Fatigue Methodology for the Polymeric Materials

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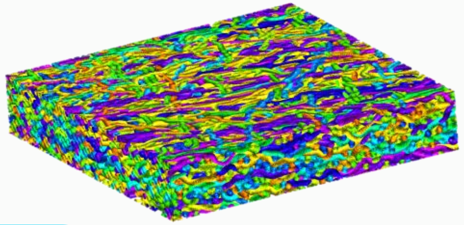
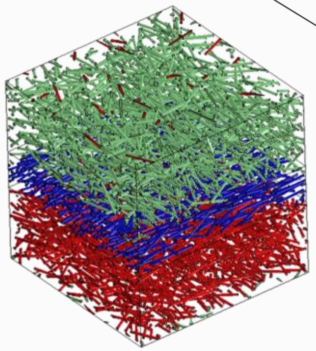
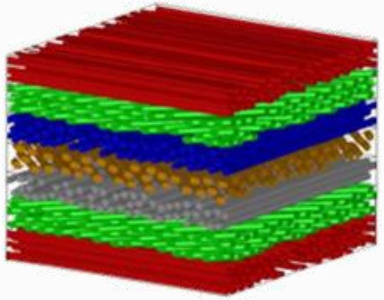
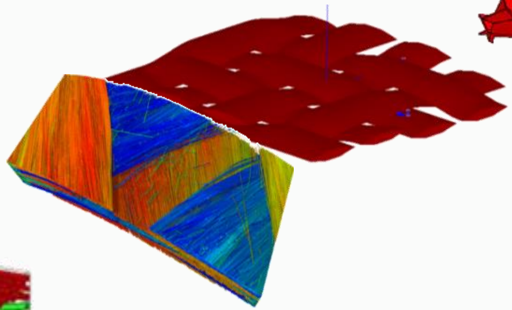
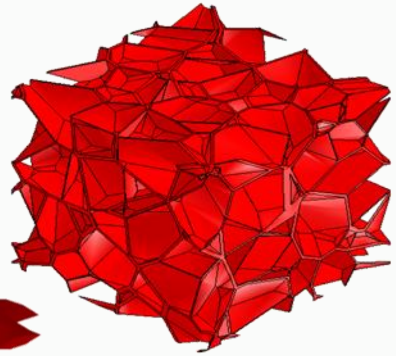
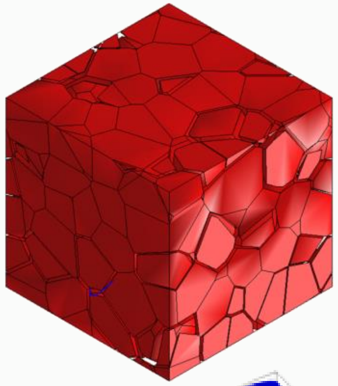
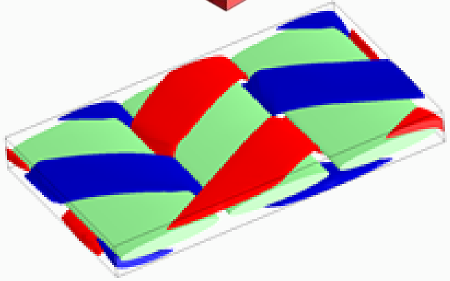
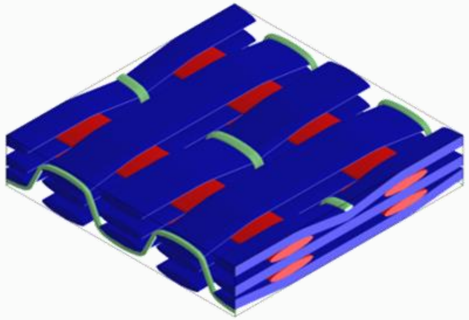
Composite Challenges

Composite Challenges

What should one pay attention to?

- **Composites:**
  - Combination of 2 or more constituent materials in order to produce a new material with different/increased properties compared to the constituents

- **Examples:**
  - Chopped fiber reinforced plastics : short or long
  - Continuous fibers : UD, woven or braided
  - Other materials : Metals, rubbers, foam etc.

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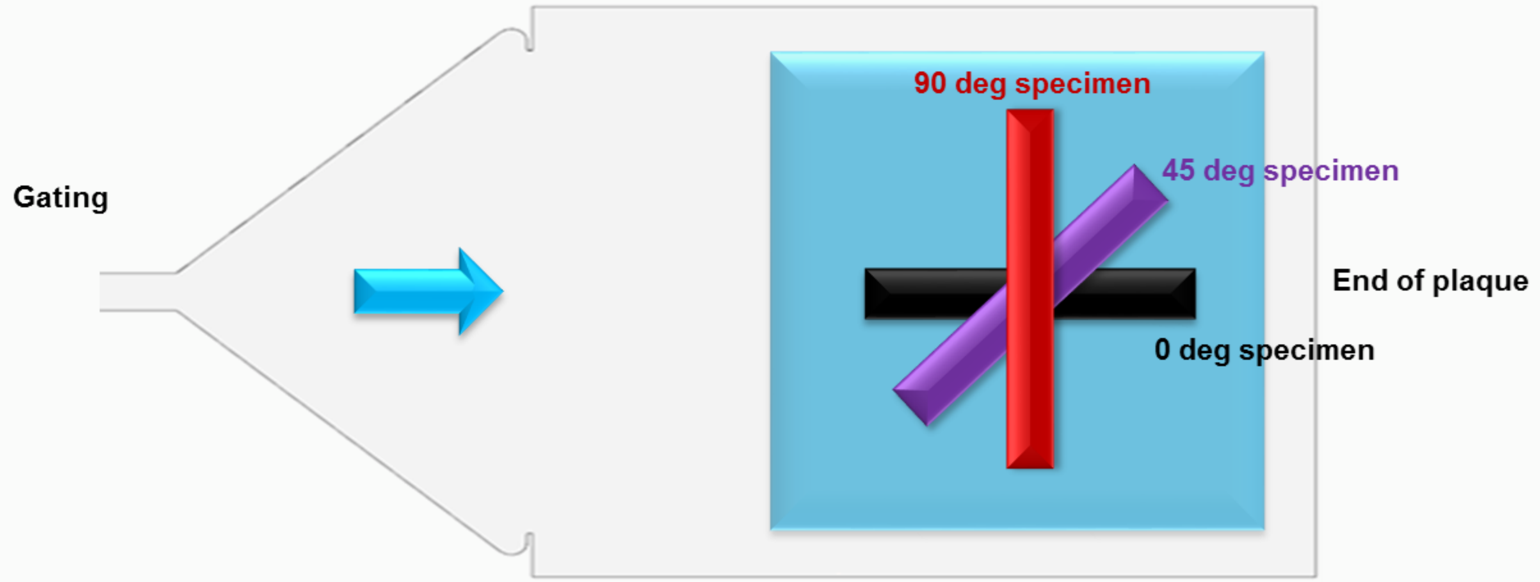
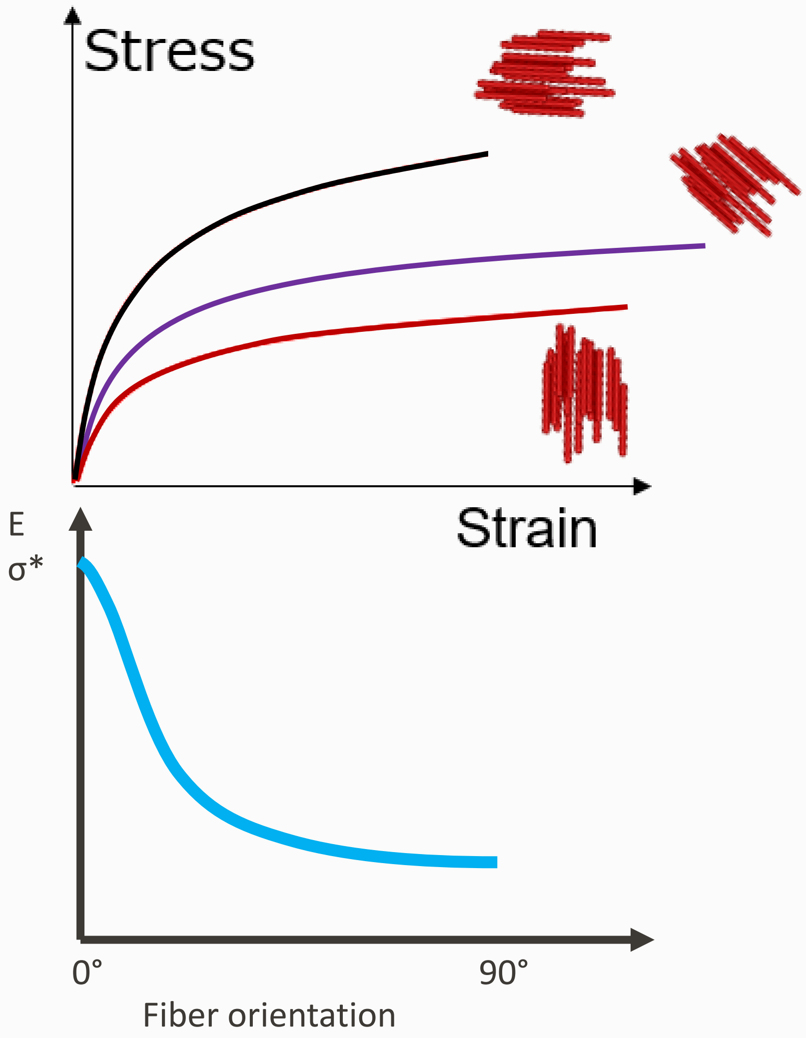
Composite Challenges

