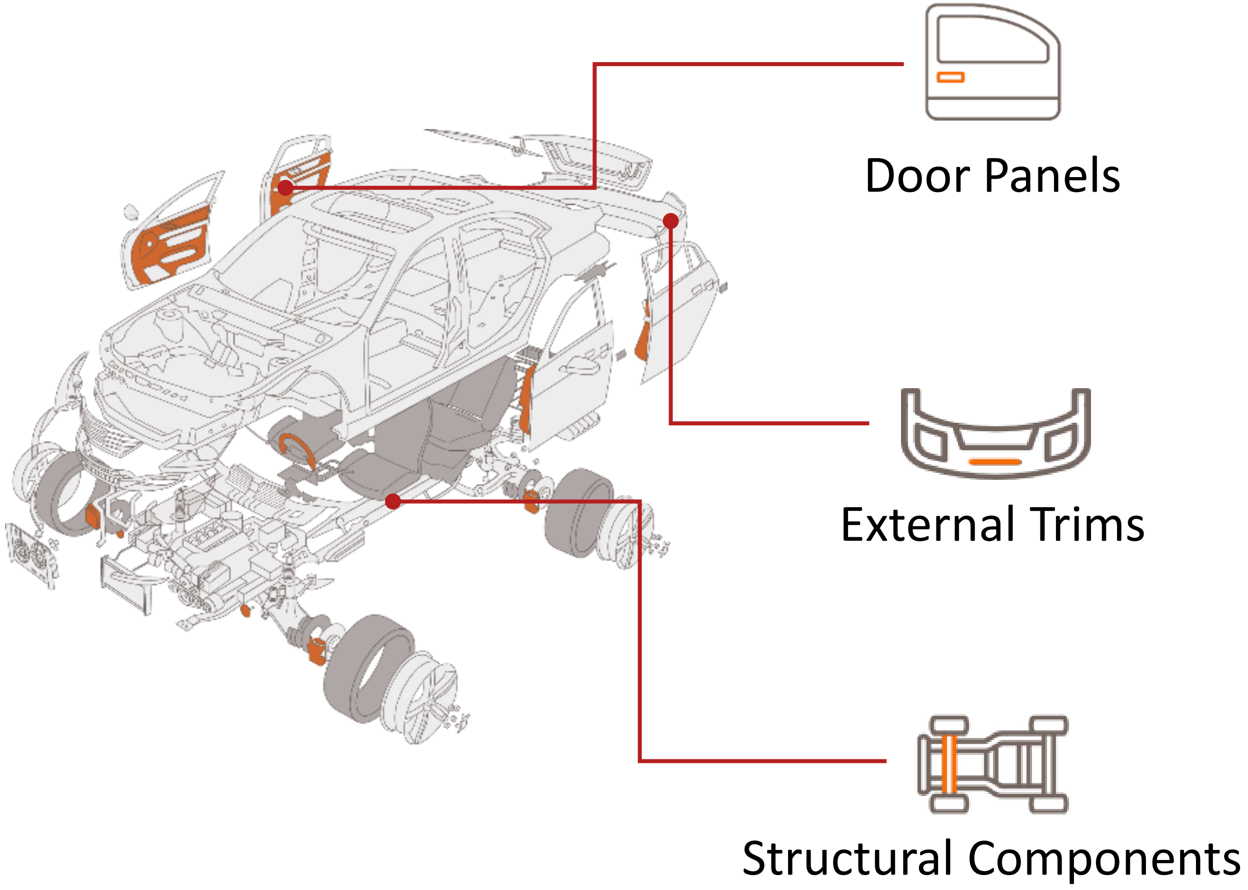
Long fiber reinforced thermoplastic materials (CFRTP) offer to industry a **sustainable alternative** to thermoset composites, combining fibers (like glass, carbon, or aramid) with thermoplastic polymeric matrices for lightweight and durable materials.



