LEVERAGING PREDICTIVE MANUFACTURING TECHNIQUES TO DE-RISK AND ACCELERATE COMPOSITE DESIGN

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Victrex (TxV Aero Composites) / Hexagon / MCS Software

#1 PEEK EXPERTS

40+ Years since the invention of PEEK, with Victrex as the first to commercialise this exceptional thermoplastic

victrex

FACTS & FIGURES

WE BRING TRANSFORMATIONAL SOLUTIONS THAT ADDRESS WORLD MATERIAL CHALLENGES EVERY DAY

POLYMER MANUFACTURING

Delivering the key PEEK & PAEK materials with No.1 manufacturing capacity of 7,150 tonnes

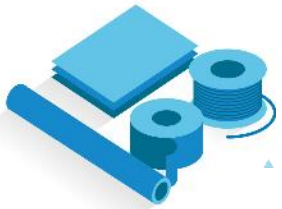
A WORLD LEADER IN VALUE CREATION THROUGH PEEK AND PAEK-BASED POLYMER SOLUTIONS

Enabling customers to develop sustainable solutions and overcome complex design & engineering challenges across 6 key markets

DIFFERENTIATE THROUGH INNOVATION TO CREATE NEW MARKETS

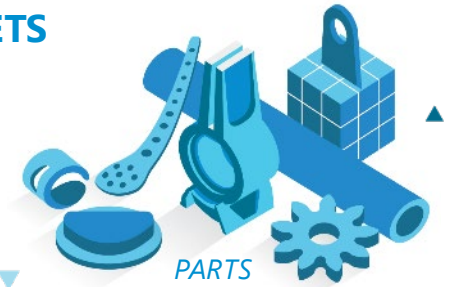
POLYMER

Pioneering new grades Including for Composites & Additive Manufacturing (3D Printing)



PRODUCT FORMS

Manufacturing product forms: Pipes, Films, Fibres and Composite Tapes



PARTS

Developing new applications for PEEK, PAEK and Thermoplastic Composites

GLOBAL OPERATIONS

900+
Employees waking up every day focused on PEEK

40+
Countries served by Victrex across our markets

circa £2bn
Market Value

- FTSE 250 Company
- c£300m Revenue

* PEEK = Poly Ether Ether Ketone
PAEK = Poly Aryl Ether Ketone
Based on Victrex 2019 Annual Report

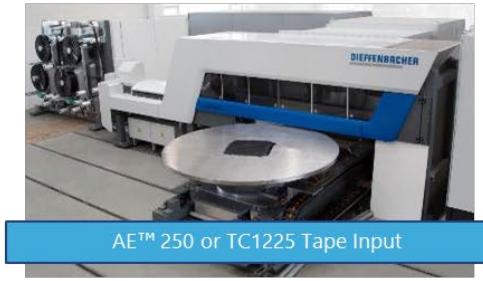
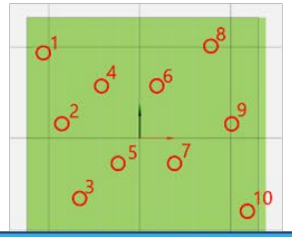
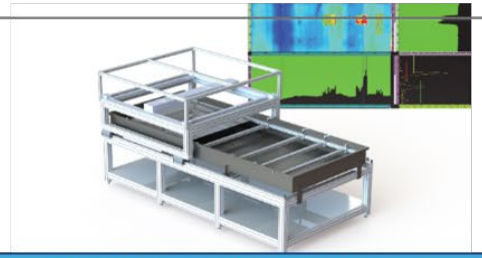
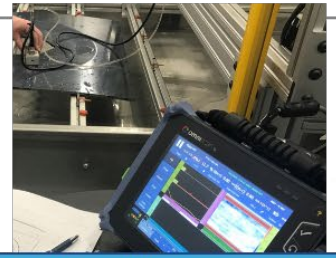
INVESTMENT IN INNOVATION

~5%
of annual sales invested in R&D

Expanded capabilities through Polymers, Forms & Parts

- Polymer Capacity
- Composites UD Tape
- Fibres
- Injection Moulding
- MAGMA pipe
- Gear Solutions
- Aerospace Parts
- Additive Manufacturing
- Medical Components

Composite Part Manufacturing Overview

Step 1 Automated Tape Laying	Step 2 Rapid Consolidation	Step 3 Automated Forming	Step 4 Injection Overmolding
			
AE™ 250 or TC1225 Tape Input	Tailored Layup Input	Consolidated Laminate Input Forming Tooling	PEEK Injection Molding Pellets & Formed Part Inputs Injection Molding Tooling
			
Tailored Layup Output	Consolidated Laminate Output	Formed Part Output	Hybrid Part Output
			
Inline Manual Ply Gap Inspection	Offline Automated Ultrasonic Inspection	Offline Manual Ultrasonic Inspection	Offline CMM and Manual Ultrasonic Inspection

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Smart Factories

that learn and adapt quickly to changing conditions in real time, pursuing perfect quality with optimized design, requiring fewer inputs and producing zero waste

SUSTAINABLE VALUE CREATION
- Fewer inputs
- Zero waste
- Perfect quality

HEXAGON

empowering an autonomous future

Did you know?

Each year, Hexagon technology touches:

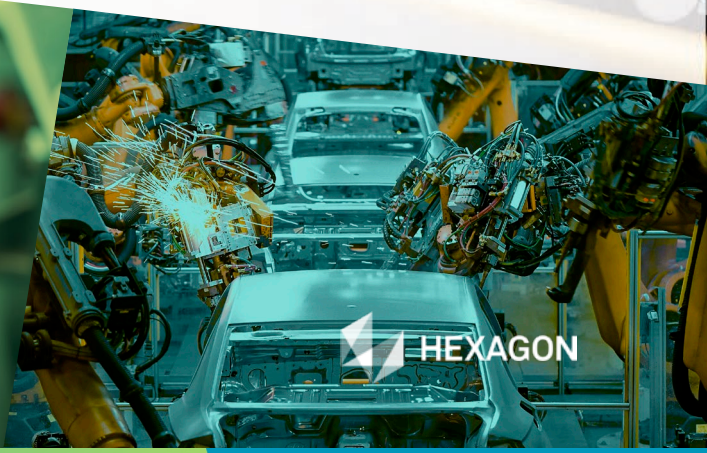
- **75%** of cars produced
- **90%** of aircraft produced
- **85%** of smartphones produced

We have expertise in and connect all stages of the manufacturing lifecycle:

DESIGN AND ENGINEERING (CAE)
Optimise designs and ensure manufacturability

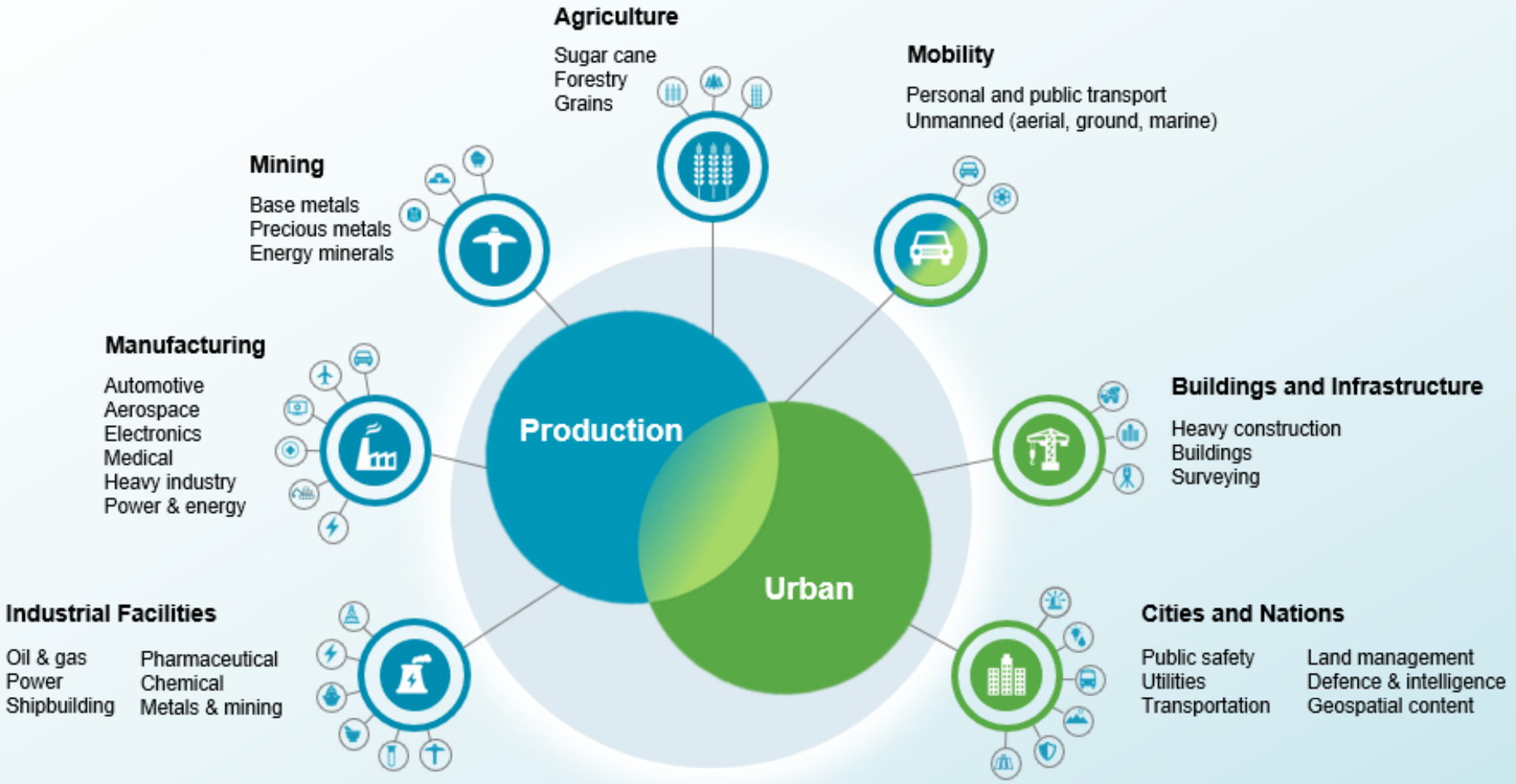
PRODUCTION (CAD/CAM)
Deliver on design intent and product quality with minimal waste

METROLOGY HARDWARE/SOFTWARE
Capture real-world data for positioning and inspection



Customers served

Ecosystems vs. markets



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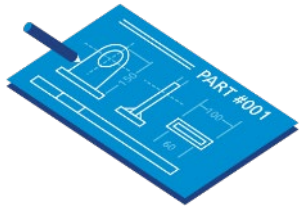
Helping Current Market Trends
Materials for faster, lighter, greener mobility

