ADVANCED ANISOTROPIC DAMPING MODELING FOR NVH OPTIMIZATION

Applications to Short Fiber Reinforced Plastic (SFRP) Oil Pan and Engine Bracket

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Outline

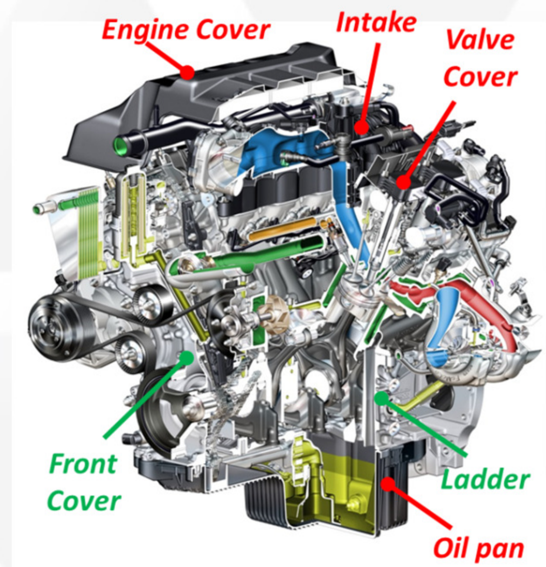
- **Introduction**
- **Objectives**
  - *Objective #1*: Quantify the impact of material anisotropy on the dynamic behavior of SFRP Components ?
  - *Objective #2* : Can microstructural aspects be tuned to optimize the damping and stiffness in order to improve the dynamic behavior of SFRP components ?
- **Approach**
- **Results**
  - *Case Study #1*: Impact of material anisotropy on the dynamic behavior of an engine oil pan
  - *Case Study #2*: Improving the dynamic behavior of a SFRP engine mount bracket thru microstructural modifications.
- **Conclusions and Next Steps**

Introduction

- **Short Glass Fiber Injected Plastics offer 2 main advantages for powertrain applications**:
  - Lightweight designs
  - Good damping behavior

Short fibers
Length << 1mm
Straight
Typical aspect ratio (AR) = 10 to 20

Long fibers
1mm < Length < 50mm
Curved
Typical aspect ratio (AR) = 25 to 40



- **Dynamic behavior of SFRP components is affected by the fiber orientation distribution. The material anisotropy impacts:**
  - Frequency dependent stiffnesses
  - Frequency dependent damping

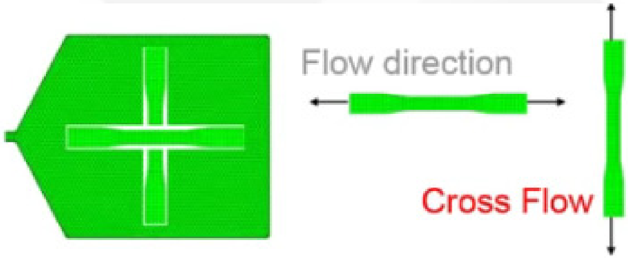
- **Dynamic behavior optimization of SFRP powertrain components requires :**
  - A method to characterize the material behavior
  - A multi-scale material model capable to capture such behaviors
  - Application of such model to improve the prediction of the dynamic response
  - Optimization of fiber orientation to improve the component's dynamic performance

Objectives

- **Objective # 1 : What is the impact of material anisotropy on the dynamic behavior of an SFRP engine oil pan ?**
  - **Testing:**
    - Samples : characterize stiffness & damping as function of frequency and fiber orientation
    - Oil Pan : hammer tests to measure global dynamic behavior of the component
  - **Material Modeling:**
    - Create a material model that provides the correct material property function of the fiber orientation based on test sample data
    - In parallel create an isotropic model following current method using material supplier's data
  - **Microstructure:**
    - Perform an injection simulation on an oil pan to predict fiber orientation distribution
  - **Frequency response analysis on component:**
    - Perform FRF analysis with the isotropic and anisotropic material model accounting for the effect of fiber orientations and frequency
    - Compare anistropic & isotropic simulation results with experiment

Tensile & DMA tests on samples cut from injected plaques

2 fiber orientations in samples :
injection flow direction → 0°
injection cross flow direction → 90°



Objectives- Cont'd

- **Objective # 2 : Can microstructural aspects be tuned to optimize the damping and stiffness in order to improve the dynamic behavior of SFRP engine mount bracket ?**
  - **Analyze vibrational behaviors of 2 material grades:**
    - PA66 resin reinforced with 40% mass fraction of glass fiber (PA66 GF40)
    - PA66 resin reinforced with 60% mass fraction of glass fiber (PA66 GF60)
  - **Microstructure:**
    - Perform injection simulations on an engine bracket with two different injections setups
    - Observe the effect on fiber orientation distribution
  - **Component's behavior :**

    Run FRF analysis for different materials and injection setups:
    - Effect of fiber volume fraction
    - Effect of fiber orientation distribution from two different injection settings
    - Effect of fiber length