What should one pay attention to?

- **Consider plastics and composites for what they are**
  - Anisotropic/Orthotropic by nature





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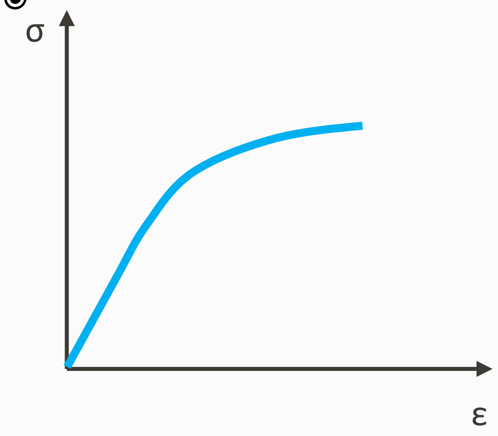
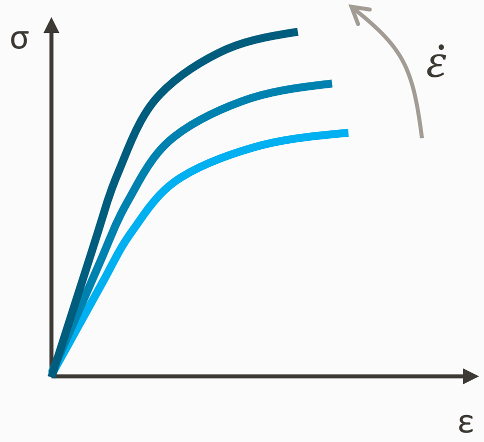
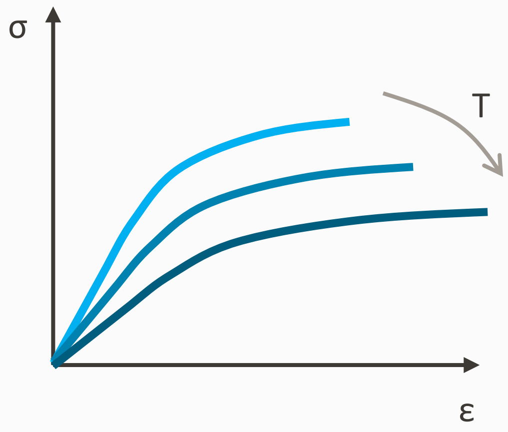
Composite Challenges

What should one pay attention to?

- **Consider plastics and composites for what they are**
  - Anisotropic/Orthotropic by nature
  - **Nonlinear**
  - **Strain rate dependent**
  - **Temperature dependent**



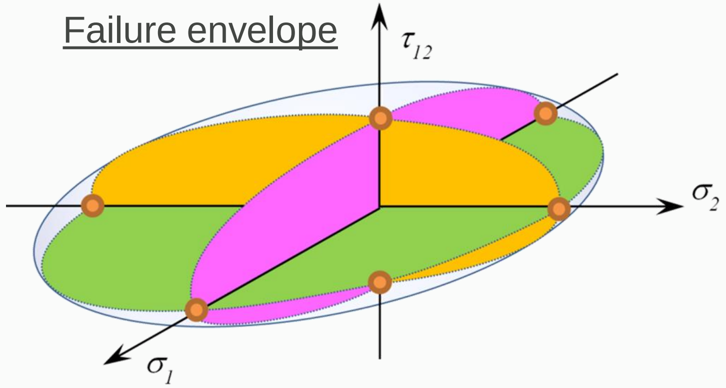




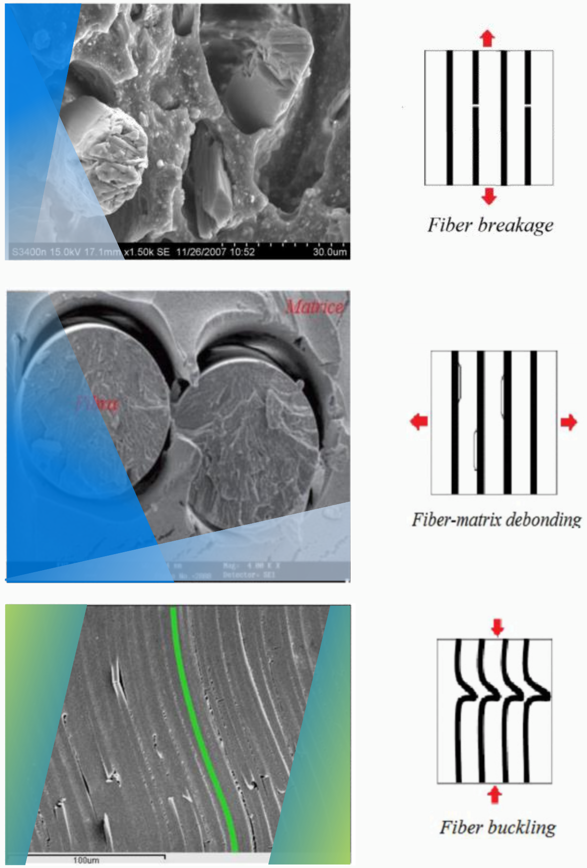
Composite Challenges

What should one pay attention to?

- **Consider plastics and composites for what they are**
  - Anisotropic/Orthotropic by nature
  - Nonlinear
  - Rate dependent
  - Temperature dependent
  - **Complex failure mechanisms/modes**



http://mechanicalengineeringblog.tumblr.com/post/121684647734/failure-index-vs-strength-ratio-in-a-quadratic



Dario Tipa, Thesis "Progettazione di strutture in tessuto composito: tecniche di omogeneizzazione e simulazione numerica", March 2016, Universita di Genova, Figures 2.15 to 2.17