Customer Journey
Concept to manufacturing

IDENTIFY APPLICATION

Design & economic feasibility assessment

PART CONCEPT & DESIGN

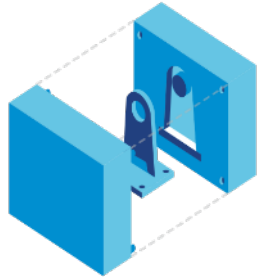


Thermoplastic part design

TOOL DESIGN & BUILD

Modeling & analysis (design for manufacture)

FIRST ARTICLE MANUFACTURING

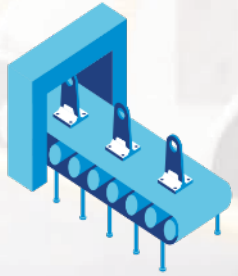


Process development & part testing

DESIGN & PROCESS VALIDATION

Performance confirmation & transition to production

SERIAL PRODUCTION



Aerospace-quality automated production

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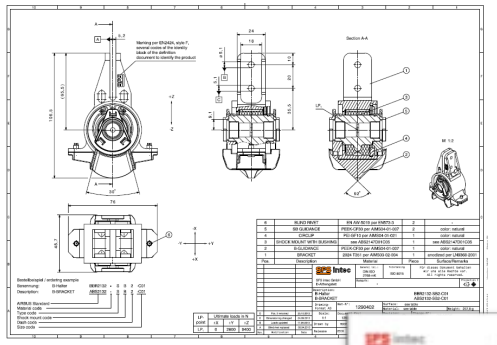
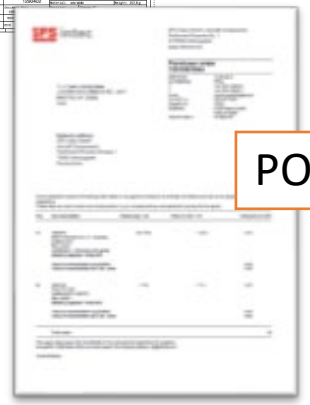
Part Journey

Customer

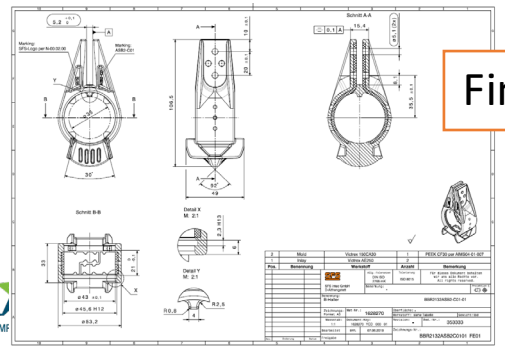
Victrex / TxV



RFQ & Drawing



PO & Feedback



Final Drawing

Preliminary Concept

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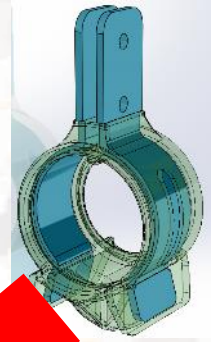
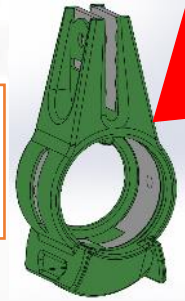
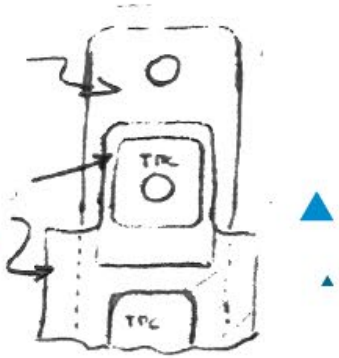
Final Concept
- Design IP Ownership
- ATP





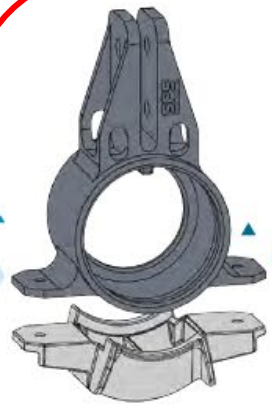
Parts & Testing

Capabilities



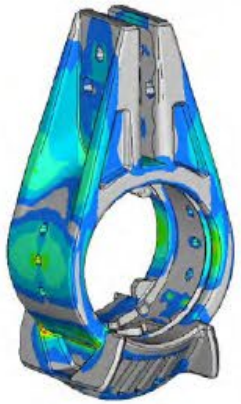
DESIGN FEASIBILITY

Initial assessment of how well a composite design is expected to deliver against application requirements and project objectives.



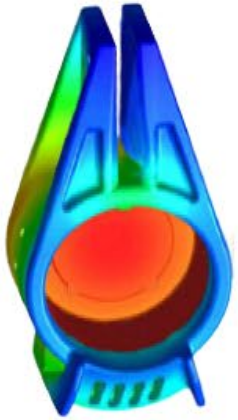
DIGITAL MODELING

Initial creation of a digital twin is used to represent the composite part design and provide confirmation that requirements have been understood.



OPTIMIZATION

Analytical tools are used to optimize the part design to meet the application demands and see how design choices impact results.



PROCESS SIMULATION

Advanced simulation tools are used to see how design choices impact manufacturability.

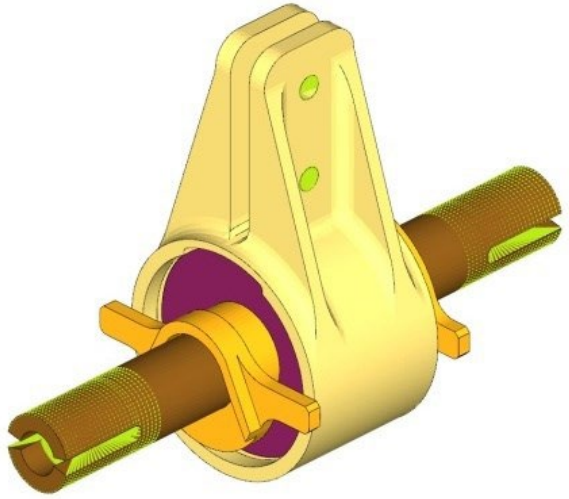
PROTOTYPING

First parts are produced to verify manufacturability and validate part performance.

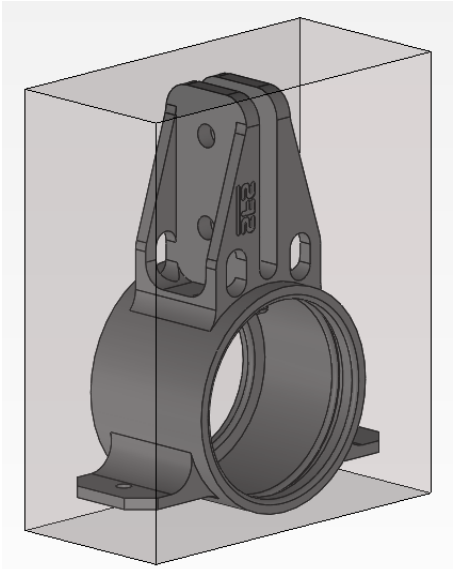
COMMERCIAL PRODUCTION

APQP framework, production quality tooling, and automated equipment allows for a seamless transition to commercial production.

Define the Problem
SFS A350 B-bracket case study



Need for cost and weight reduction



Buy-to-Fly of 10.6 : 1

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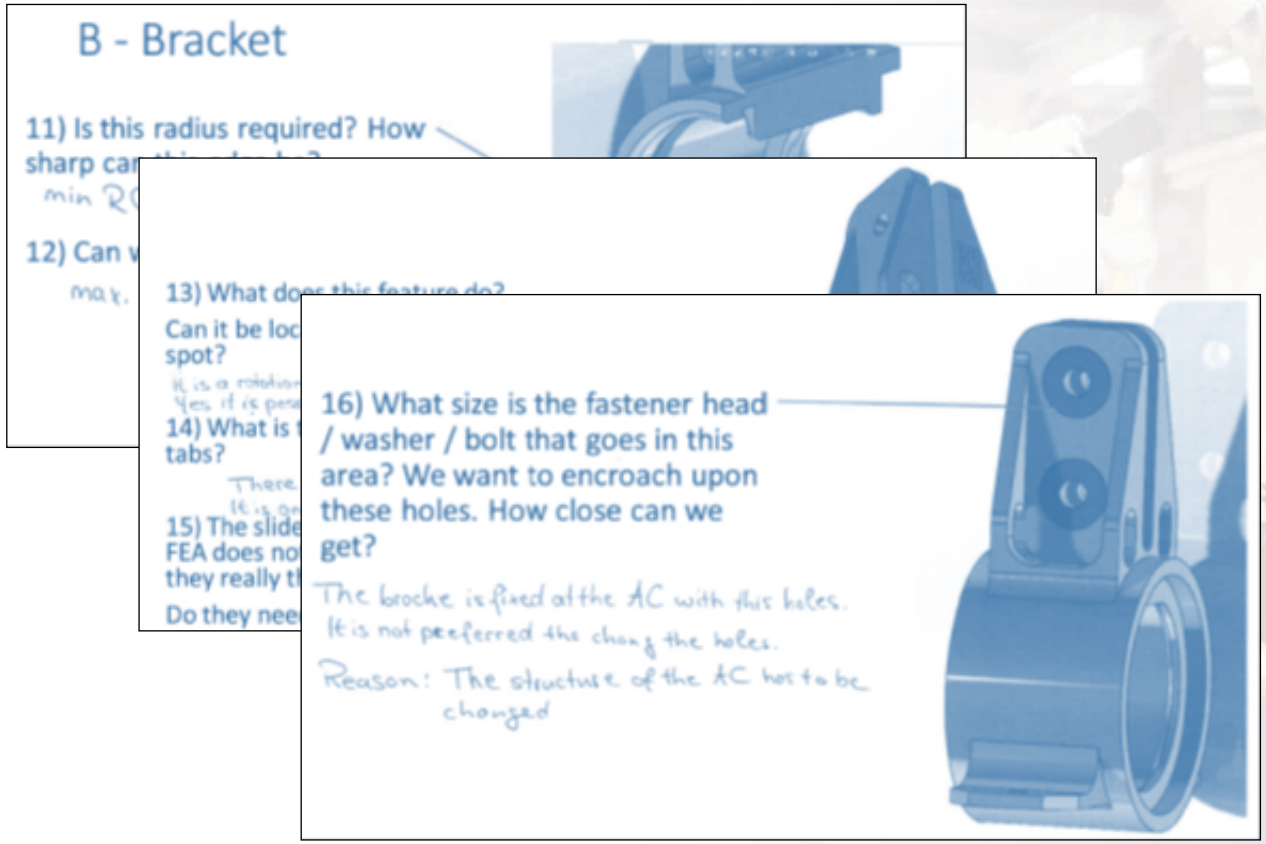
Understanding the Part
Understanding the problem

- Customer Q&A
- What problem does it solve?
- Usage & intent?
- Loading in use, during testing?
- Design limitations / space envelope?
- Installation?
- Compromises were made for incumbent materials?
- Compromises made due to manufacturing method?