Approach

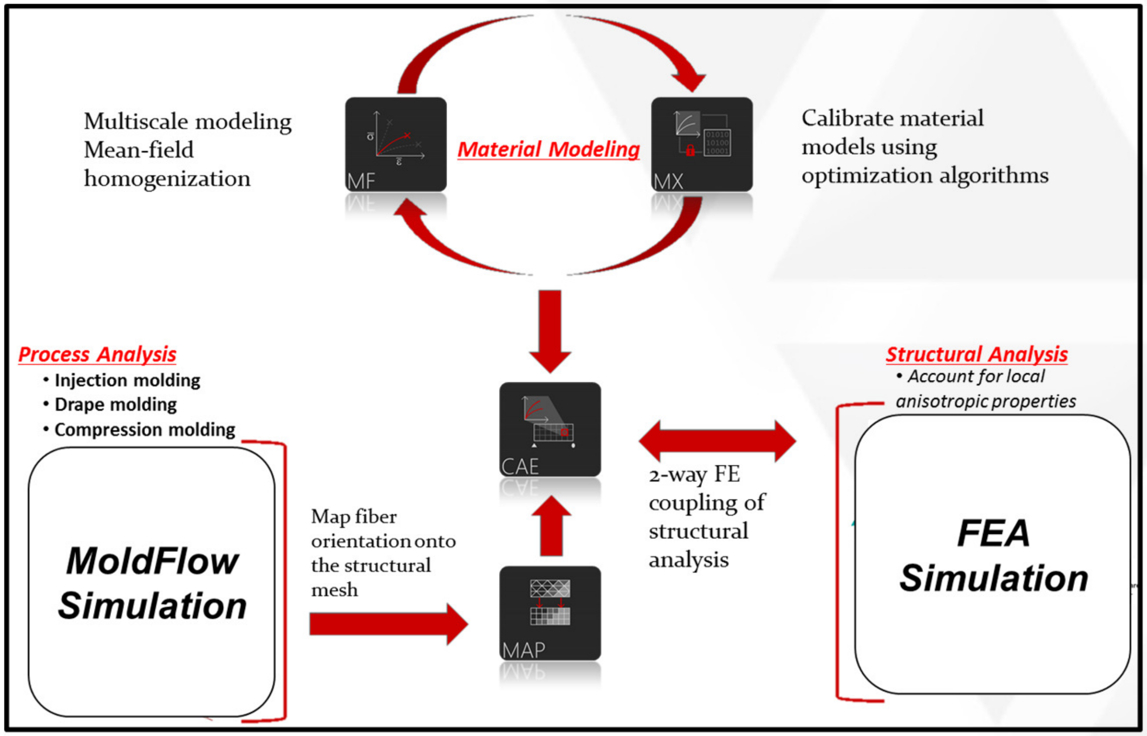
The approach is based on the creation of a Multi-scale material model for the SFRP components. This model is required in the dynamic simulations to account for fiber orientation distribution.

The workflow process used to perform dynamic simulations includes 3 main steps:

(1) Mold flow simulation

(2) Material modelling

(3) FEA simulation



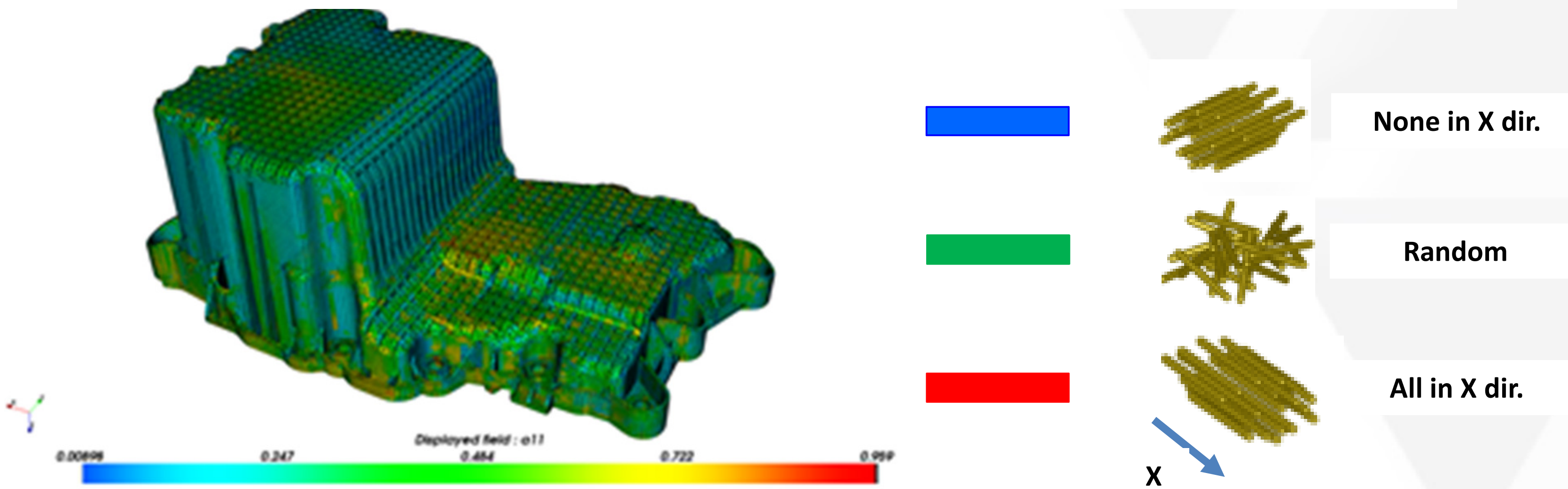
Approach- Cont'd

Step (1): Mold Flow Simulation

Mold flow analysis predicts the fiber orientation based on injection process parameters, gate locations, drops and gate sizes.

Typical mold flow analysis provides the *probability* of the fibers to be oriented along a given *direction*: the fiber orientation tensor

Fiber orientation tensor – Coefficient A11 (11 stand for X direction)
Color indicates orientation intensity in the given direction, here X