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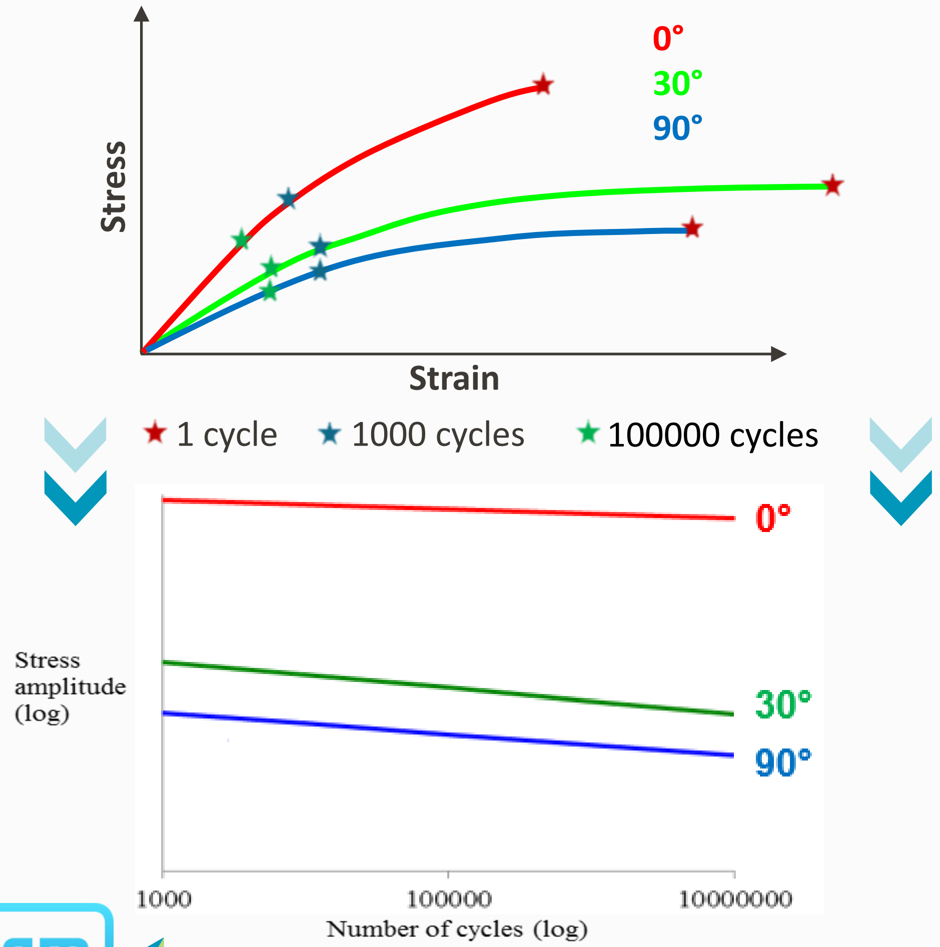
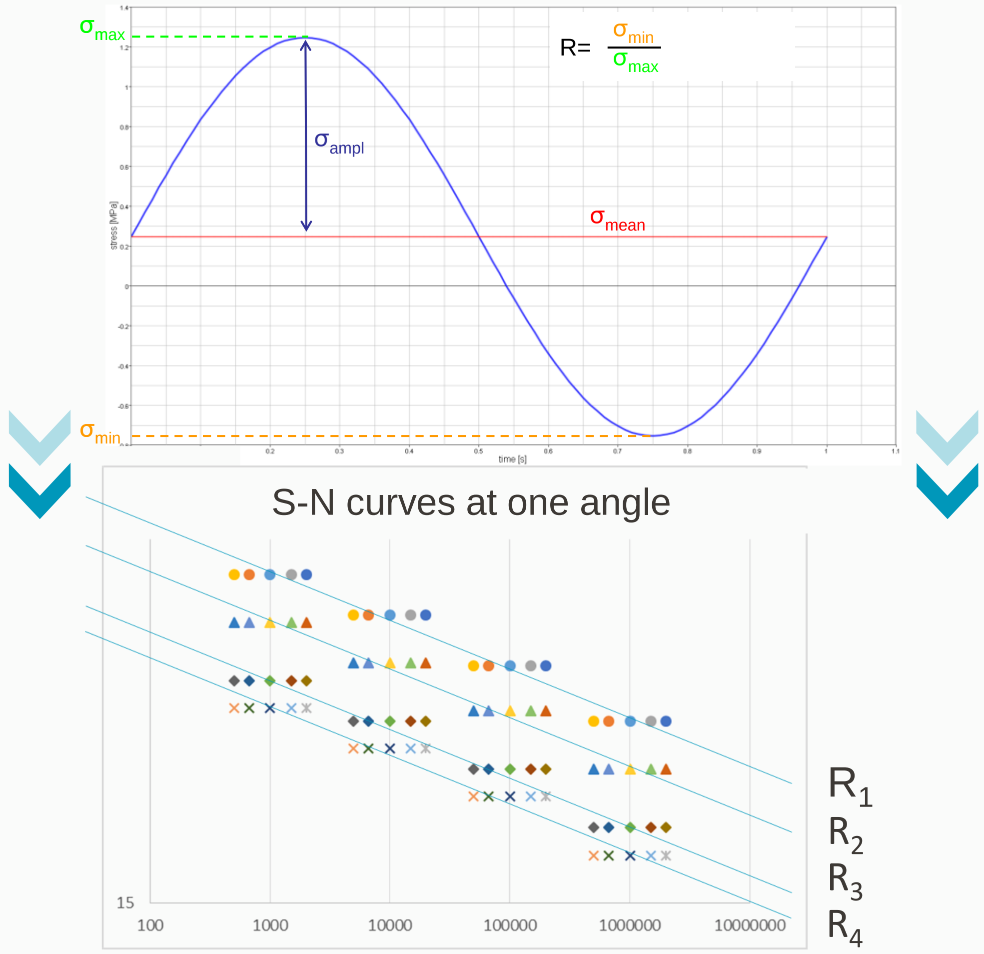
Composite Challenges

What should one pay attention to?

- **Dependent on number of cycles (N)**



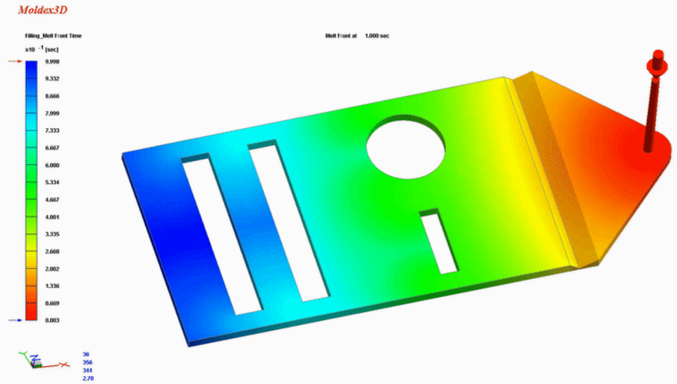
- **Dependent on load ratio, R**



Composite Challenges

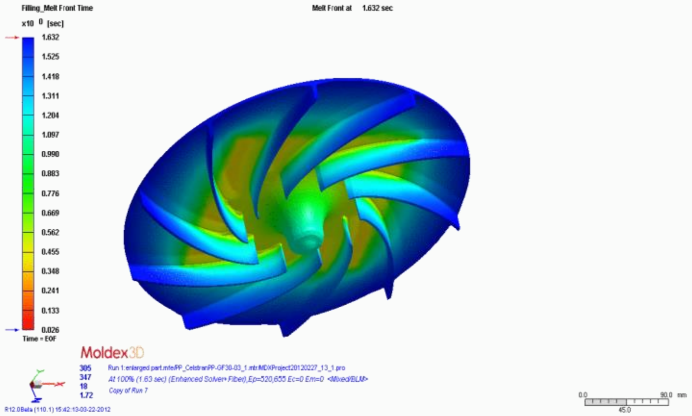
What should one pay attention to?

- **Recognize the effects of the manufacturing process on the resulting properties**

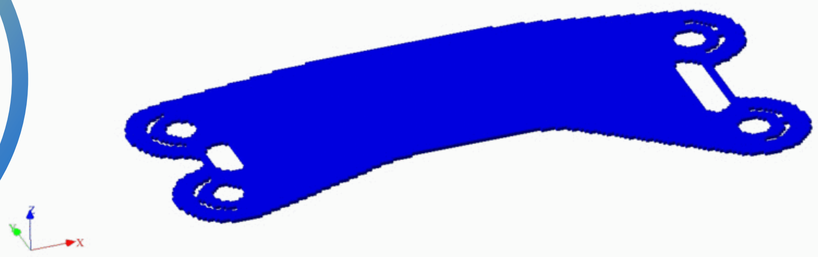


Injection Molding

Draping



Compression Molding



Additive Manufacturing

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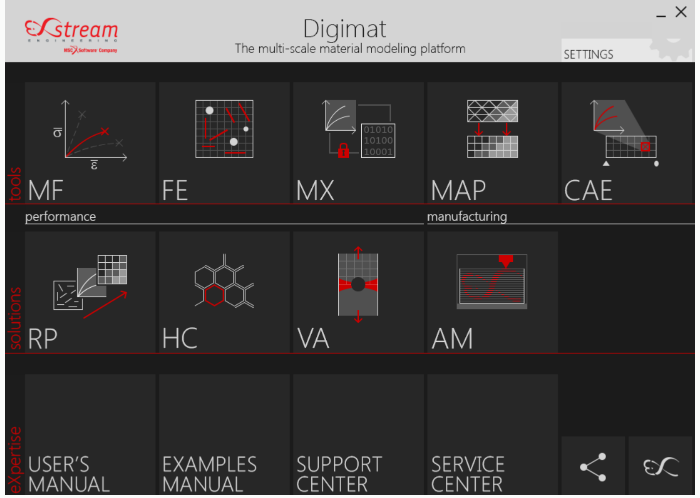
Composite Challenges

What should one pay attention to?