In-depth knowledge used to create a parallel solution

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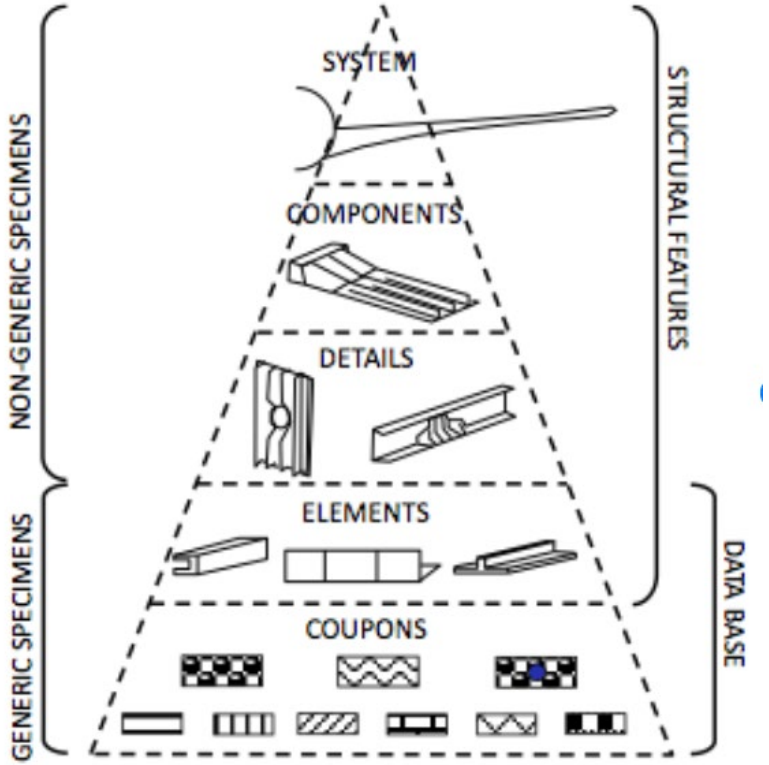
Path to Certification Begins with materials

Designing with certification in mind from the onset



Raw materials with allowables database

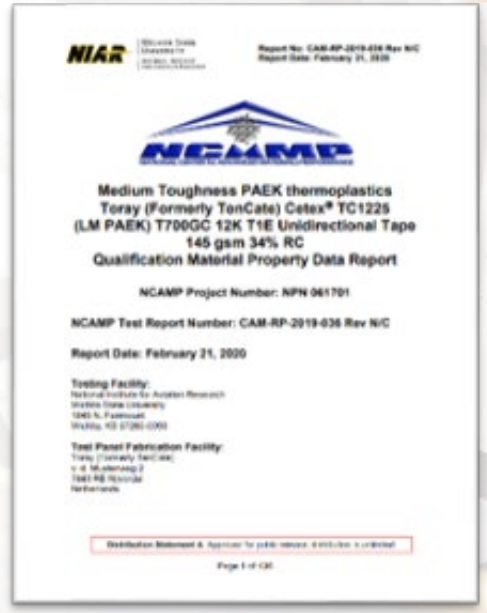
- UD Tape
- Injection molded plastic

Repeatable manufacturing processes

Long life tooling

Documentation

- ERP based quality system


NIAR

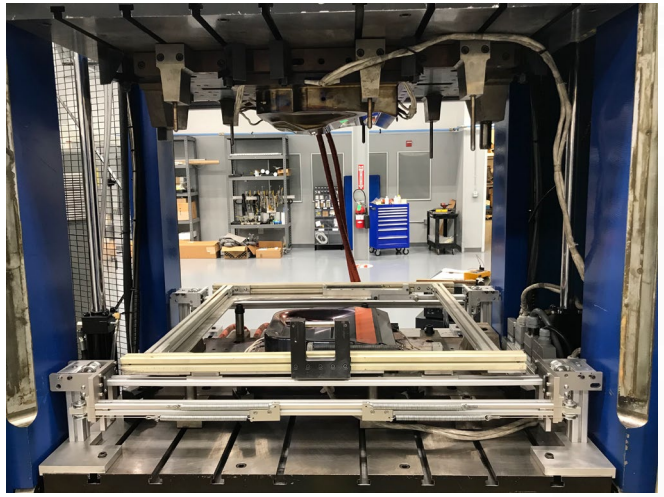
NCAMP

Medium Toughness PAEK thermoplastics
Toray (Formerly TenCate) Cetex® TC1225
(LM PAEK) T700GC 12K T1E Unidirectional Tape
145 gsm 34% RC
Qualification Material Property Data Report

NCAMP Project Number: NPN 061701

NCAMP Test Report Number: CAM-RP-2019-036 Rev N/C

Report Date: February 21, 2020



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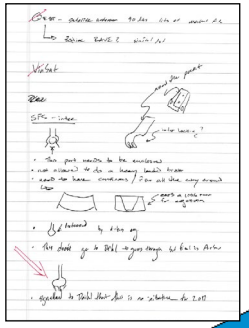
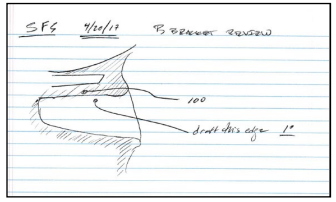
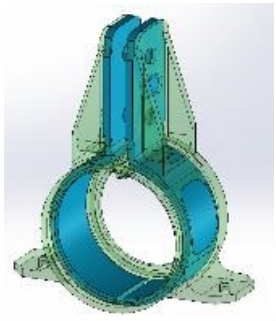
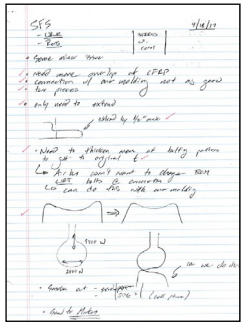
Application Design
Quickly understand the problem

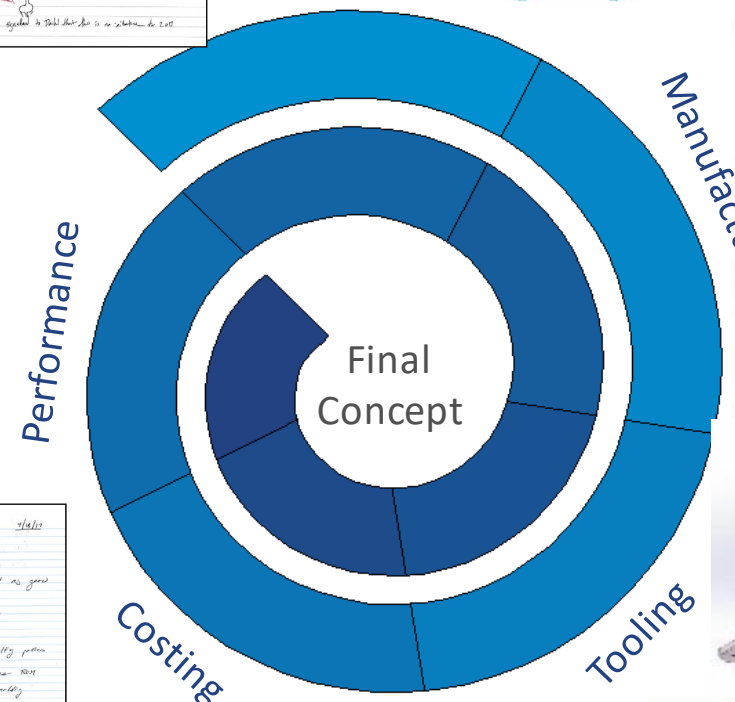
- Fast concept development (and failure)
- Customer feedback and corrections
- Driving towards understanding
- Developing the conceptual solution

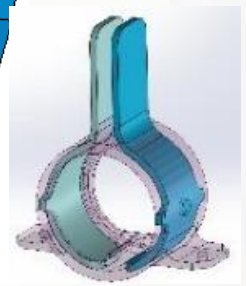


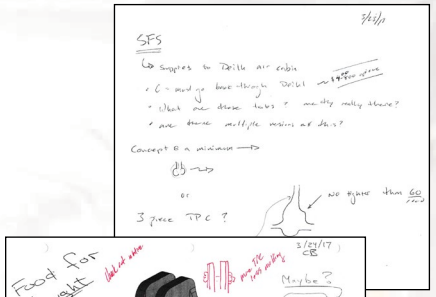


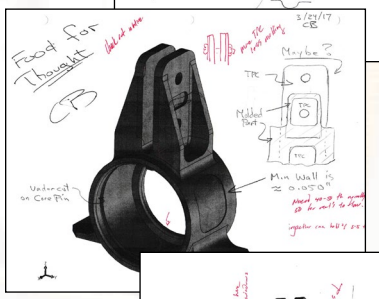


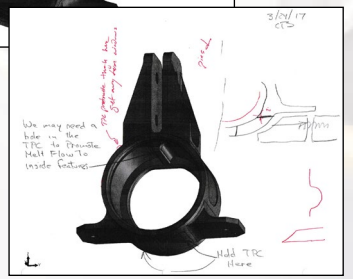












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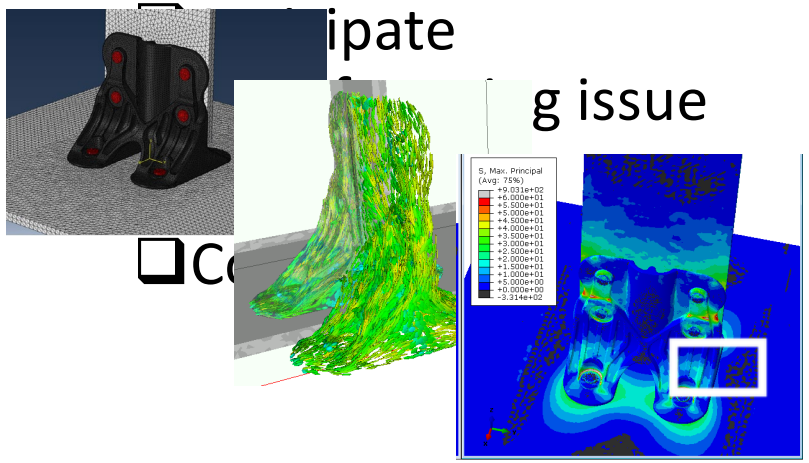
Using Efficiently Materials in Parts Development

Could we develop lightweight component faster & lower cost?