Note : complete tensor includes 6 coefficients : a11, a22, a33, a12, a23, a13

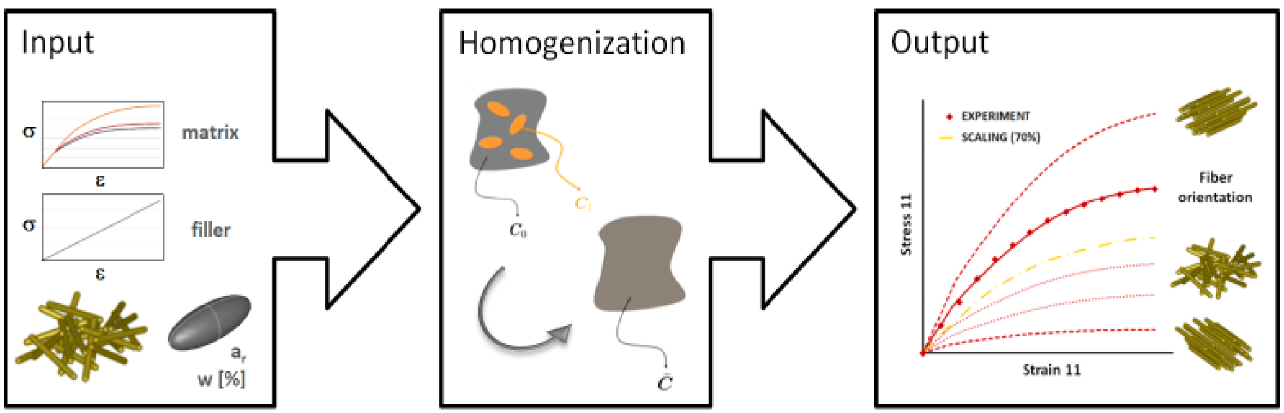
Approach- Cont'd

Step (2): Material Modeling

Mutli-scale material model is obtained from micromechanics with mean-field homogenization techniques.

Local anisotropic properties are computed based on the properties and the microstructure of the underlying constituents of a multi-phase material (the original multi-phase material is represented locally by an equivalent homogeneous one).

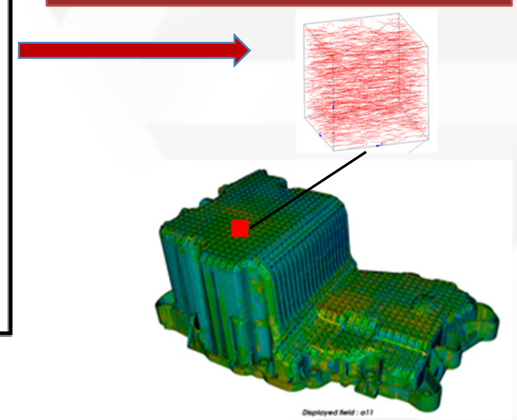
Homogenized behaviour to feed each element (= RVE) in component function of local fiber orientation



Per-phase material properties + microstructure information

State-of-the-art homogenization methods

DIGIMAT material model sensitive to composite microstructure



RVE = representative volume element

Approach- Cont'd

Step (3): FEA Simulation

- Material data are mapped to the FEA model according to the predicted orientation of the fibers.
- Forced Response Analysis is performed using unit load applied at specific locations of the component, to determine the Eigen-frequencies and the inertance at these locations.
- FEA simulation is based on free-free boundary conditions.

Results- Cont'd

Case Study #1: Application on engine oil pan

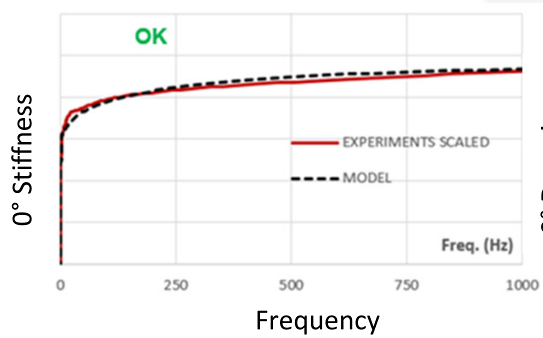
Multi-scale material model calibration

- **The *Digimat* material model's behavior captures correctly post processed measurements on 0° and 90° samples**

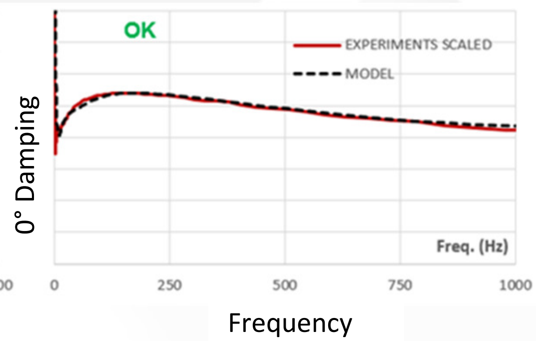
- 0° ***(Fibers Aligned with Injection Flow Direction):***
  - Stiffness & Damping behaviors are perfectly captured by the multi-scale material model

- 90° ***(Fibers Aligned with Injection Cross Flow Direction)***
  - Behavior is correctly predicted by the material model.
  - Improvement needed for Damping response

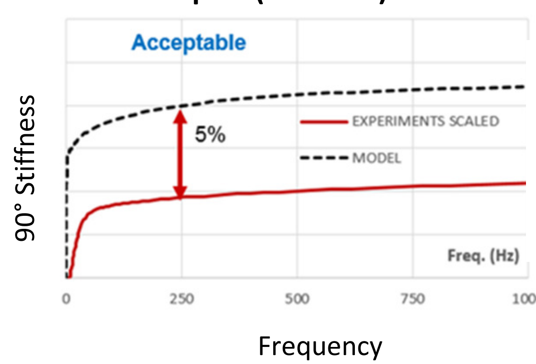
Real part (Stiffness)



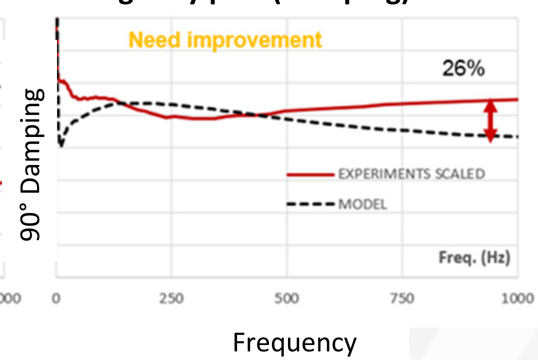
Imaginary part (Damping)



Real part (Stiffness)



Imaginary part (Damping)