- **The mechanical performance of the part depends on:**
  - the orientation of the fibers relative to the loading type and direction
  - the non-linear, strain rate dependent, temperature dependent behavior of the resin

- **Fiber orientation in the part is governed by the manufacturing process**

- **Accurate predictions require a solution that captures the effect of the fiber orientation and the performance of the resin.**



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Structural Application Procedure

Structural Application Procedure

Bridging gap between manufacturing and performance

Process Software

Molding
AUTODESK MOLDFLOW · Moldex3D MOLDING INNOVATION · Simpoe · SIGMASOFT Virtual Molding · REM3D · 3D TIMON

Additive
Digimat

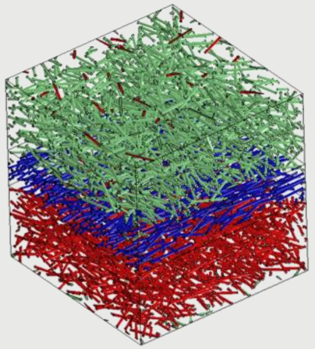
Draping / Stamping / RTM / AFP
Simulayt · ANIFORM VIRTUAL FORMING · esi get it right™

CT Scan
VOLUME GRAPHICS

Metal Casting
esi ProCAST · MAGMA Committed to Casting Excellence

Material Modeling

Digimat



FEA Software

Structural
HEXAGON · Ansys / LS-DYNA · SIMULIA ABAQUS · Altair · SAMTECH · esi get it right™ · INTES

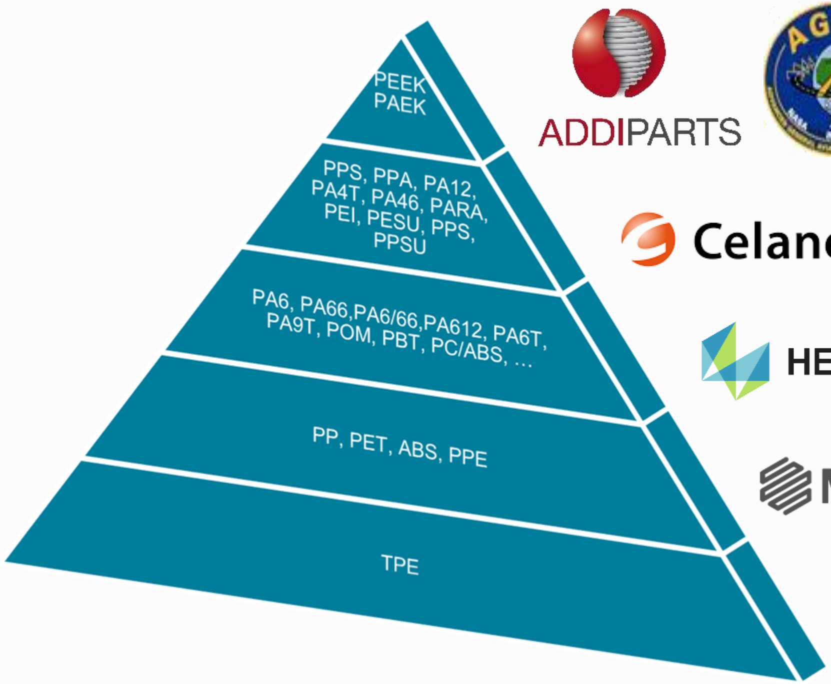
Fatigue
nCode® n' ...an HBM brand · LMS® A Siemens Business

gm · HEXAGON

Structural Application Procedure

Material models

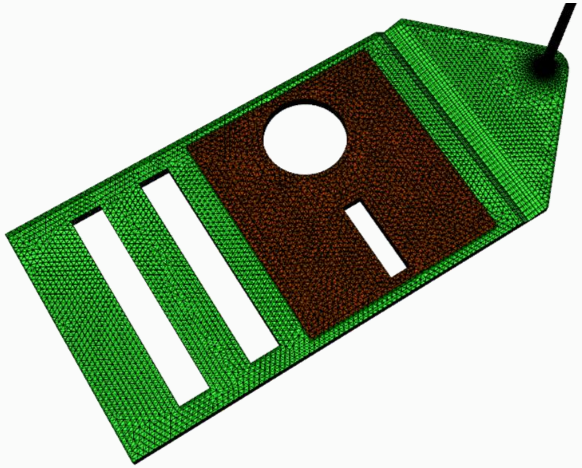
- **Digimat material models and data accessible by ALL Digimat users**
  - 600+ Grades and 58,000+ Digimat material models → largely built by material suppliers for their potential customers
  - Thermoplastic & Thermosets
  - Glass/Carbon reinforcement



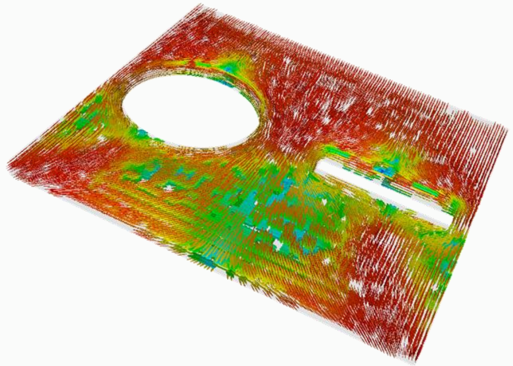
Structural Application Procedure

Mapping

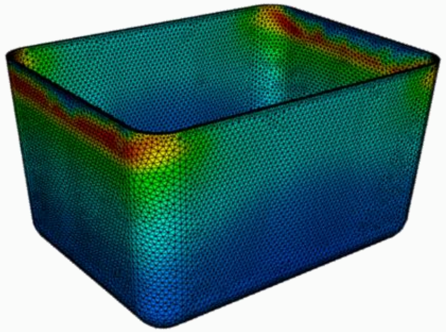
- **Fields to map:**
  - Fiber orientations
  - Volume fractions
  - Initial stresses
  - Temperature fields
  - Porosities
  - Weld lines