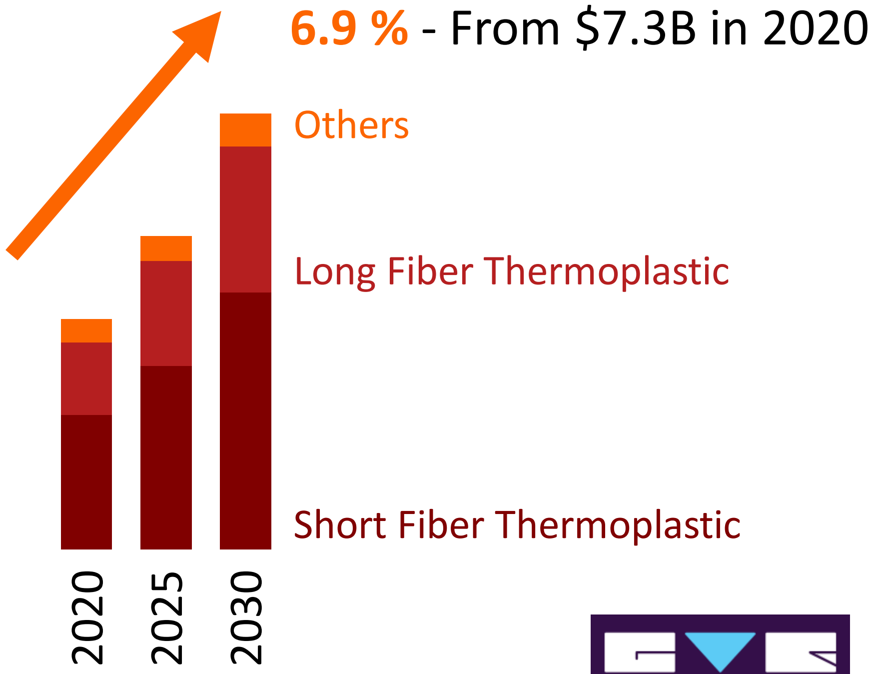
- High strength-to-weight ratio
- Tailored properties
- Design flexibility
- Fast processing
- Re-workable
- Fatigue resistance
- Thermal and electrical resistivity
- Corrosion resistance

Background - CFRTP in the Automotive industry

CFRTP automotive applications



U.S. Thermoplastic Composites Market



GRAND VIEW RESEARCH

Background - Project overview

Objective of the study

- To develop new testing capabilities for calibrating composite materials at meso-scale and macro-scale levels

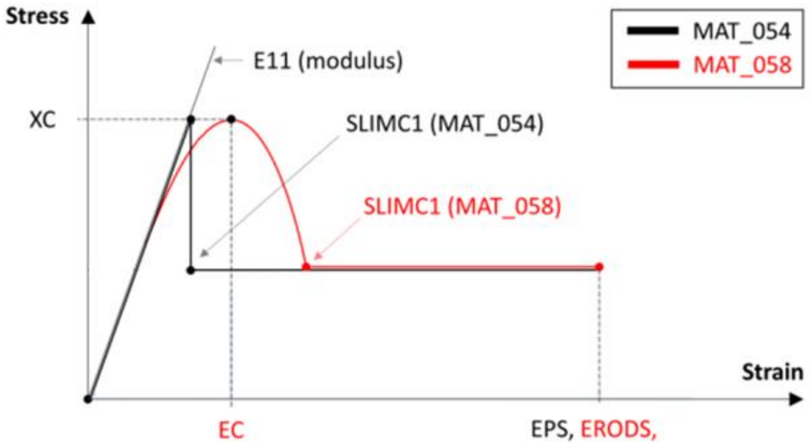
- Case 1: Macro-scale model (Laminate including EPS core)
  - To conduct the necessary tests for calibrating a composite material model in LS-DYNA for laminates
  - To calibrate the model using the experimental data
  - To validate the calibrated models using the close-loop validations

- Case 2: Meso-scale model (Laminae)
  - To conduct the necessary tests for calibrating a composite material model in LS-DYNA for laminae
  - To calibrate the model using the experimental data
  - To validate the calibrated models using the close-loop validations

Methods - Models selection: LS-DYNA MAT054 vs LS-DYNA MAT058

MAT054/55: *MAT_ENHANCED_COMPOSITE_DAMAGE

- Linear elastic orthotropic response up to failure at ply level
- No pre-peak or post peak softening
- Three failure criteria (Chang-Chang, 2-way Fiber Flag Failure and Tsai-Wu)
- Requires calibration of non-physical parameters
- Accepts shell elements