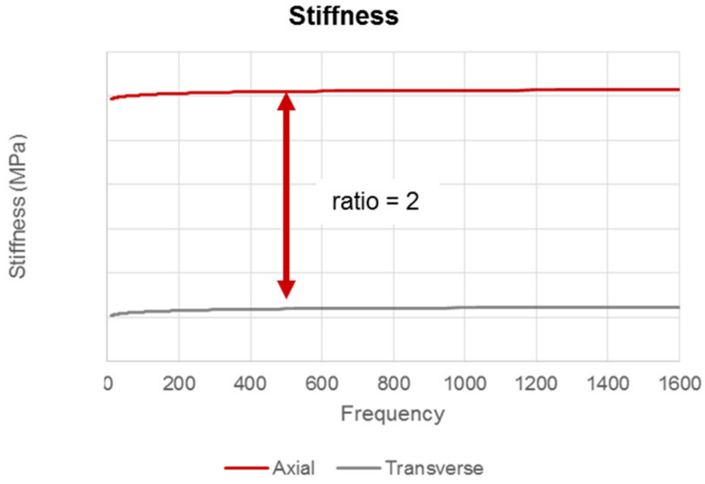
Experimental scaled curves = post processed curves from measurements on 3 samples

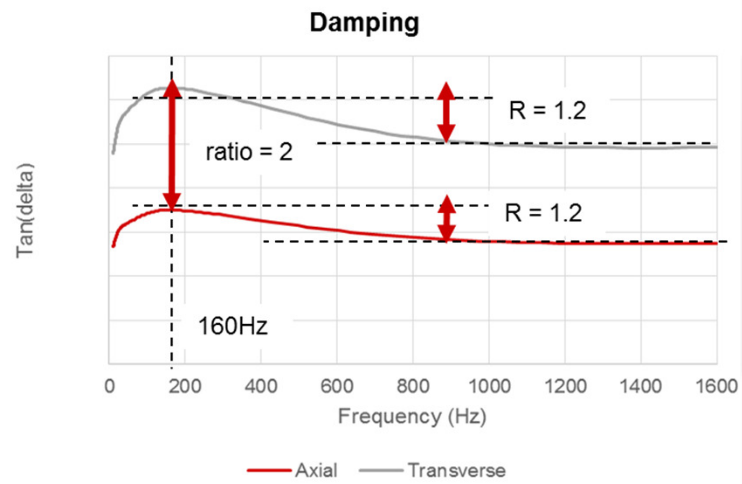
Results- Cont'd

Case Study #1: Application on engine oil pan

Observations on anisotropy & frequency dependency

- **Stiffness:**
  - High anisotropy due to fiber orientations : ratio = 2 between axial and transverse tensile behaviors
  - Negligible dependency to frequency
- **Damping:**
  - High anisotropy due to fiber orientations : ratio = 2 between transverse and axial tensile behaviors
  - Higher frequency dependency than stiffness between 160Hz and 800Hz but remain low in absolute values
  - Saturation effect over 800Hz which lead to a negligible dependency to frequency



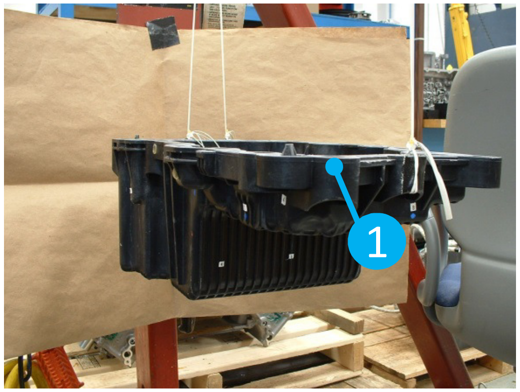


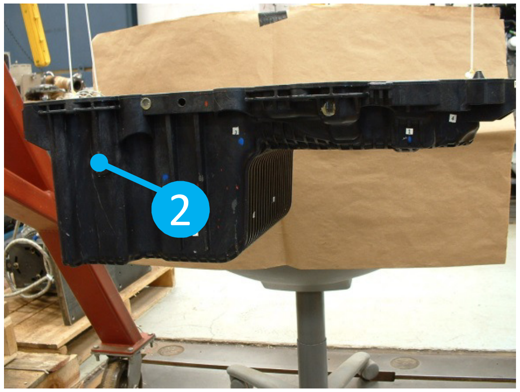
Results- Cont'd

Case Study #1: Application on engine oil pan

Impact tests on engine oil pan

- Experimental hammer tests are performed on the oil pan, in a free-free condition, without oil in the pan.
- The oil pan has been submitted to a drying procedure to make sure material behavior is consistent with the one characterized with DMA tests.