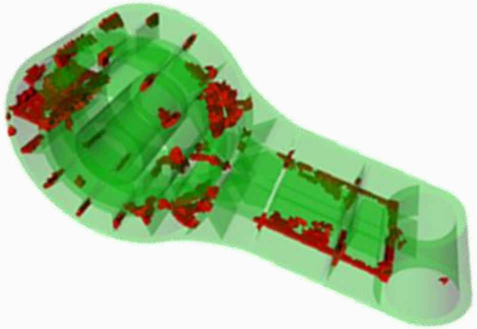
Different meshes



Orientation tensors



Porosity



Weld lines

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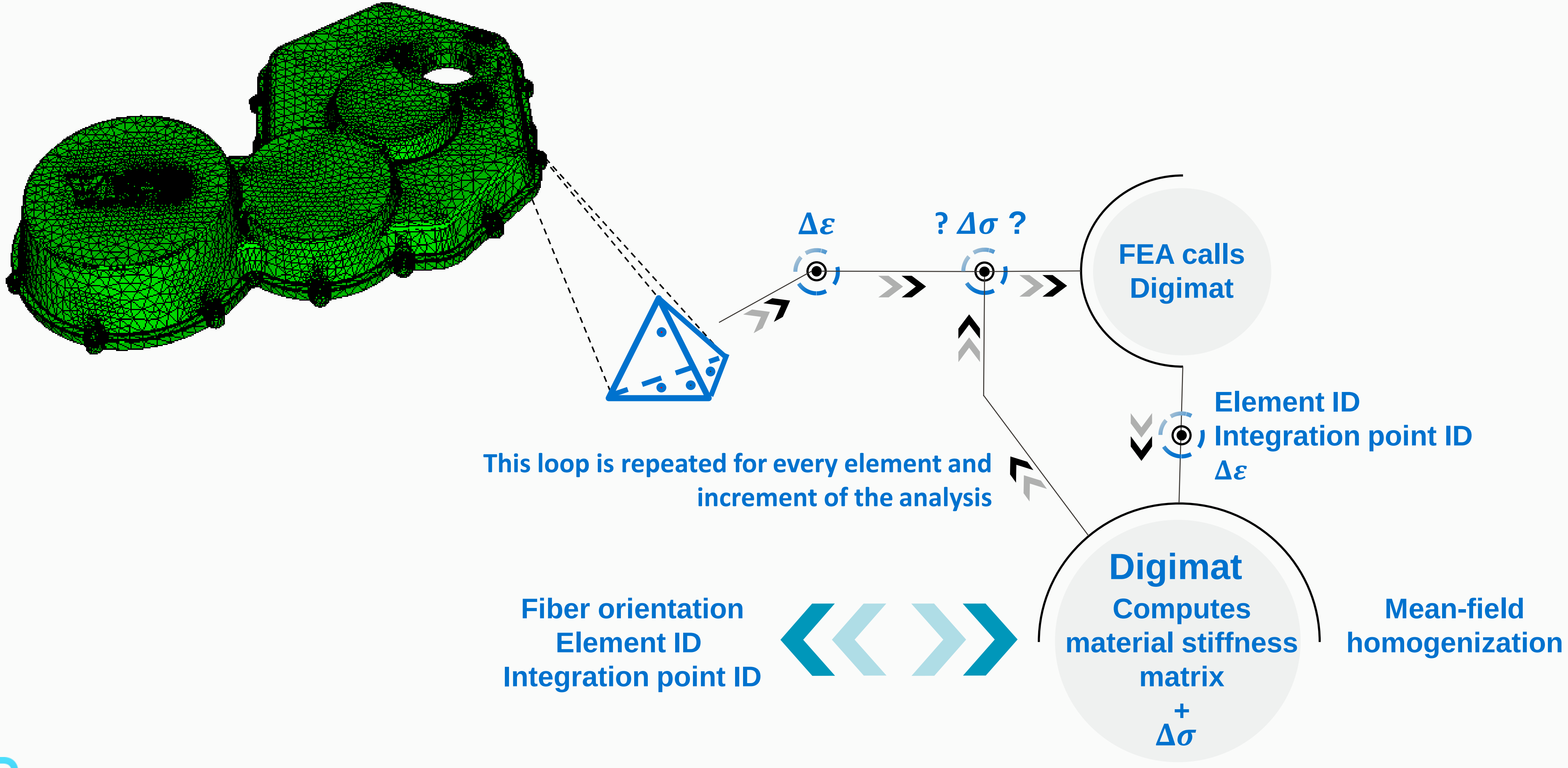
Structural Application Procedure

Coupling to FEA solvers



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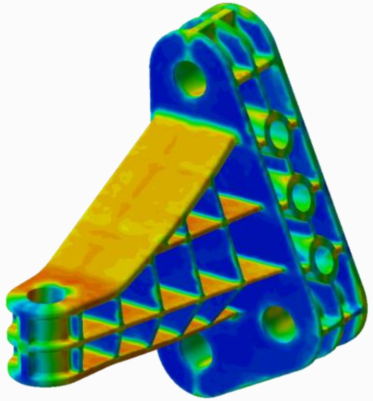
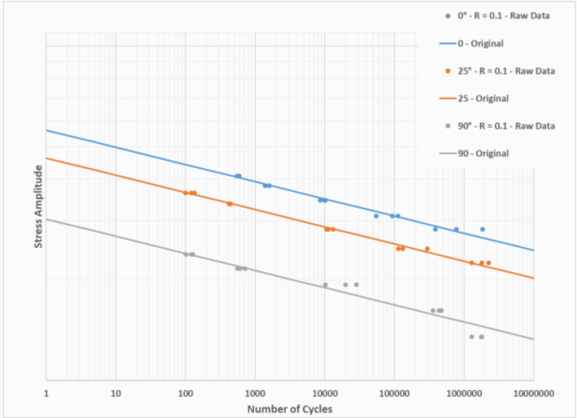
Application

Methodology Workflow



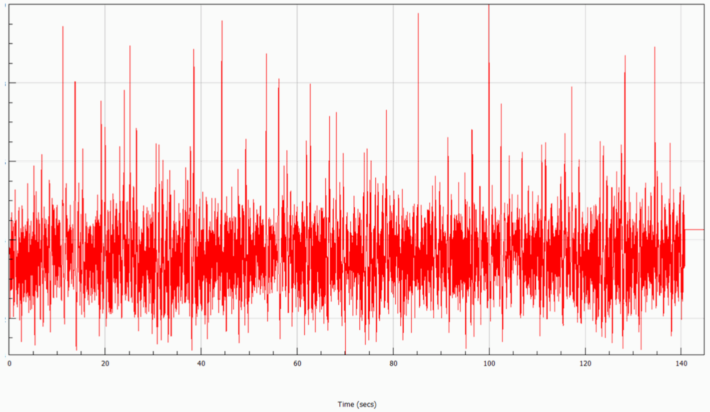
Introduction

- **Objective** : **Evaluate accuracy of fatigue predictions subjected to variable amplitude loading**



- **Solvers**
  - Structural : Optistruct
  - Material modeling : Digimat
  - Fatigue : nCode

- **Part** : **Bracket (shown in top right)**



- **Material** : **PA6GF30**

- **Loading** : **Variable amplitude loading (shown below)**

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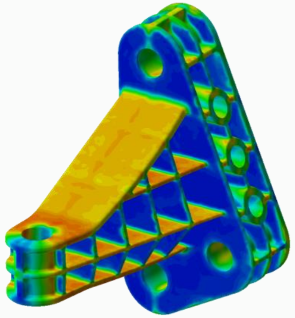
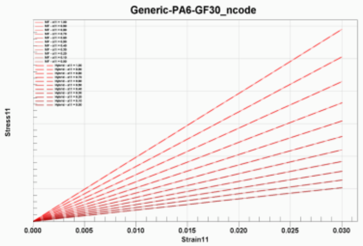
Methodology Workflow

Simulation setup

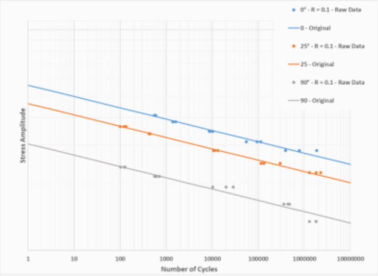
Fiber orientation



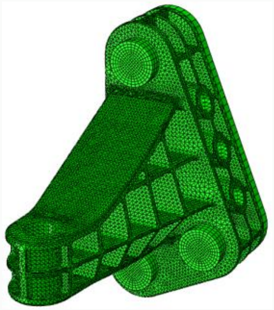
Anisotropic linear elastic properties



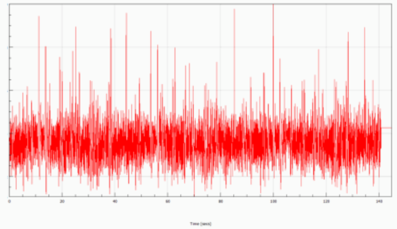
Anisotropic fatigue properties



FEA model



Load cycle history



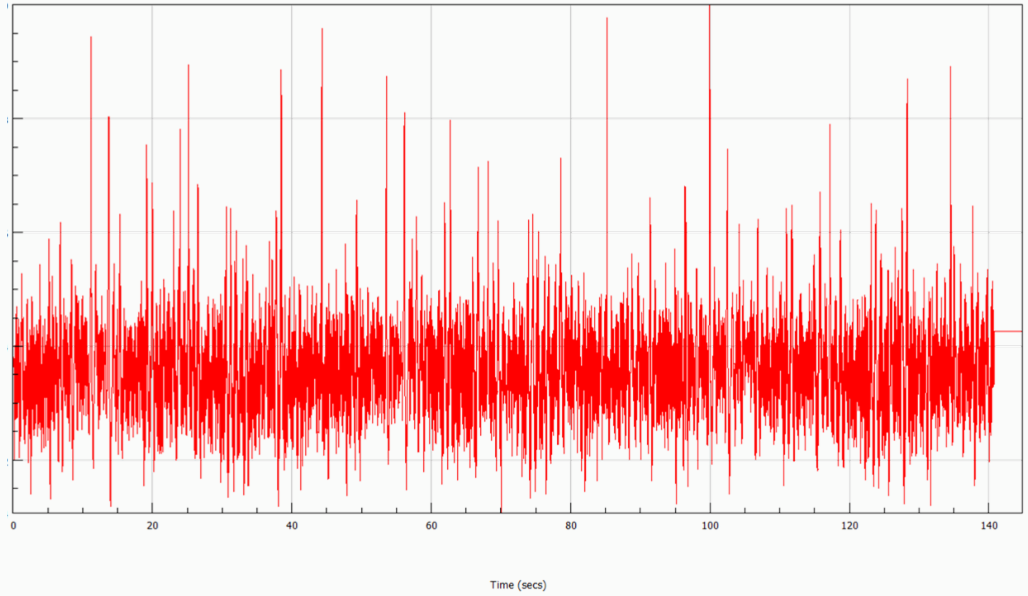
nCode ...an HBM brand

Component Testing

Test setup

- **Manufacturing**
  - Part : 5 brackets
  - Conditioning : RH0 (dry-as-molded)