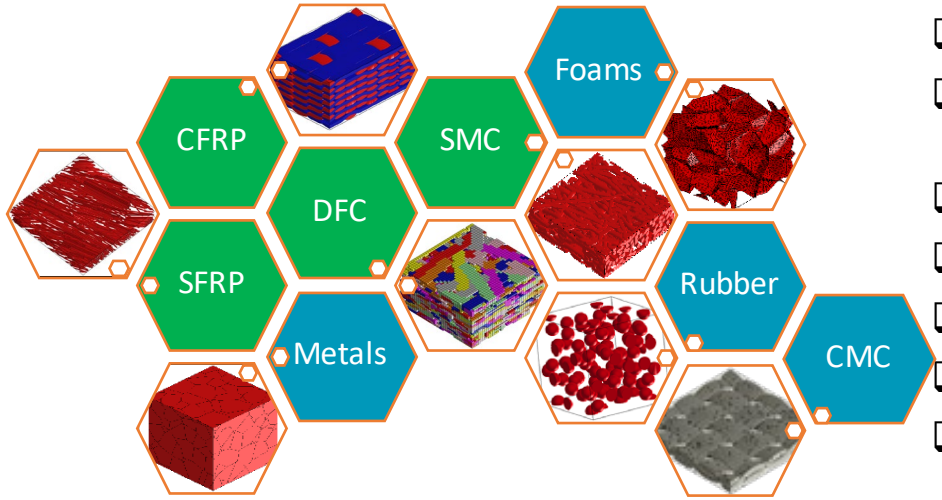
Industry needs

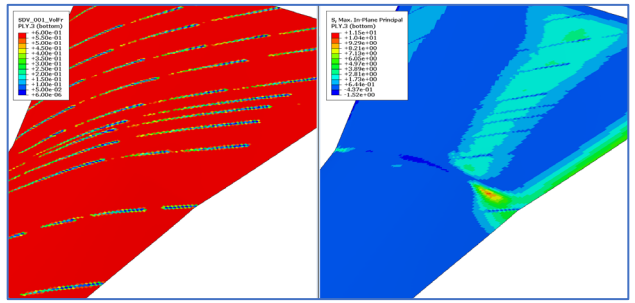
- ❑ Lightweight vs Performance
- ❑ Predictive simulation
- ❑ ipate
- ❑ g issue
- ❑ C



Failure of CF/PEEK T-Bracket

Materials & Applications

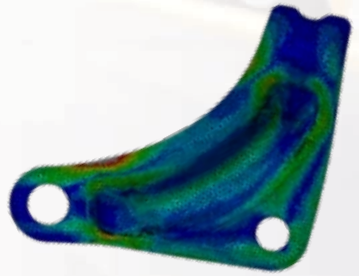




Effects of gaps on aircraft wing skin made by AFP

What ICME enables

- ❑ Multiscale predictive FEA
- ❑ Account for local microstructure induced by manufacturing
- ❑ Account for manufacturing defect
- ❑ Virtual prototyping
- ❑ Weight reduction (up to 40%)
- ❑ Reduce cost of changes by 70%
- ❑ Design to cost & to manufacturing



Performance of CFRP part after forming

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Materials Description
Materials used for inserts and overmold

Overmold

Injected polymer (Fiber reinforced) - Isotropic

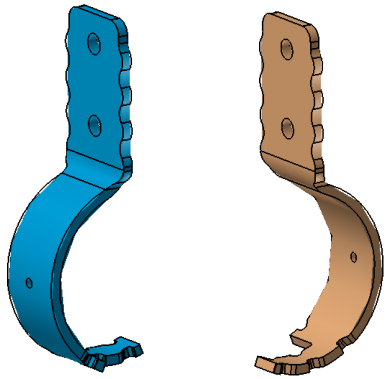
- ❑ E = 21300 MPa
- ❑ Poisson's ratio = 0.4
- ❑ Density = 1200kg/m3
- ❑ Yield = 200 MPa

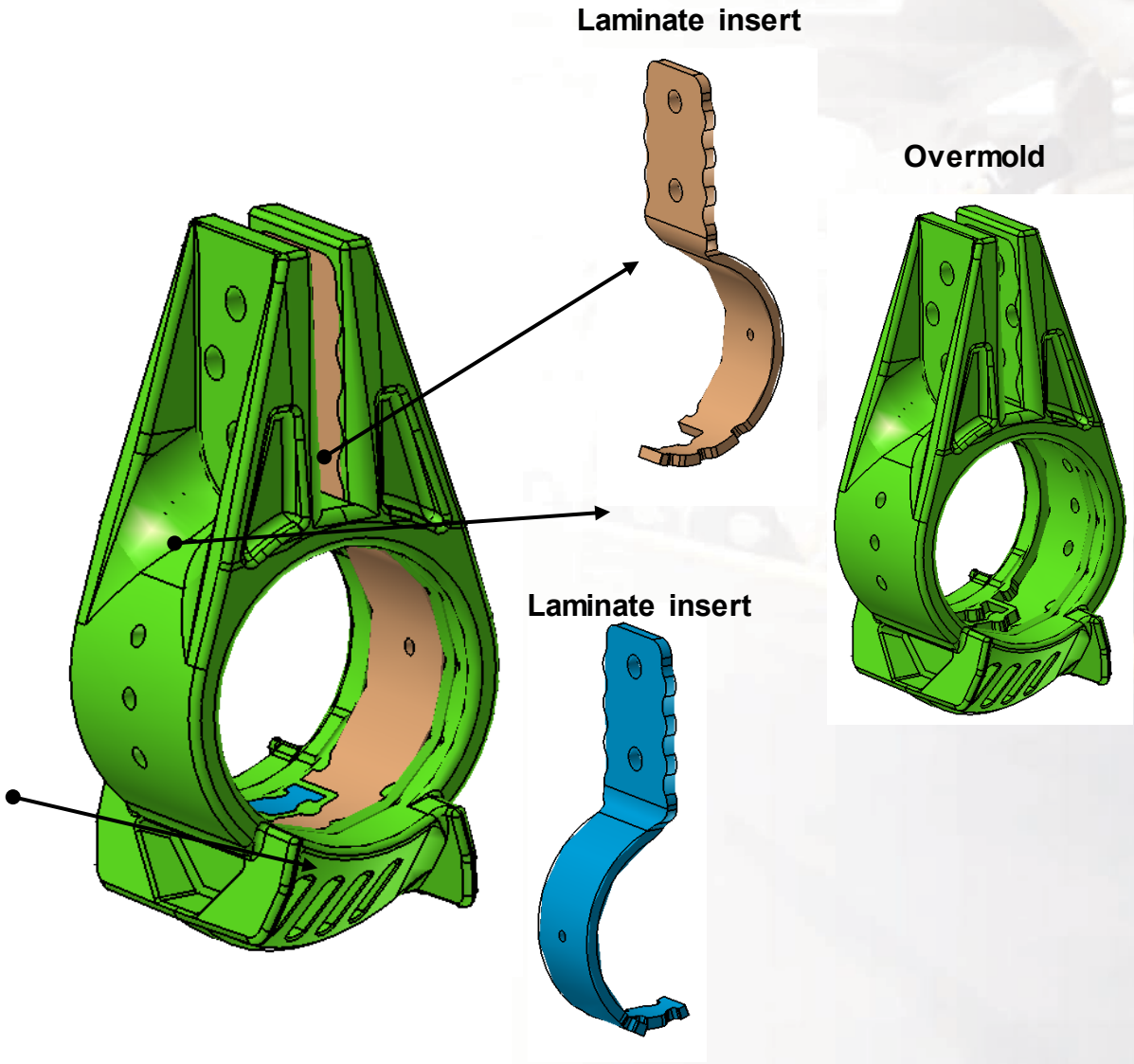
Inserts

Laminate with the following ply layup

Ply Layup

Ply	Orientation (+/-1°)
1	0
2	-25
3	0
4	25
5	0
6	0
7	-25
8	0
9	25
10	25
11	0
12	-25
13	0
14	0
15	25
16	0
17	-25
18	0





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CAE Tools Used
Steps identified for realistic simulation:

1. Part geometry clean-up for adequate meshing
2. Positioning and orientation of the different geometry (Overmold, insert, …)
3. Part geometry adaptation and simplifications (Mid-plane, geometry feature changes, …)
4. Meshing
5. Material application
6. Laminate generation
7. Boundary conditions + Loading application
8. Contact interactions
9. Injection molding simulation for fiber orientation (Geometry modifications done during Step 3)
10. Fiber orientation transfer
11. Fiber reinforced material model definition
12. Simulation/Solving
13. Post-processing

Pre-processor/CAD

Pre-processor

ICME/Material modeling

Solver

Post-processor

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CAE Tools Used

Tools for all simulation steps available through Hexagon/MSC

Pre-processor/CAD	Pre-processor	ICME/Material modeling	Solver/coupling	Post-processor
MSC Apex	Marc Mentat	Digimat	Moldex3D	Marc Mentat	Marc Mentat

Marc Mentat

MSC Apex

Moldex3D

HEXAGON

MSC Software
Simulating Reality, Delivering Certainty™

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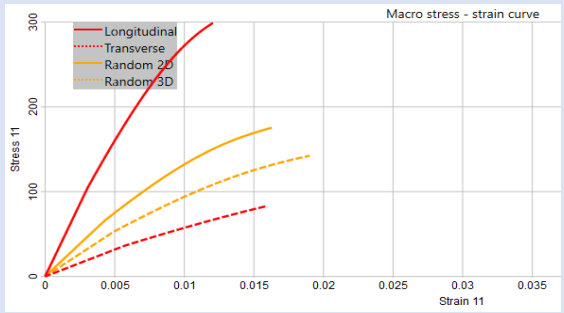
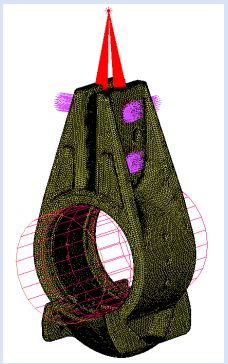
Multi-Scale Analysis Workflow

Integral computational materials engineering: Connecting Process <> Materials <> Performance