Oil pan attached to bungee cords and locations of the FRF driving points

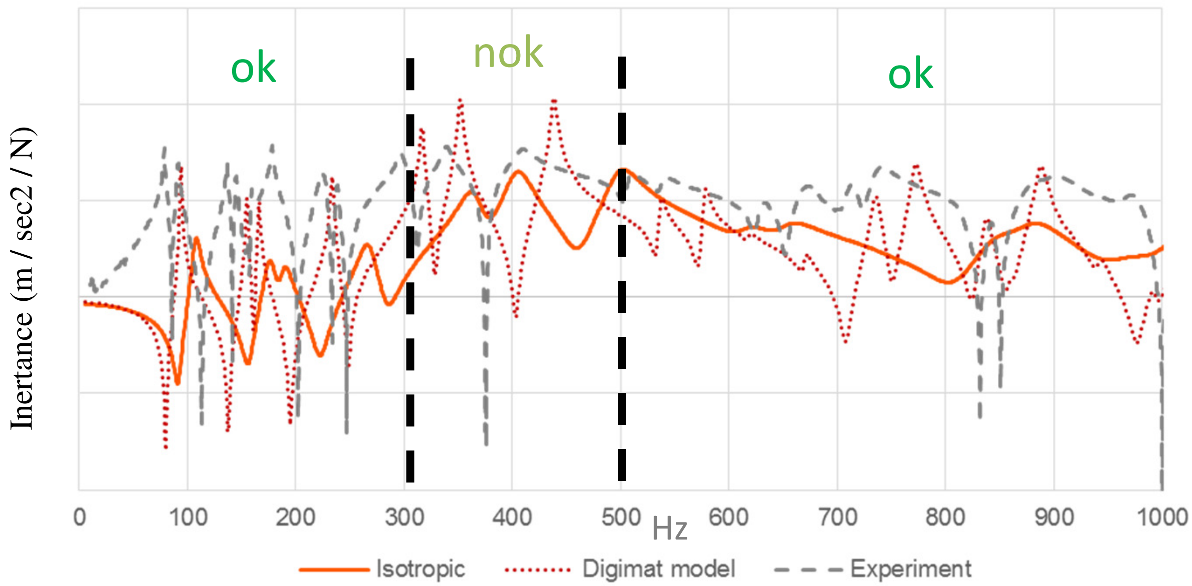
Results- Cont'd

Case Study #1: Application on engine oil pan

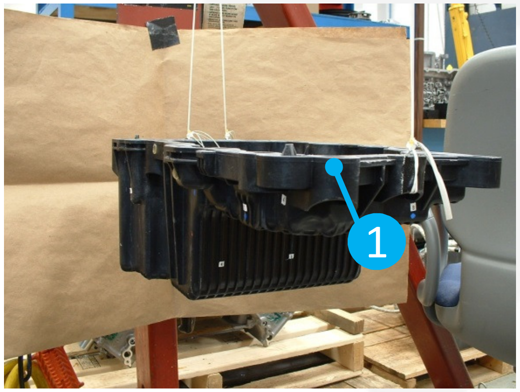
Simulation vs experiment- improved prediction

- **Anisotropic vs Isotropic**
  - The overall accuracy is significantly improved with Anisotropic model compared to Isotropic modeling both on identifications of eigenfrequencies and acceleration response maximums

- **Focus on Anisotropic results**
  - Levels of the acceleration peaks below 300Hz and over 500Hz are correctly capture by simulation → good prediction of the component's damping performance
  - Between 300-500Hz, Damping effect looks underestimated by simulation



Driving point
X direction

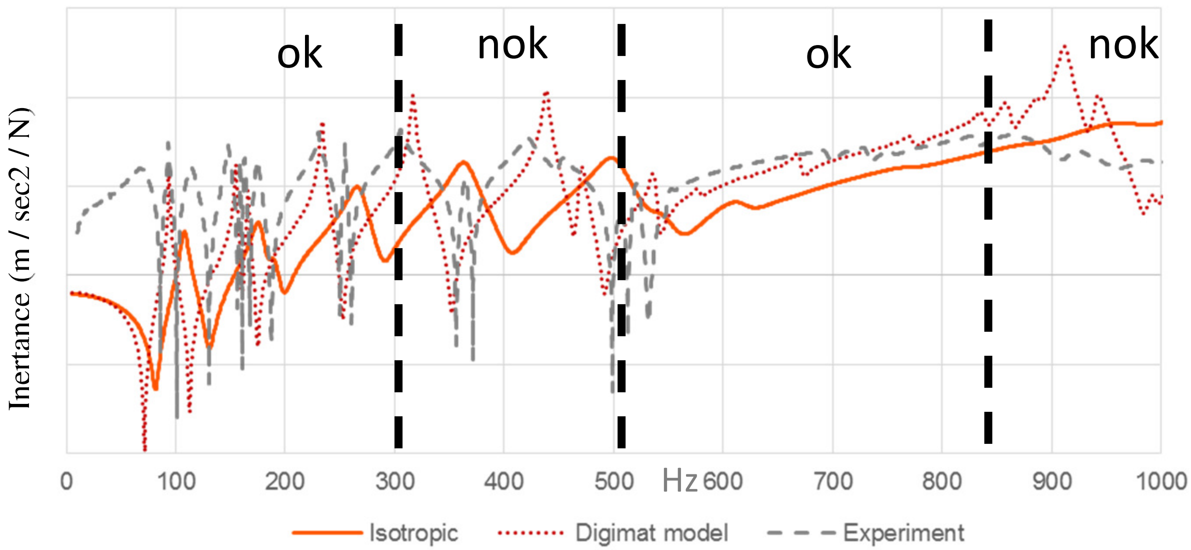


Results- Cont'd

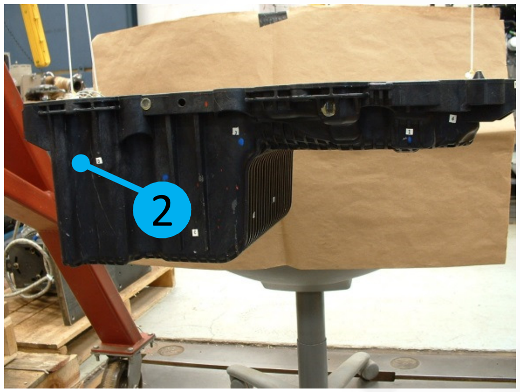
Case Study #1: Application on engine oil pan

Simulation vs experiment- improved prediction

- **Anisotropic vs Isotropic**
  - The overall accuracy is significantly improved with Anisotropic model compared to Isotropic one both on identifications of eigenfrequencies and acceleration response maximums
- **Focus on Anisotropic results**
  - Levels of the acceleration peaks below 300Hz and between 500-850Hz are correctly capture by simulation → good prediction of the component's damping performance
  - Between 300-500Hz and over 850Hz, Damping effect looks under-estimated by simulation