- **Testing**
  - Location : University of Michigan-Dearborn
  - Conditioning : RH50
  - Loading : Normalized variable amplitude loading with multiple scale factors applied



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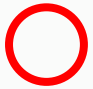
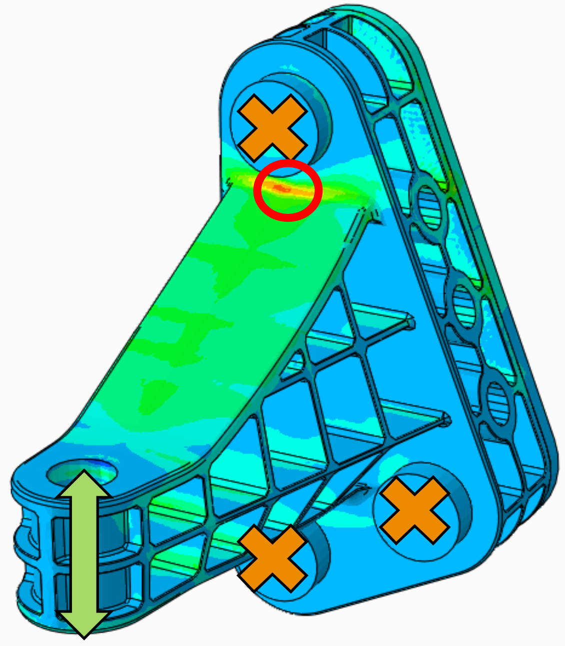
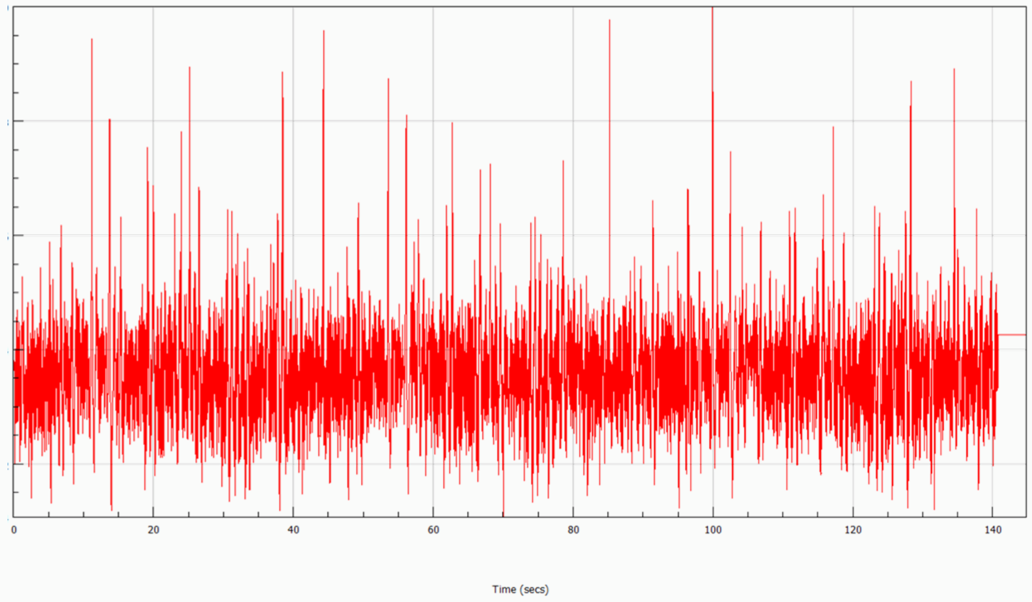
Component Testing

Simulation setup

- **Unit load case**
  - Solver : Optistruct & Abaqus
  - Loading : Unit load
  - Bolted location : 
  - Loading : 
  - Peak stress location : 
- **Fatigue load case**
  - Solver : nCode
  - Loading : Normalized variable amplitude loading with multiple scale factors applied

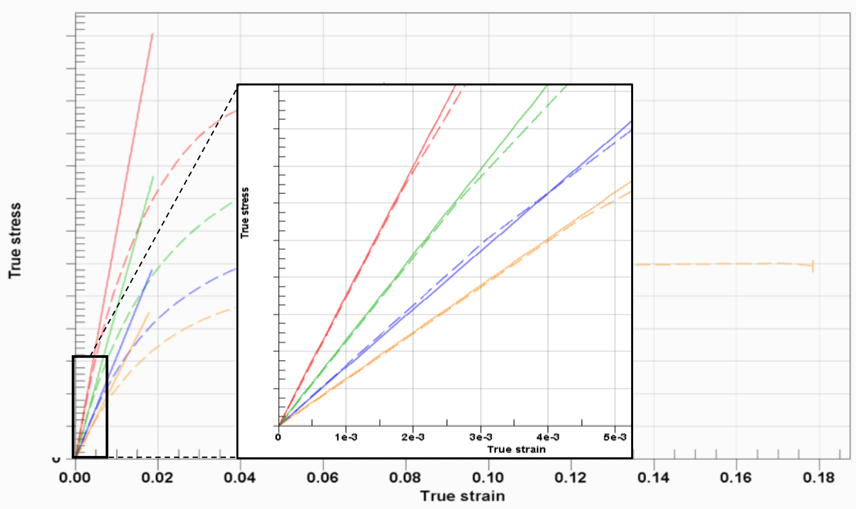


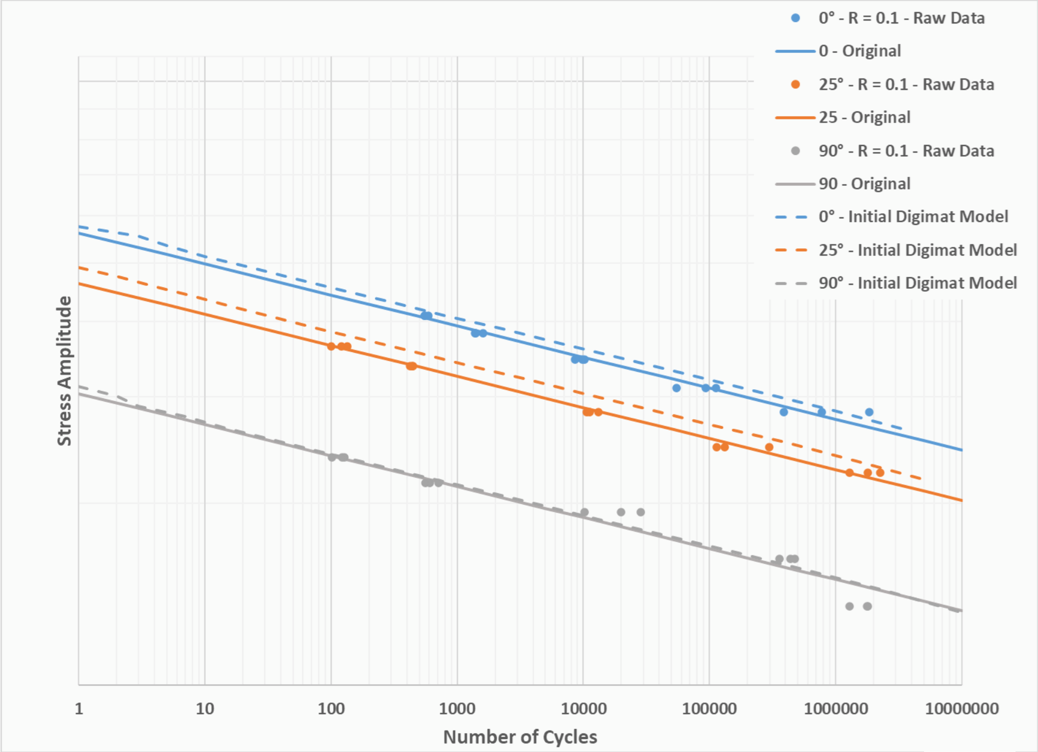


Material Model

Initial model

- **Overview**
  - Matrix : PA6
  - Reinforcement : 30% glass fibers
- **Calibration**
  - Stiffness
    - Fatigue material model capabilities, at the time, limited stiffness to purely elastic
    - Elastic stiffness calibrated to 0°, 25°, 45° & 90° quasi-static stress-strain curves
    - Digimat used to calibrate stiffness
  - Fatigue
    - Fatigue failure indicator calibrated to 0°, 25° & 90° S-N curves
    - Model validated on coupon FEA with results displayed on right
    - Great correlation to coupon data via coupon FEA
- **Results**
  - Initial Digimat fatigue model did not predict good results
  - Lifetimes were lower by a factor of 200 (Results shown on next slide)