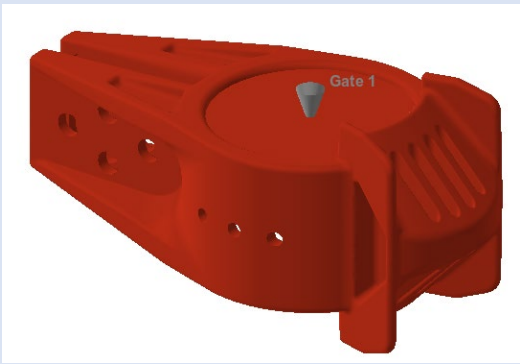
Material Models ICME



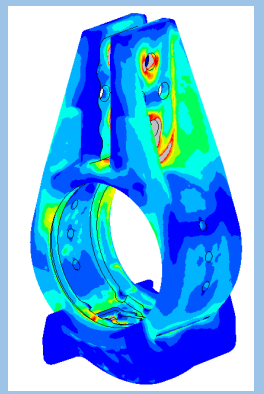
FEA Model Generation



Injection Molding Simulation



Coupled Analysis



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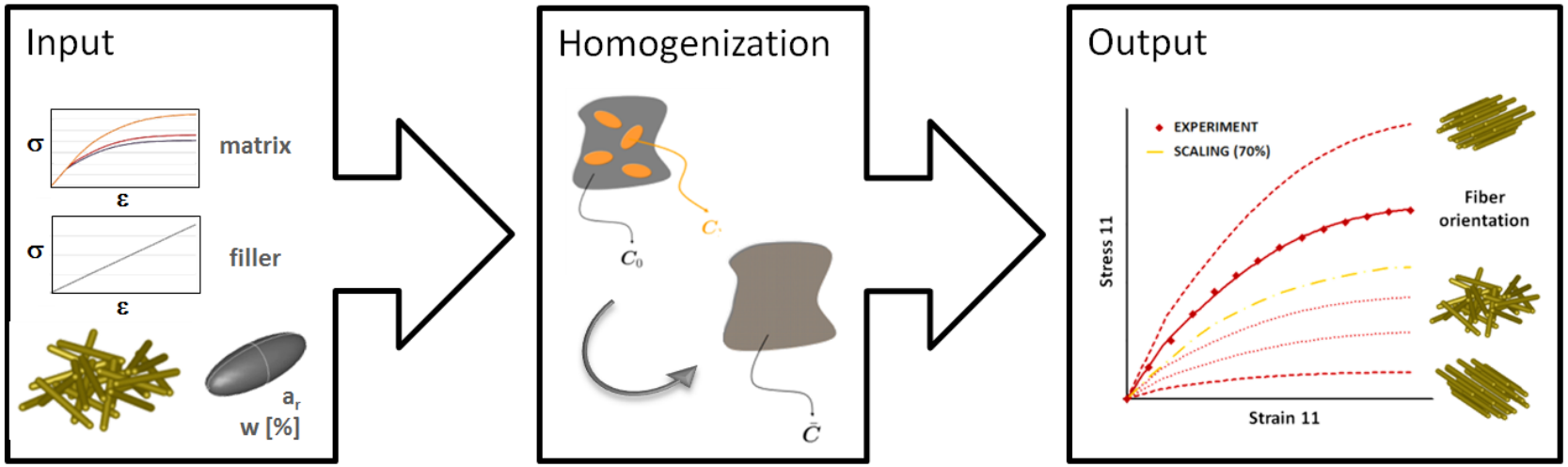
Multi-Scale Modeling Workflow

Material models adapted to both microstructures and loading conditions



- Composite material is described at the micro level
  - Matrix material model
  - Fiber material model
  - Microstructure : Fiber orientation tensor, fiber shape and fiber volume fraction
- Homogenization methods are used to calculate macroscopic anisotropic behavior from microstructure information

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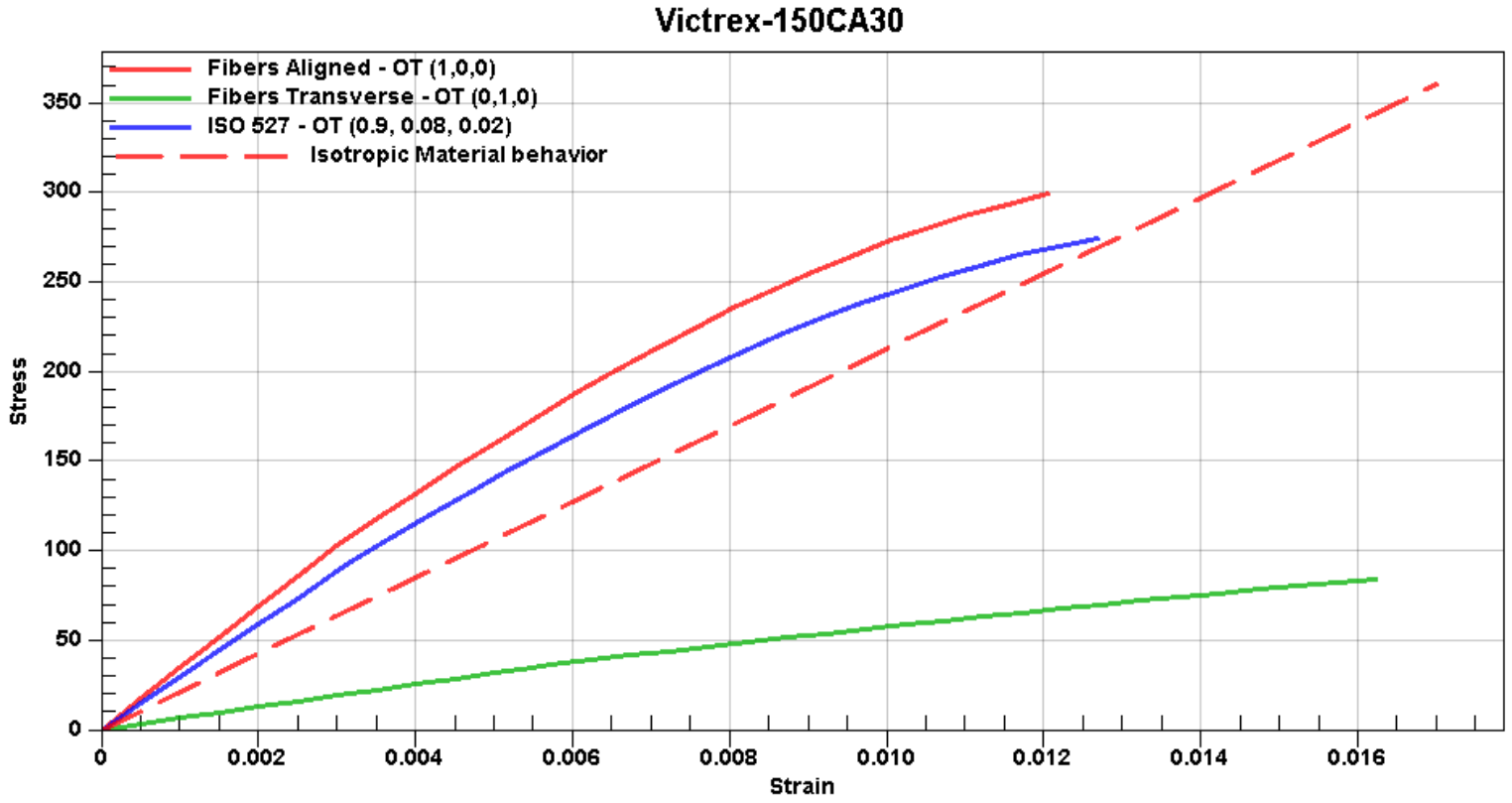
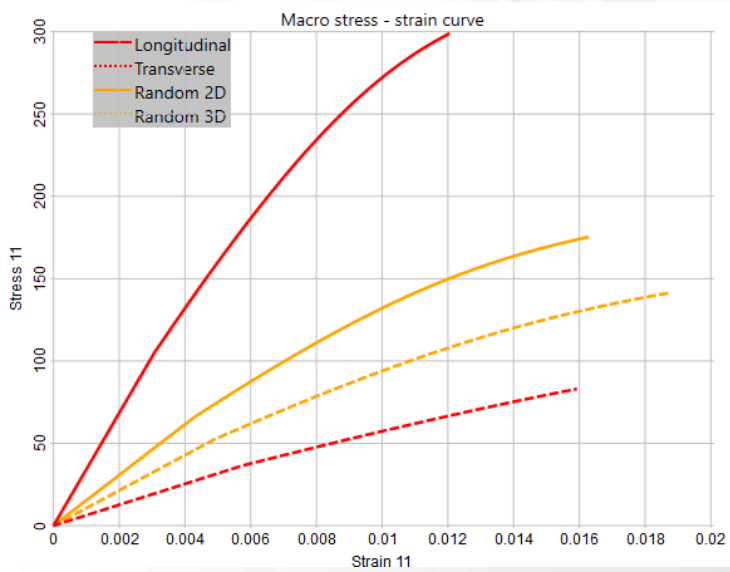
Digimat Material Model Behavior Review

Isotropic material behavior vs. extreme fiber alignment behavior

- The curves below highlights where the behavior of Victrex-150CA30 material model calibrated for Victrex
  - NOTE: The ISO 527 microstructure isn't necessarily representative of what you will find in the part being injected



Curves from Digimat-RP



Digimat

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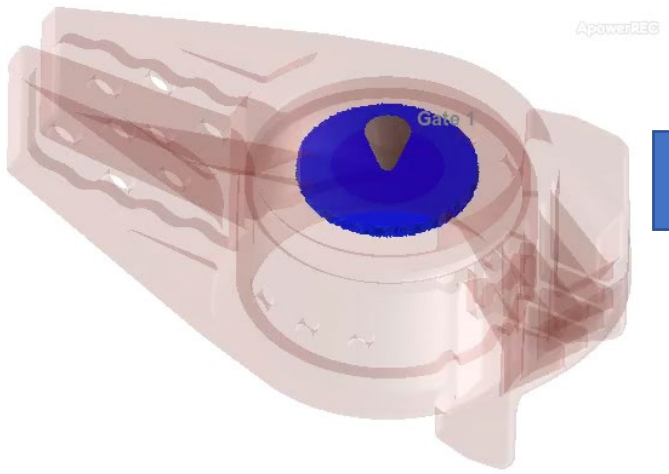
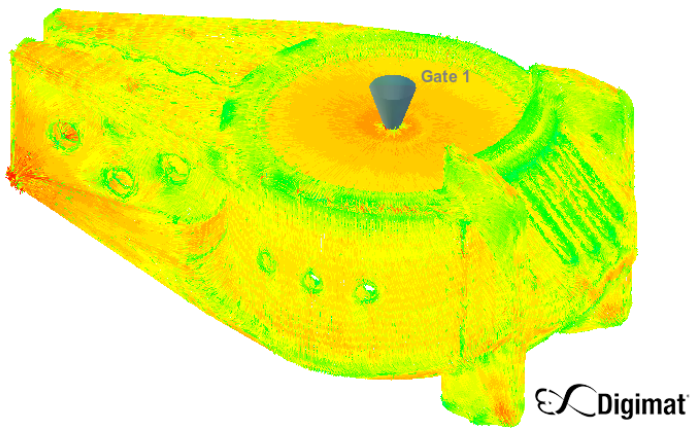
Injection Molding Simulation – Fiber Orientation
Melt front animation for flow visualization & fiber orientation