Driving point
Y direction



Results- Cont'd

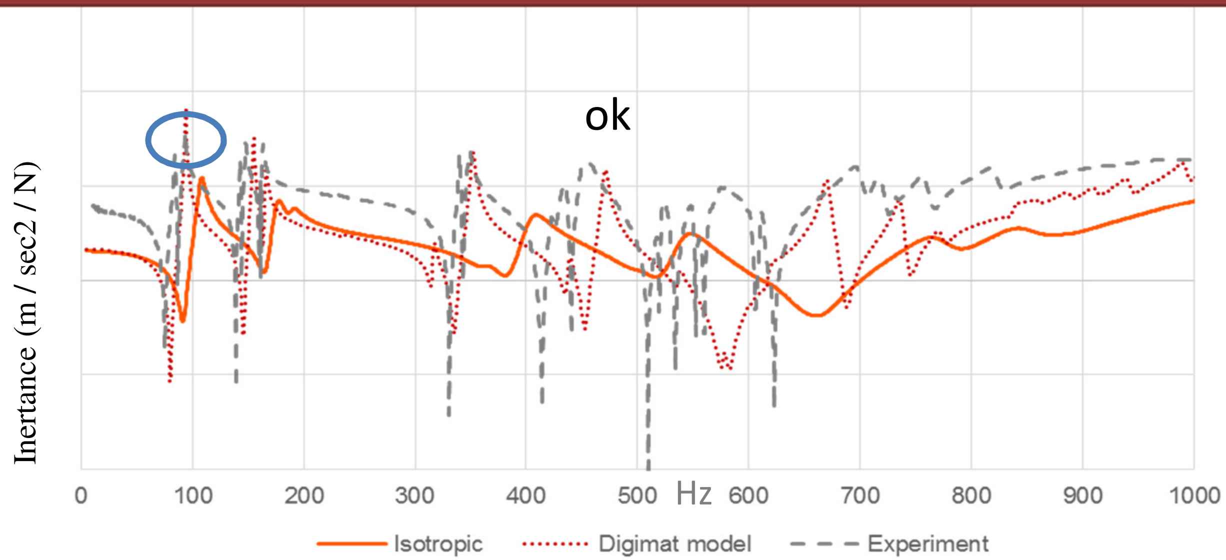
Case Study #1: Application on engine oil pan

Simulation vs experiment- improved prediction

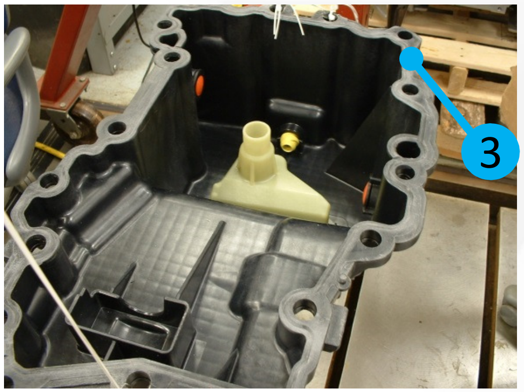
- **Anisotropic vs Isotropic**
  - The overall accuracy is significantly improved with Anisotropic model compared to Isotropic modeling both on identifications of eigenfrequencies and acceleration response maximums

- **Focus on Anisotropic results**
  - Levels of the acceleration peaks on the overall frequency range is captured in the correct range of values (only 2nd peak at 100Hz shows under-estimation of damping in simulation)

> ➢ Overall - The accuracy observed for the 3 directions of loading proves that the Multi-scale material modeling helps capture correctly the physics of SFRP materials
>
> ➢ Anistropic modeling significantly improves the prediction's accuracy compared to current Isotropic modeling



Driving point
Z direction



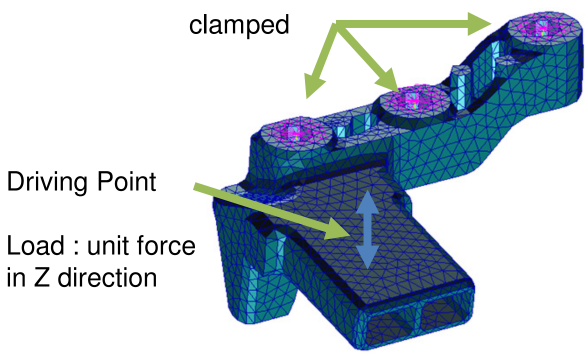
Results- Cont'd

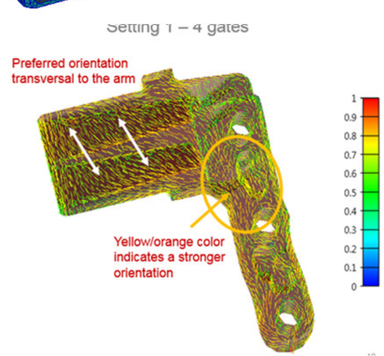
Case Study #2: Application on an engine mount bracket

Compliance Analysis: Fiber mass fraction (% of fiber glass increase from 40 to 60%) highly influences overall damping and eigenfrequencies

Peak	Stiffness Effect Frequency (Hz)			Damping Effect Displ. (e-03mm)		
	GF 40	GF 60	Effect	GF 40	GF 60	Effect
P1	300	360	20%	2	2.3	15%
P2	525	645	23%	0.3	0.68	127%
P3	845	1035	22%	0.16	0.17	6%