MAT058: *MAT_LAMINATED_COMPOSITE_FABRIC

- Damage mechanics-based model with strain-rate option
- Non-linear elastic stiffness with pre- and post-peak softening
- Different failure surfaces for UD, complete laminates and woven fabrics
- Requires calibration of non-physical parameters
- Accepts shell elements, thick shell elements, and solid elements

Cherniaev A. et al. (2018). Modeling the axial crush response of CFRP tubes using MAT054, MAT058 and MAT262 in LS-DYNA. *15th International LS-DYNA users conference*. Composites. https://www.dynalook.com/conferences/

LS-DYNA. Keyword user’s manual Volume II Material models. California: Livermore Software Technology Corporation. 2013

Methods - Model Calibration

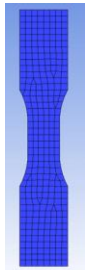
Reverse engineering - Iterative model calibration

Testing

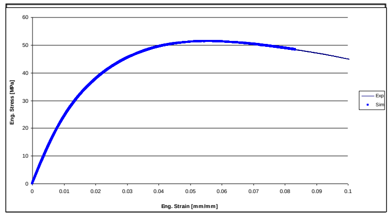
Initial Parameters and Calibration

```
*MAT_PIECEWISE_LINEAR_PLASTICITY_TITLE
MAT1
$#     mid        ro         e        pr      sigy      etan
   434801.07000E-9    6200.0     0.352       0.0       0.0
$#       c         p      lcss      lcsr        vp
                          1000                 3.0
$#    eps1      eps2      eps3      eps4      eps5      eps6
       0.0       0.0       0.0       0.0       0.0       0.0
$#     es1       es2       es3       es4       es5       es6
       0.0       0.0       0.0       0.0       0.0       0.0
*MAT_ADD_DAMAGE_DIEM
$#     mid    ndiemc     dinit      deps    numfip
     43480       1.0         01.00000E-4       1.0
$#   dityp        p1        p2        p3        p4        p5
       0.0      2000       0.0       0.0       0.0       0.0
$#   detyp     dctyp        q1        q2        q3        q4
       0.0       0.0         5       0.0        10       0.0
```

Simulation



Error Calculation



CAE-Ready Material Card

Ansys / LST | LS-DYNA

New Parameters and Calibration

python

Methods - Case 1: Laminate - Testing

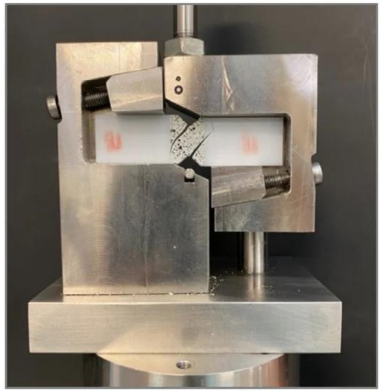
Material

- Automotive grade composite material: Glass Fiber Woven Fabric / Polypropylene matrix with EPS core

TestPak: G-794

- ASTM D792-20 - Solid Density
- ASTM D3039/3039M-17 - Tensile Stress-Strain, Strength, Modulus, And Poisson's Ratio (2 Orientations)
- ASTM D5379/D5379M-19E1 - Shear Stress-strain (2 Orientations)
- ASTM D6641/D6641M-16E2 - Combined Loading Compression (CLC) (2 Orientations)