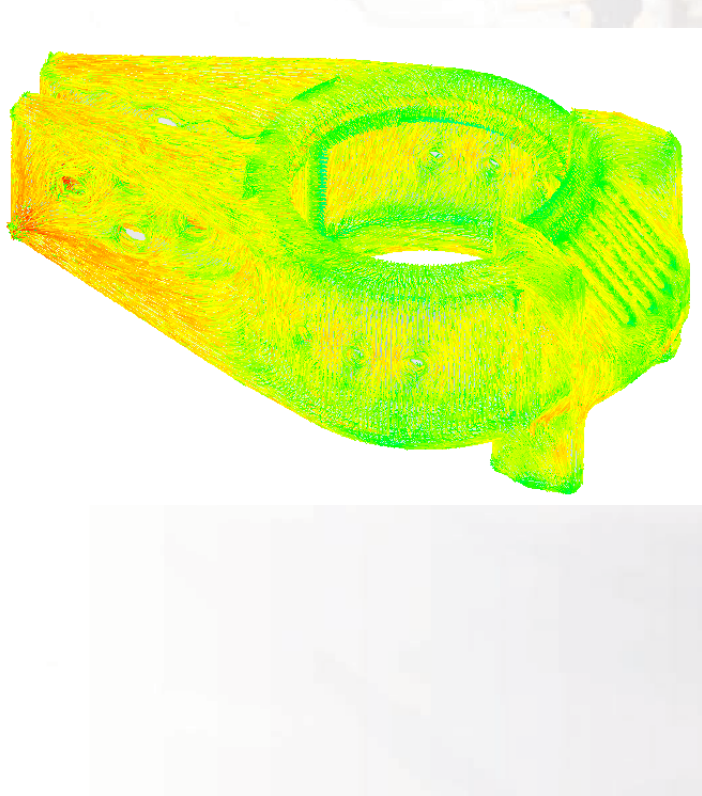
Melt Front animation



Local Fiber Orientation



Fiber Orientation Mapped on FEA Model



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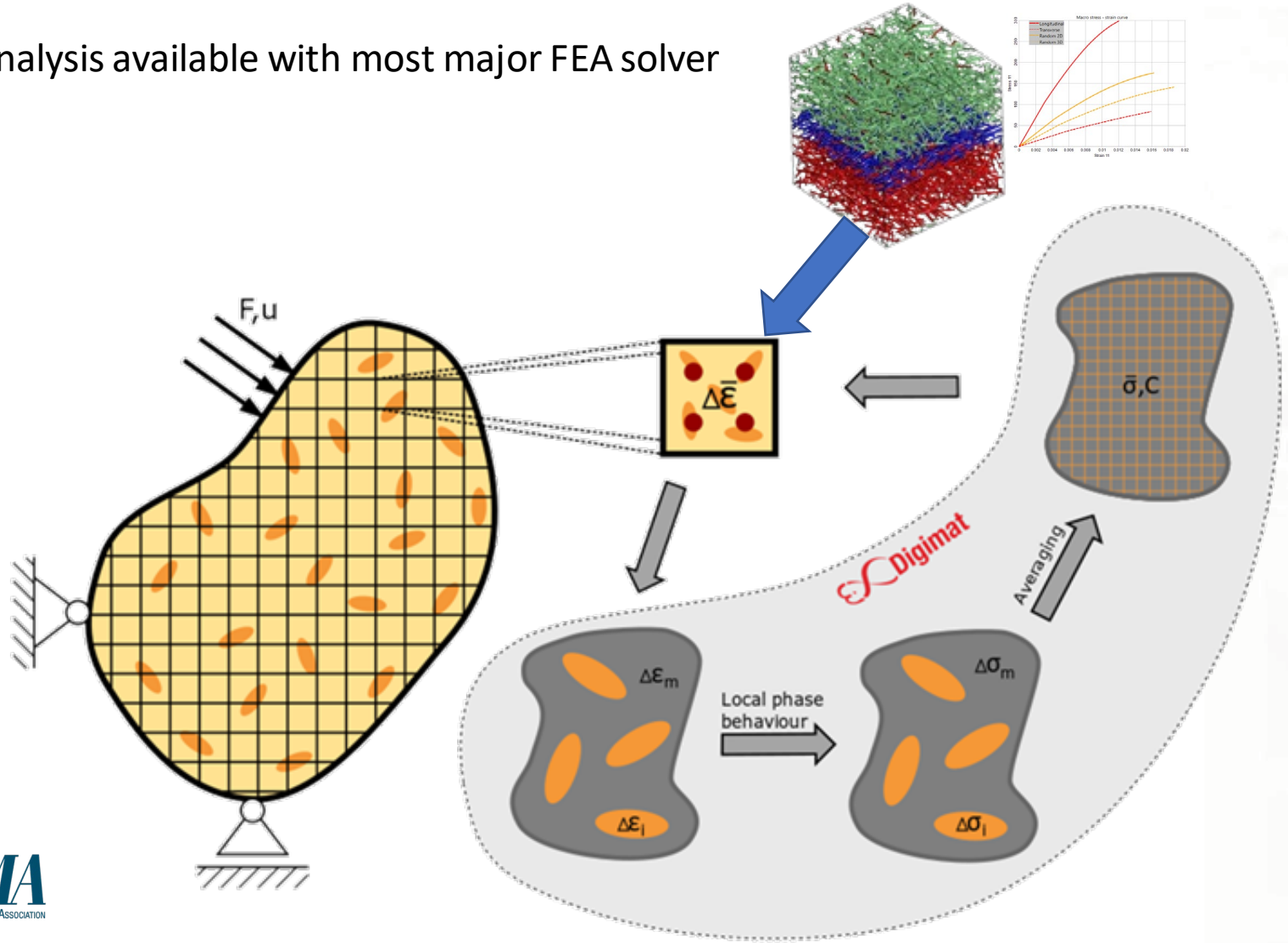
Multi-Scale Modelling Approach
Coupling with FEA codes via subroutines

Coupled analysis available with most major FEA solver



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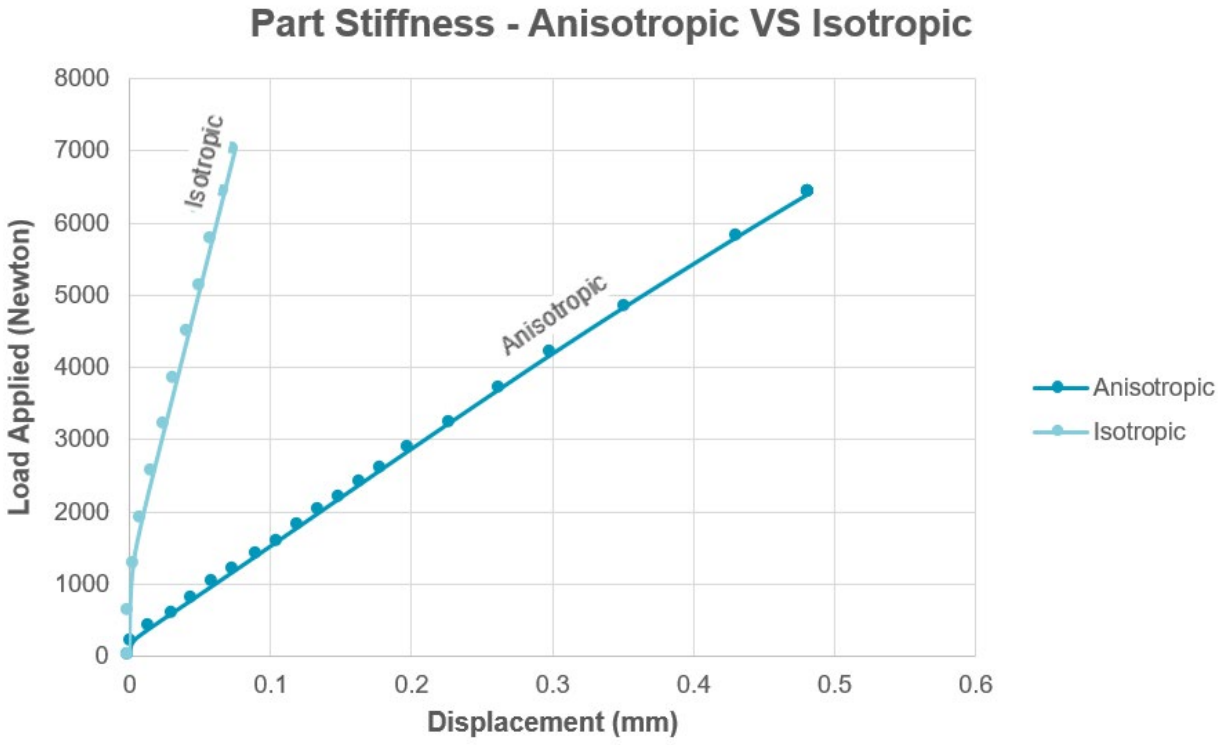
Part Stiffness Comparison – Isotropic vs. Anisotropic

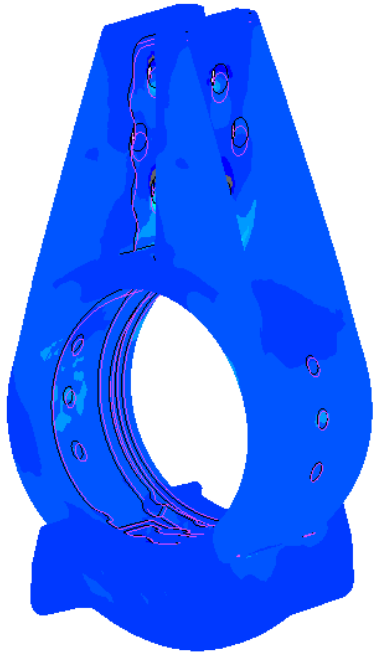
How using fiber orientation may influence the results