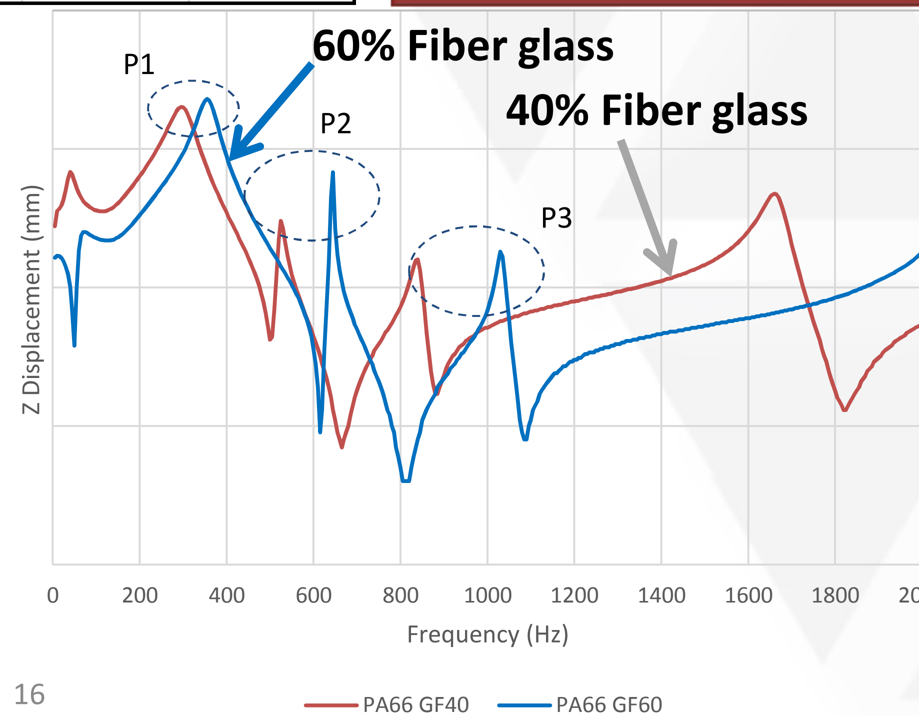
Increase in Fiber Glass Content moves Engine Bracket peaks to higher frequencies





Fiber orientations from injection setting 1

PA66GF40
vs
PA66GF60



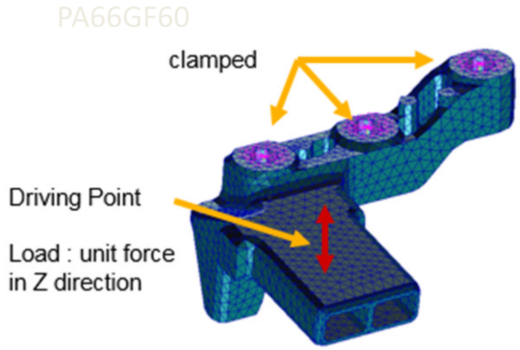
Results- Cont'd

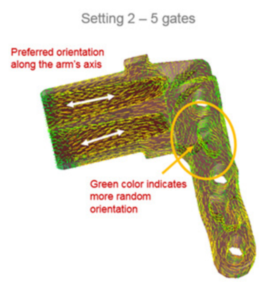
Case Study #2: Application on an engine mount bracket

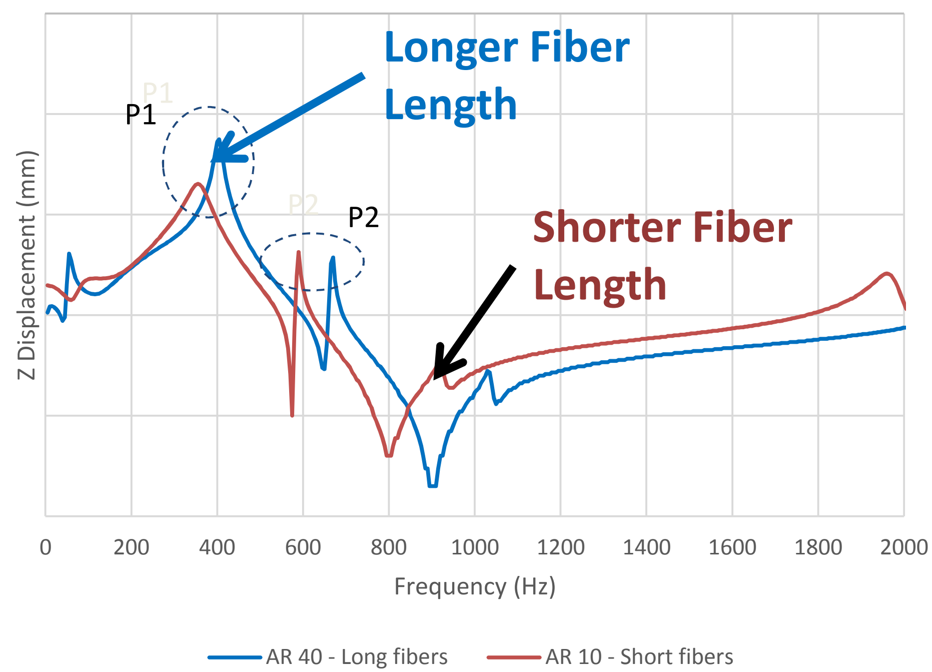
Compliance Analysis: (Longer Fiber length) highly influences the overall damping and eigenfrequencies in lower proportions

Peak	Stiffness Effect Frequency (Hz)			Damping Effect Displ. (e-03mm)		
	Short	Long	Effect	Short	Long	Effect
P1	365	401	10%	2	5.6	180%
P2	590	670	14%	0.42	0.37	-12%

Increase in Fiber Length moves Engine Bracket peaks to higher frequencies







Aspect ratio = 10

Short fibers
Length < 1mm

VS

Aspect ratio = 40

Long fibers
1mm < Length < 50 mm

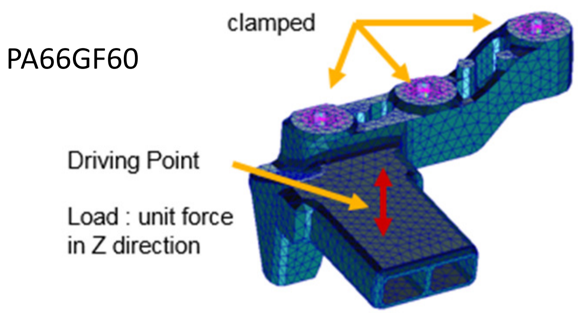
Results- Cont'd

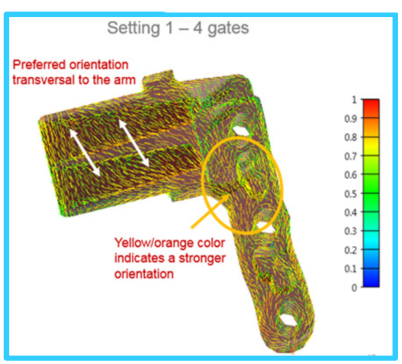
Case Study #2: Application on an engine mount bracket