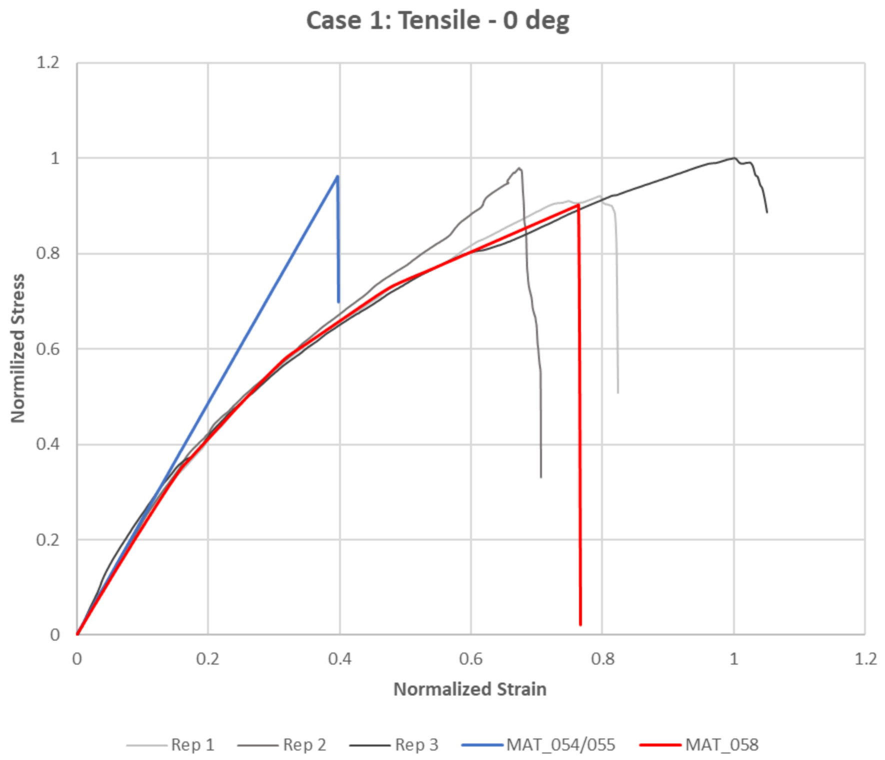
ASTM D3039/3039M-17

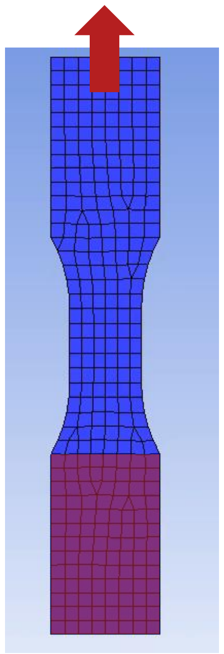


ASTM D5379/D5379M-19E1

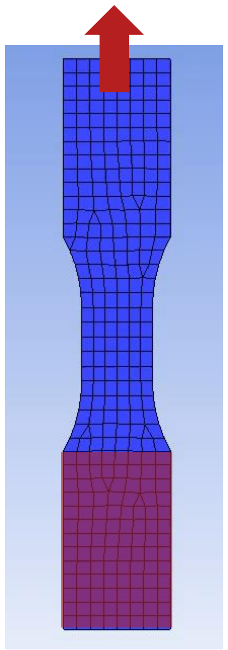
ASTM D6641/D6641M-16E2

Results - Case 1: Laminate – Tensile Validation





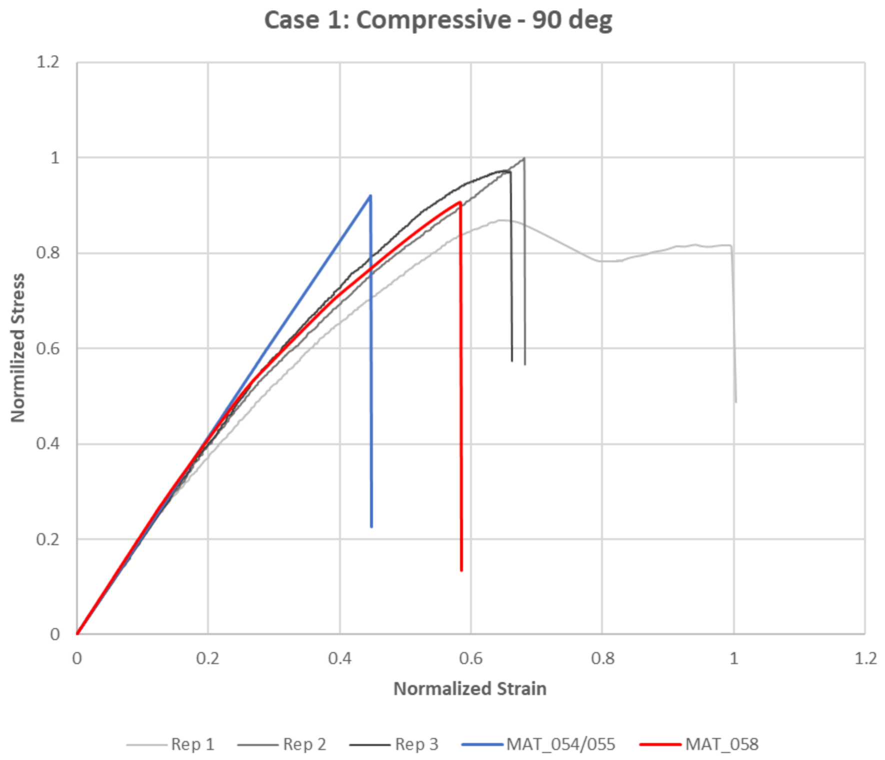
MAT_054

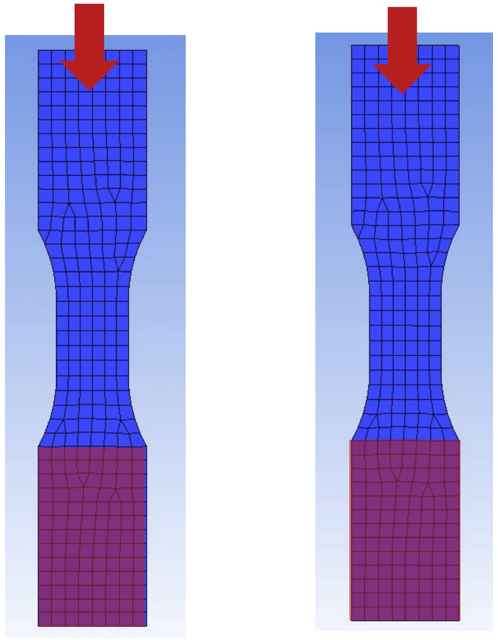


MAT_058

Strain and stress have been normalized due to project confidentiality

Results - Case 1: Laminate – Compressive Validation

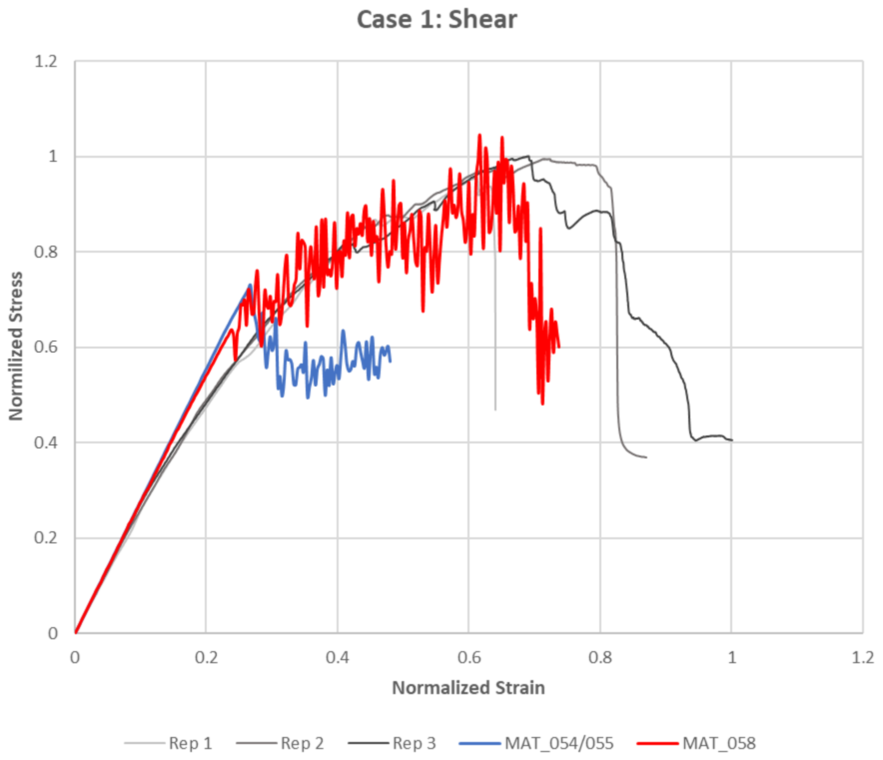


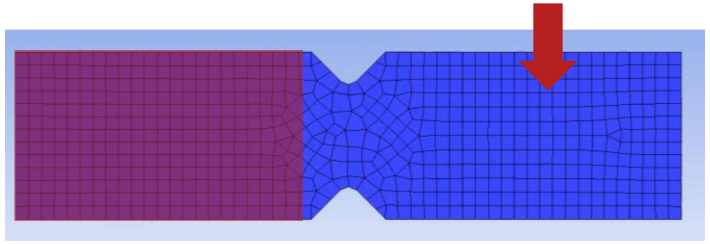