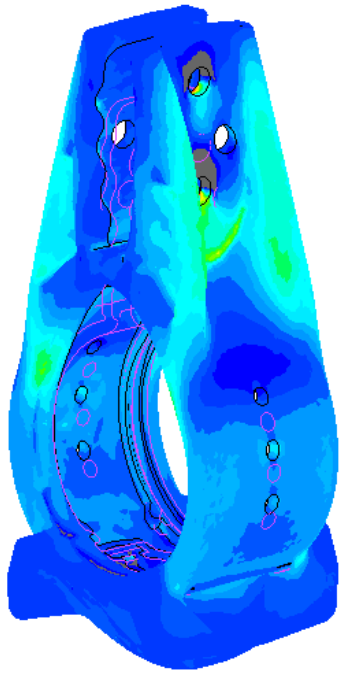
Deformation under same applied load

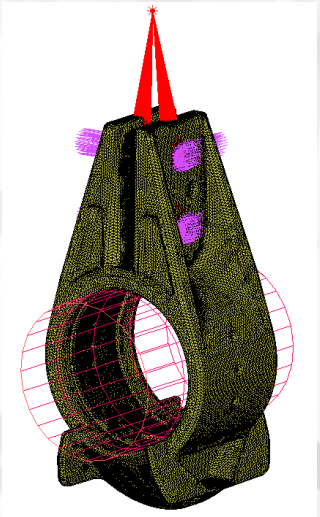
Deformation factor – 25:1

Isotropic



Anisotropic





**The pink contour would be considered as the initial geometry (undeformed)

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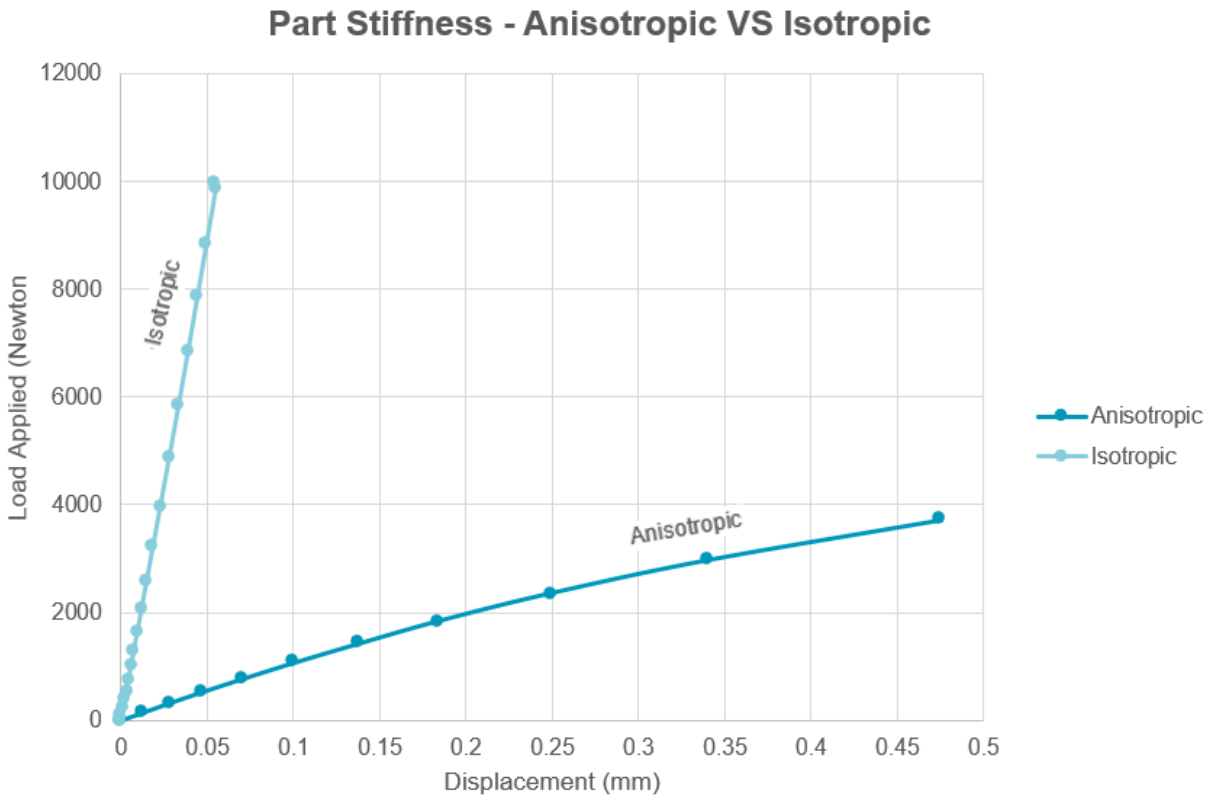
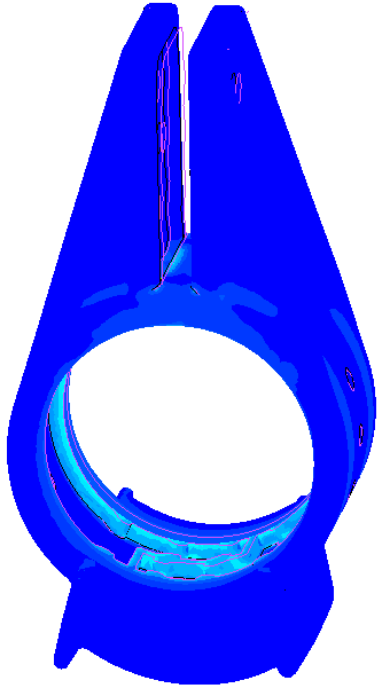
Part Stiffness Comparison – Isotropic vs. Anisotropic
How using fiber orientation may influence the results

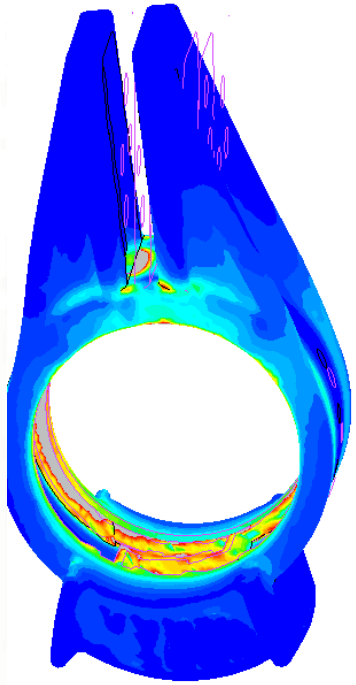


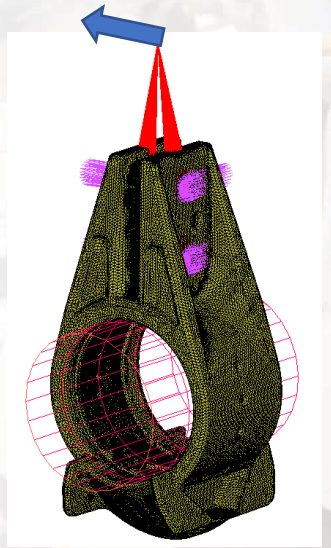
Deformation under same applied load
Deformation factor – 25:1

Isotropic



Anisotropic





**The pink contour would be considered as the initial geometry (undeformed)

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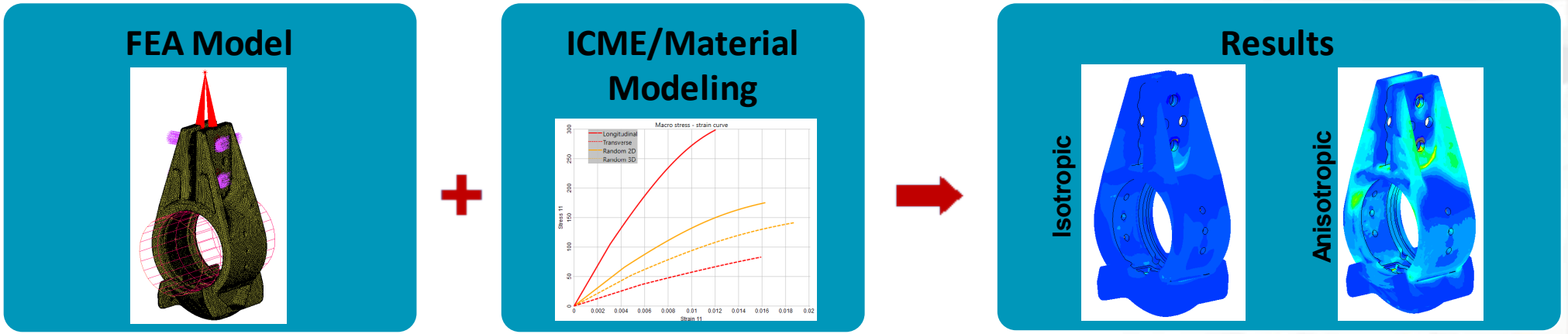
Enriched FEA Simulation
ICME material modeling + FEA simulation



- This workflow shows the benefits of Digimat tools and how they can be coupled to other FEA codes to quickly evaluate and simulate different test specimen and extract local loading history to evaluate failure modes and predict strength
  - **ICME/Material Modeling** -> Provides with easy material model calibration and help engineers to get quick general anisotropic material behavior evaluations
  - **FEA Simulation** > Enable to evaluate different loading condition requirements while accounting for all materials microstructures involved
  - **Injection Molding Simulation** -> Access to fiber orientation estimation for quick flow evaluation and Fiber OT data.