Compliance Analysis : fiber orientations resulting from different injection setting, influence the overall damping and has slight influence on eigenfrequencies

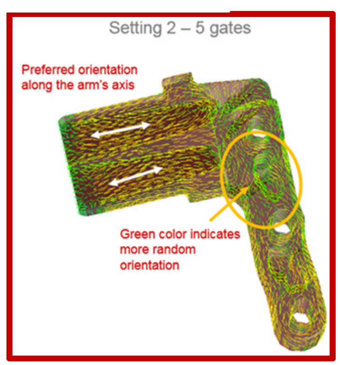
Peak	Stiffness Effect Frequency (Hz)			Damping Effect Displ. (e-03mm)		
	Setting 1	Setting 2	Effect	Setting 1	Setting 2	Effect
P1	370	395	7%	2.2	3.2	45%
P2	645	645	0%	0.68	0.53	-22%
P3	1035	995	-4%	0.026	0.17	554%

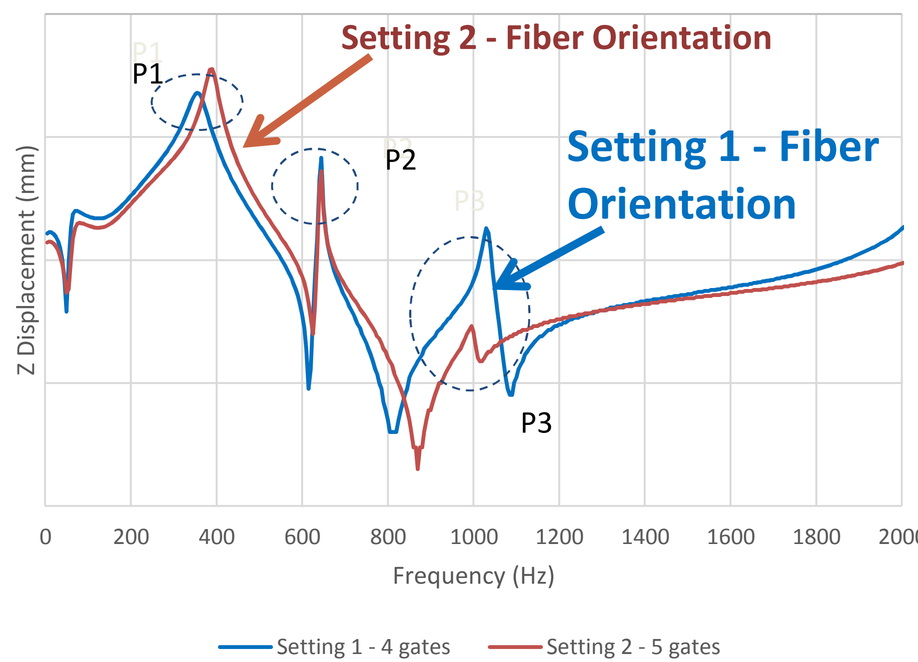
Fiber Orientation has mininimum effect in shifting frequency peaks, but influences resonant peak amplitudes





VS





Summary and Conclusions

Mastering the microstructure could improve the component's dynamic behavior

- **Case Study #1**
  - Material characterization reveals the influence of fiber orientation on material stiffness and damping.
  - Accounting for material anisotropy improves the predictions of the dynamic behavior of the SFRP oil pan.
  - Further investigation should be considered to improve the simulation results:
    - Effect of local variations in fiber mass fraction influencing local stiffness, damping and also mass

- **Case Study #2**
  - An application to engine mount bracket reveals that the microstructure resulting from the injection process and the material selection, notably fiber orientations, fiber volume fraction and fiber length can have a significant influence on:
    - component's dynamics properties
    - component's eigenfrequencies
  - Design engineers could optimize the SFRP components by acting on injection setting parameters and material selection, in addition to the conventional geometry optimization.
  - However the method to « reverse engineer » injection settings from a desired orientation distribution doesn't exist yet and should be the object of further investigations

Next Steps

Next Steps in the application of Multi-scale Material Modeling for Engine NVH Simulation include:

1. Apply Multi-Discipline Optimization methods to evaluate interaction effects between fiber orientation, length and % glass content to determine best tuning for NVH

2. Apply this method in combination with a morphing tool to evaluate the effects in (1) in conjunction with shape optimization for optimum NVH response

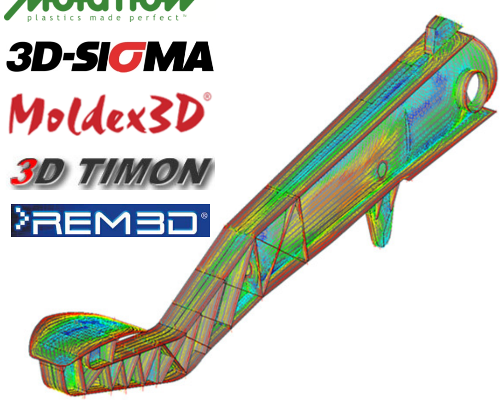
3. Apply a combination of (1) and (2) on other engine components to best attenuate the overall acoustic response of these structures

Thank You!

Appendix :
DIGIMAT Technology Coupling with CAE codes

Process → **Material** ↔ **Structure**

Injection Molding / Draping



Phase Material & Composite Microstructure

-Fiber Shape

-Fiber Weight Fraction

-Fiber Length Distribution

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