MAT_054 MAT_058

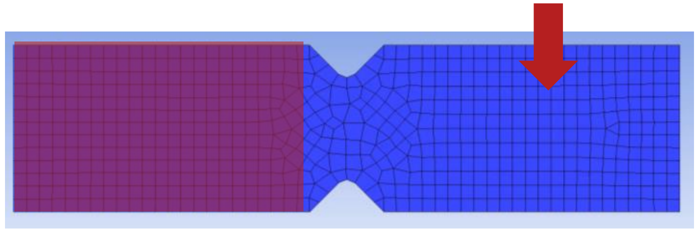
Strain and stress have been normalized due to project confidentiality

Results - Case 1: Laminate – Shear Validation





MAT_054



MAT_058

Strain and stress have been normalized due to project confidentiality

Discussions – Case 1: Laminate

- MAT_058 card captures nonlinear behavior but is limited to specific ply sequences, cores, and thicknesses
- Both models display instabilities in shear simulations, probably due to wrong simulation settings
- MAT_058 card is recommended for impact applications since it allows test data at different strain rates, showcasing its efficacy in capturing non-linear dynamic material responses
- MAT_054/055 card exhibit limitations due to their linear-based formulation, being unable to accurately representing this sandwich laminate material (skin/core)
- MAT_054/055 card offer an easy-to-fit material card, while MAT_058 card was more resources consuming due to its complexity

Methods - Case 2: Laminae - Testing

Material

- Aerospace grade composite material: Pre-impregnated UD Carbon fiber / PEEK matrix