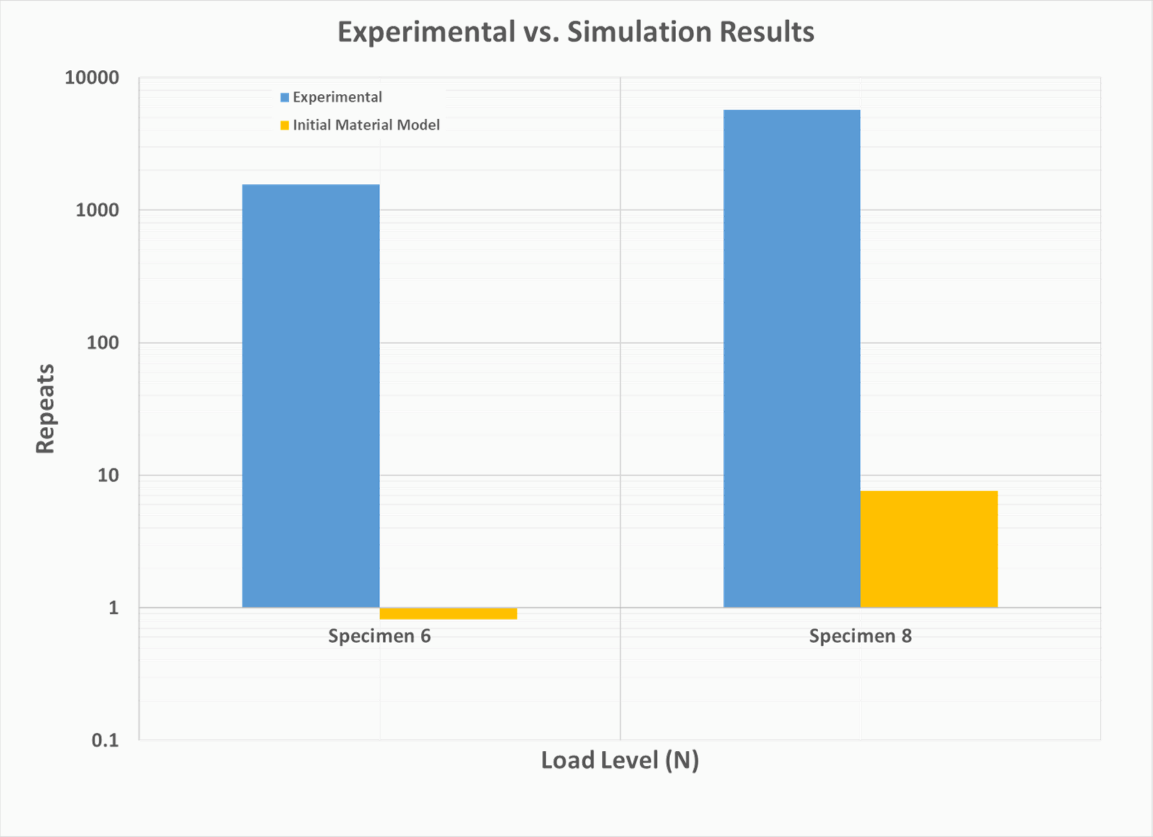


Results

Simulation – Initial material model

- **Normalized load levels tested**
  - Specimen 6 : 1
  - Specimen 7 : 0.946
  - Specimen 8 : 0.892
  - Specimen 9 : 0.851
  - Specimen 10 : 0.848

- **Results**
  - Simulation results : >3 decades from experimental results
  - % difference : >1,300% average



Load Level	Experimental (Number of Repeats)	Initial Material Model (Number of Repeats)	% Difference
Specimen 6	1555	0.8173	**1902**
Specimen 8	5727	7.573	**755**

Investigation

Reasons for differences between test & analysis

- **Test fixturing & test equipment**

- **Boundary conditions between test & analysis**

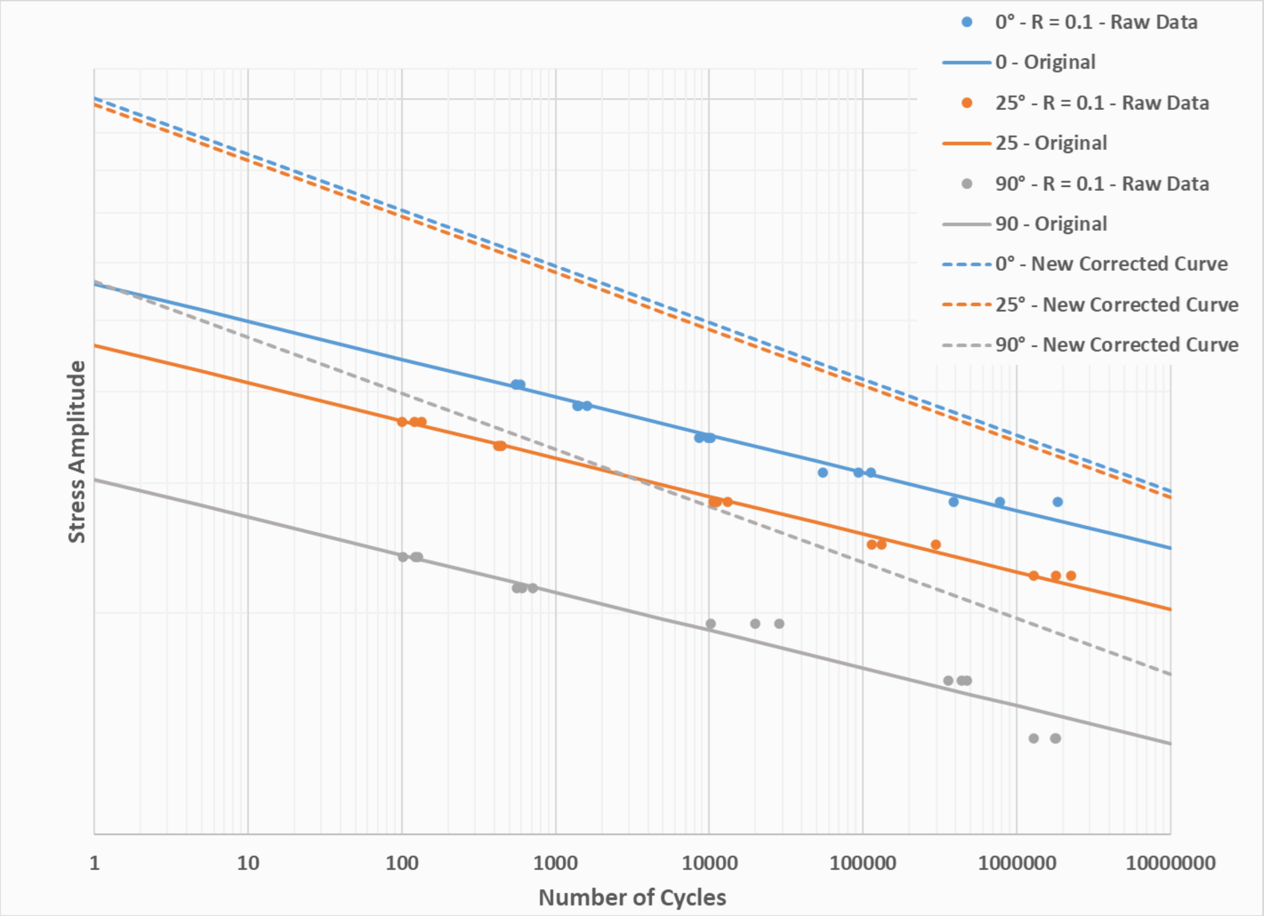
- **Conditioning of part**
  - Relative humidity is critical when working with nylons
  - Tested part moisture level must match data used to calibrate material model