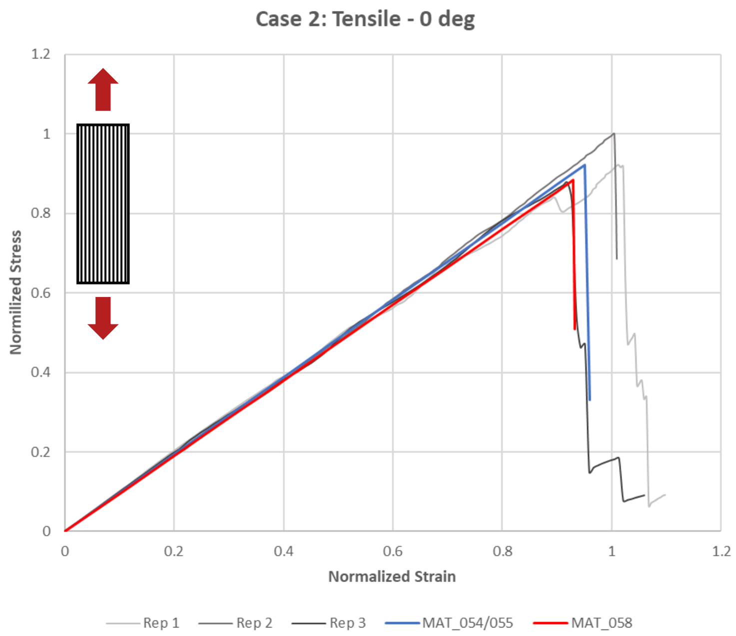
TestPak: G-794

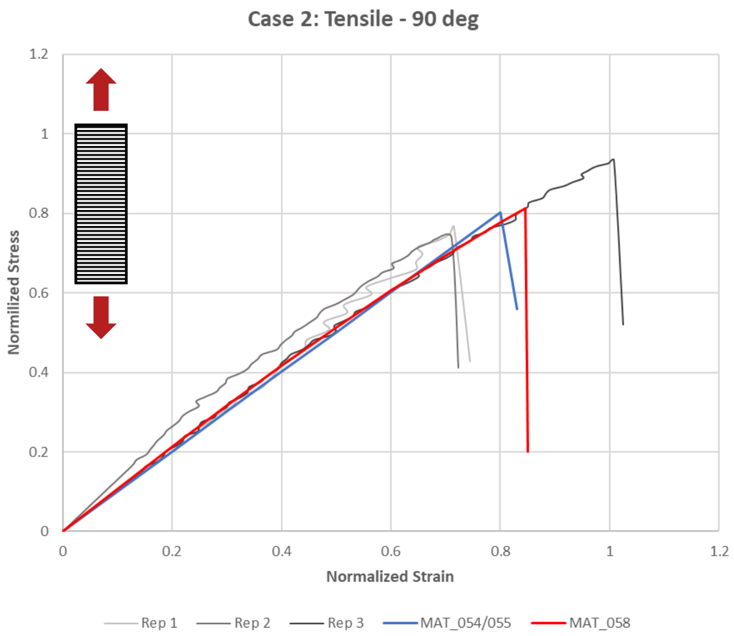
- ASTM D792-20 - Solid Density
- ASTM D3039/3039M-17 - Tensile Stress-Strain, Strength, Modulus, And Poisson's Ratio (2 Orientations)
- ASTM D5379/D5379M-19E1 - Shear Stress-strain (2 Orientations)

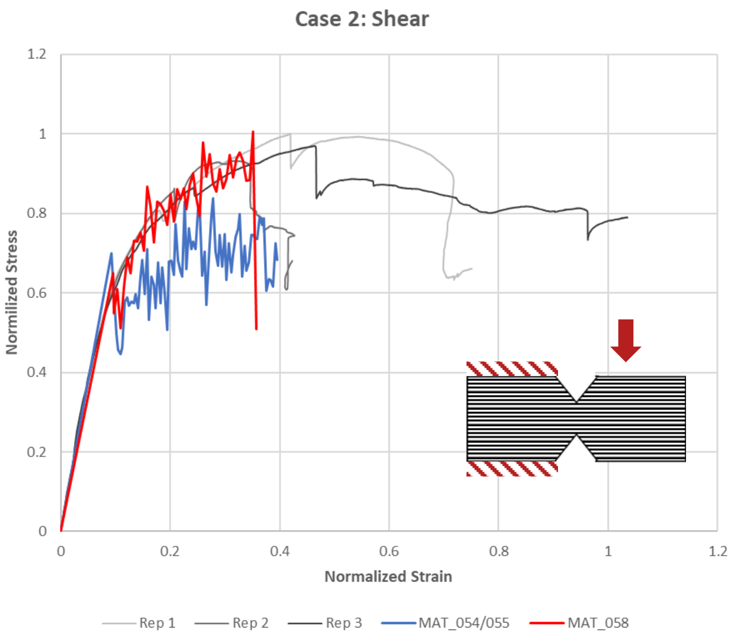
ASTM D3039/3039M-17

ASTM D5379/D5379M-19E1

Results - Case 2: Laminae – Tensile and Shear Validations







Tensile strength at 0º was **80 times higher** than tensile strength at 90º.

Due to project's confidentiality status strain and stress have been normalized

Discussions – Case 2: Laminae

- Testing at the lamina level was difficult, suggesting the need for improved methodologies
- Compression testing was challenging, revealing inherent difficulties in testing laminae materials
- Special techniques were adapted, particularly for shear testing, indicating methodological innovation
- Successful calibration of linear behavior into MAT_054/055 and MAT_058 enables integration into numerical simulations, particularly in models with robust interface models

Conclusions and remarks

- Successfully tested and modeled two thermoplastic composite materials, expanding our lab's capabilities
- Prepared to test materials under various conditions, providing material cards tailored for dynamic applications like impact testing
- Anticipate increasing demand for composite material modeling as it becomes essential for lightweight car part design
- A tailored approach to car design with composite materials will be crucial for success.
- Next steps include scaling up services and testing material cards at the component level to ensure effectiveness.

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