- **Plasticity consideration**
  - Scale factors typically applied to account for plasticity
  - Required factor >0.8 → Very large for plasticity considerations

Material Model

Adjusted model

- **Account for plasticity**
  - Stiffness of material model remains unchanged
  - New methodology developed to create new S-N curves for 0°, 25° & 90°
  - Final Digimat material model was developed based on new S-N curves



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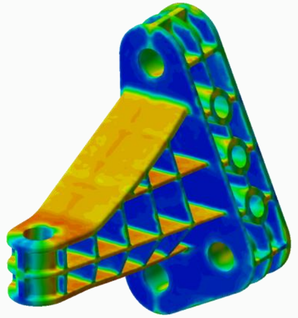
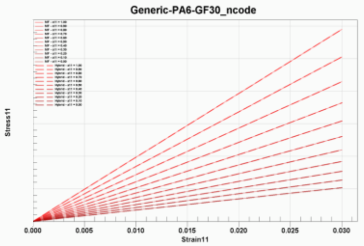
Methodology Workflow

Simulation setup

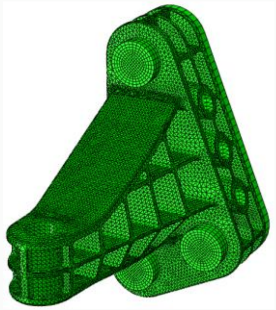
Fiber orientation



Anisotropic linear elastic properties

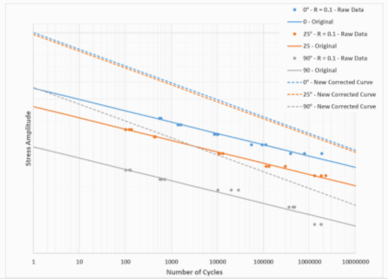


Optistruct/Abaqus FEA model



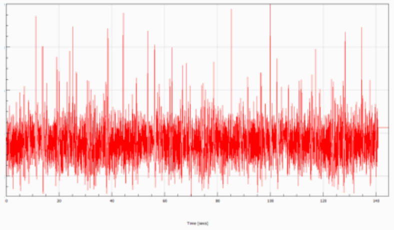
New Plasticity Material Model

Anisotropic fatigue properties



nCode ...an HBM brand

Load cycle history



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Results

Summary

- **Criteria for failure : Significant drop in load bearing capability of component**

- **Component testing**
  - Critical number of repeats
  - Pictures of failure location

- **Simulation**
  - Initial material model (with conventional fatigue material modeling methodology)
    - Critical number of repeats
    - Failure location

  - Updated material model (with new fatigue material modeling methodology accounting for plasticity)
    - Critical number of repeats
    - Failure location

- **Comparison of experimental results to two different simulation approaches to highlight differences**

Results

Component testing

Specimen number	6	7	8	9	10
Load cycle scaling	1	0.946	0.892	0.851	0.848
Total repeats	1,555	1,757	5,727	8,316	16,964

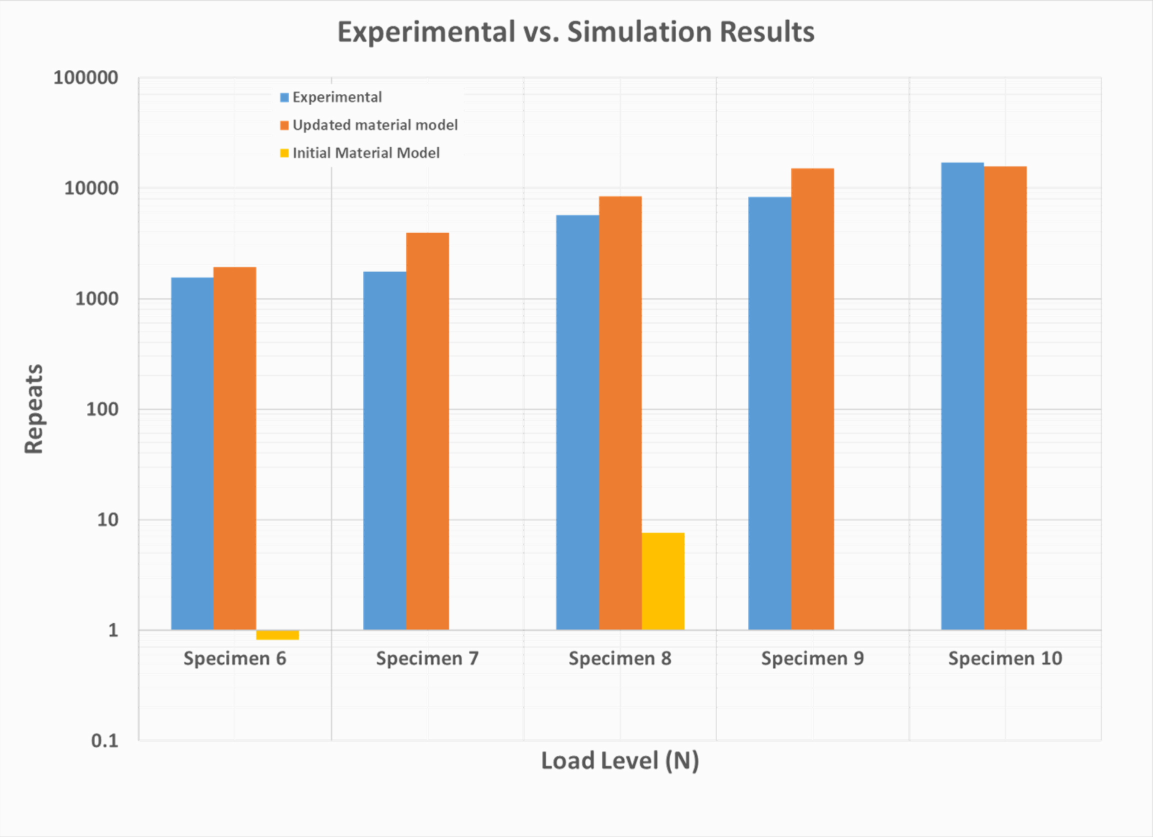
- **Critical number of repeats**
  - Specimen 6-10 used for correlation work
- **Failure location**
  - Similar in all tests
  - Filet region below single bolt fixture at top of part

Failure location

Results

Simulation – Final (Updated) material model

- **Normalized load levels tested & simulation**
  - Specimen 6 : 1
  - Specimen 7 : 0.95
  - Specimen 8 : 0.89
  - Specimen 9 : 0.85
  - Specimen 10 : 0.848
- **Results**
  - Simulation results : <1 decade from experimental results
  - % difference : <55% average
- **Conclusion**
  - New methodology successfully predicts critical repeats on bracket
  - Account for plasticity is critical in obtaining accurate results
  - Streamlined methodology now available, via Digimat + nCode, to account for plasticity



Load level	Experimental (Number of repeats)	Updated material model (Number of repeats)
Specimen 6	1555	1927
Specimen 7	1757	3934
Specimen 8	5727	8370
Specimen 9	8316	15160
Specimen 10	16964	15790

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Conclusions

- **Inputs**
  - Two Digimat fatigue material models used:
    - Initial material model (used in phase 2) : Does not account for plasticity in any way
    - Updated material model : Accounts for plasticity via new method

  - Part tested
    - 5 brackets used for fatigue correlation work
    - Specimens 6-10 used for correlation work at various load levels
    - Variable loading amplitude profile was used, with different scale factors, to consider all portions of material curve

- **Results**
  - Initial material model, without plasticity, showed results that were 3+ decades off from experimental results
  - Updated material model, with plasticity, showed results that were <1 decade off from experimental results → Excellent correlation

- **Automated methodology now available within Digimat + nCode to account for plasticity without need to create update S-N curves**

THANK YOU!