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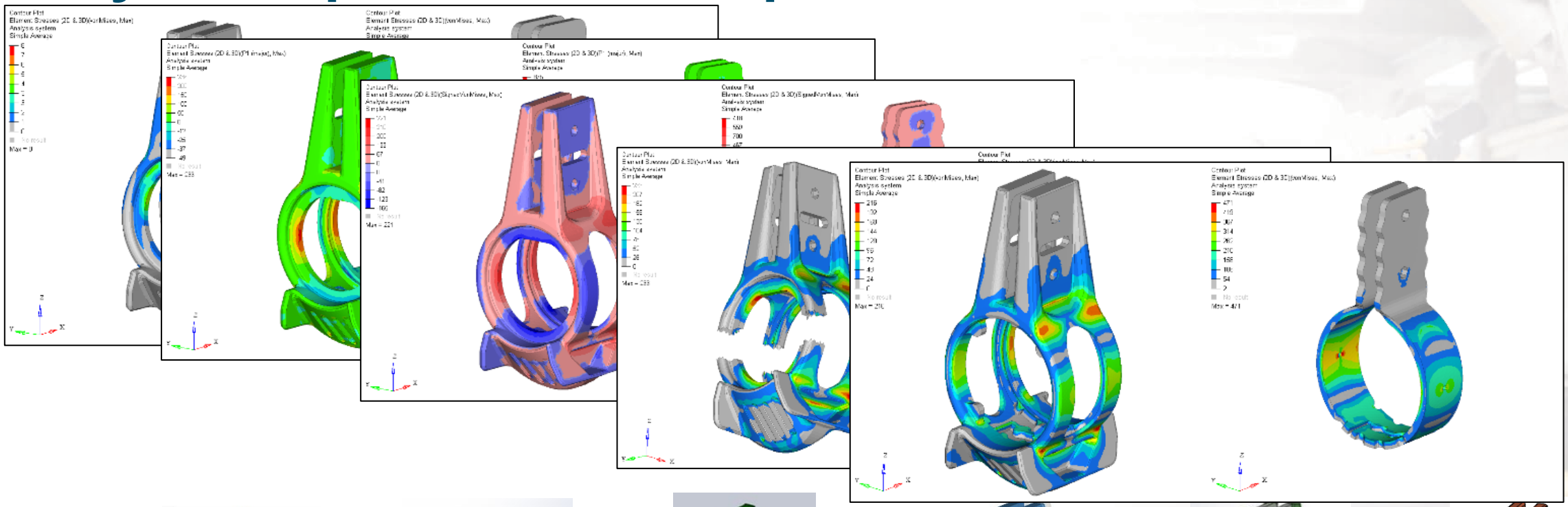
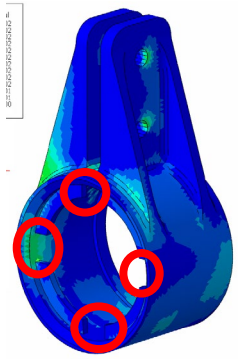
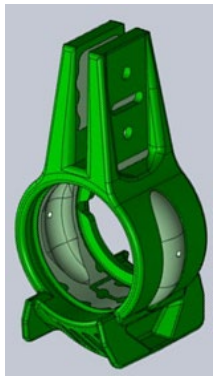
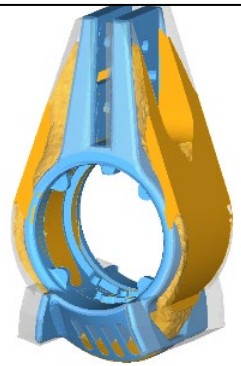
Software Aided Design & Analysis Iterations

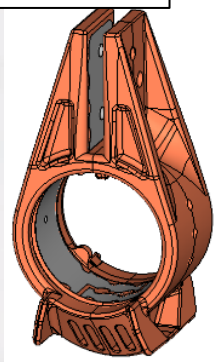
Early concept to build-able part











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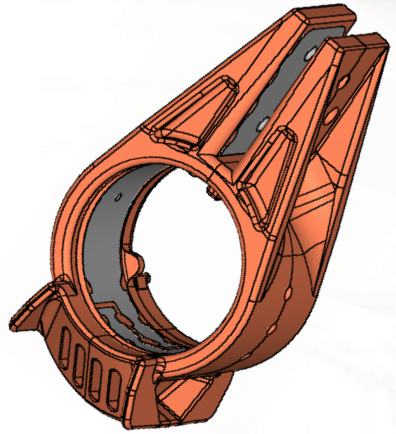
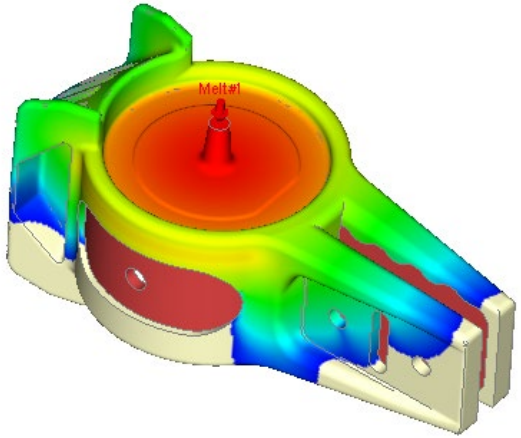
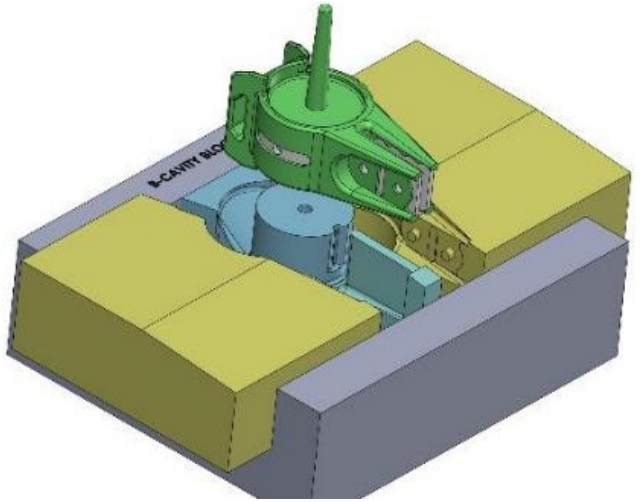
Tooling and Process Development

- Agreement on final design
- Analysis tools predict successful performance
- TxV initiates a tooling design
- Molding process simulations
- Part design modifications based on process and tooling constraints made as needed







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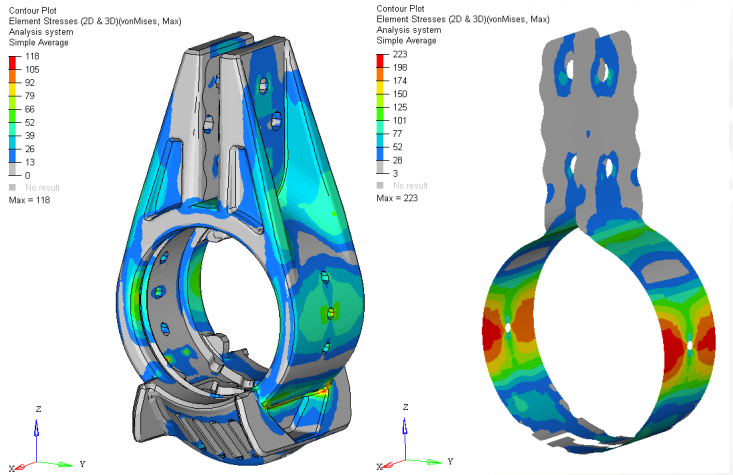
Prototype Parts, Testing, and Validation

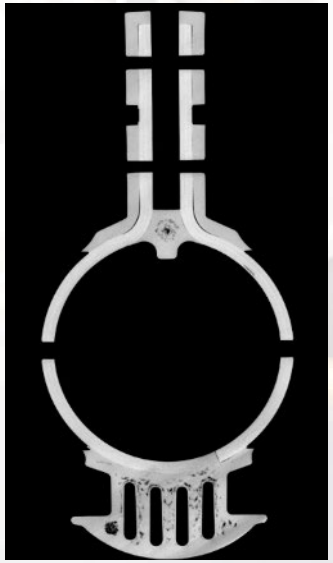
- TxV produced prototype parts
- Parts tested to validate design assumptions, analytical models and processing conditions

Prototype parts

Preliminary testing



Validated models



CT scan

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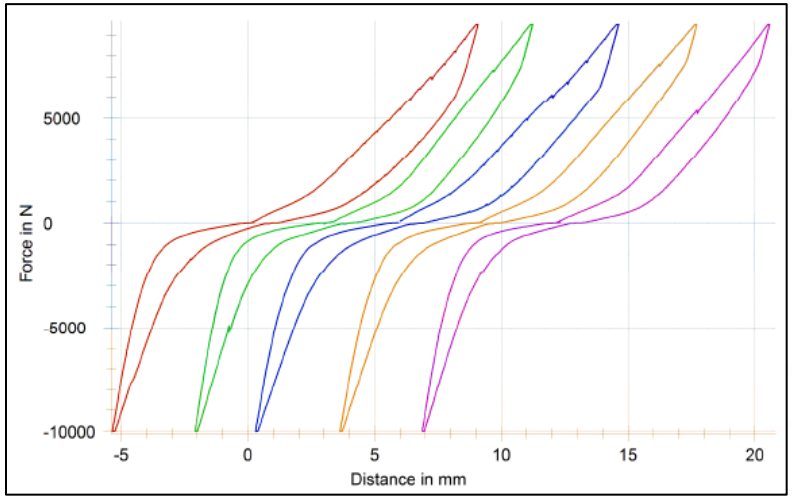
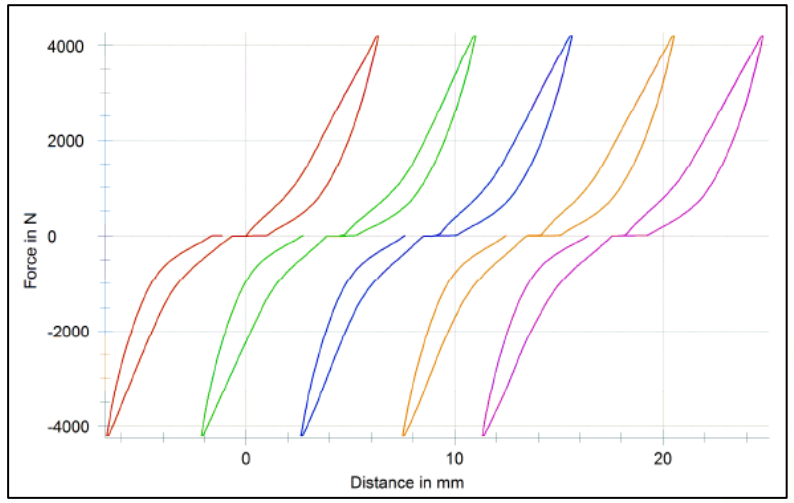
Qualification Testing and Reporting

- Parts were submitted for qualification testing in two load directions (Z and Y)
- Ultimate loads 1.50 x operational
- Tested in +/- Z, cycle full reversal from +10000 N to -10000 N
- Tested in +/- Y, cycle full reversal from +4,200 N to -4,200 N
- Maximum loads at an additional safety factor of 6 – 10%
- No cracks or visible damage is permitted
- Subsequently pulled to failure





Y +/-4,200 N

Z +8,900 N
Z -9,400 N

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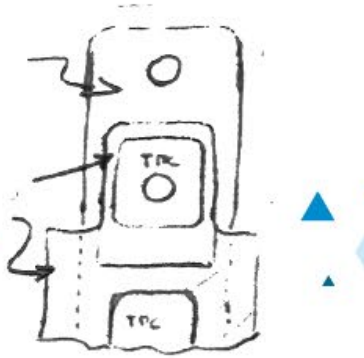
Collaborative Design

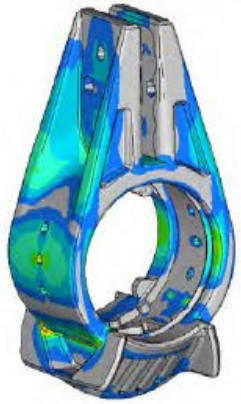


DESIGN FEASIBILITY

Initial assessment of how well a composite design is expected to deliver against application requirements and project objectives.

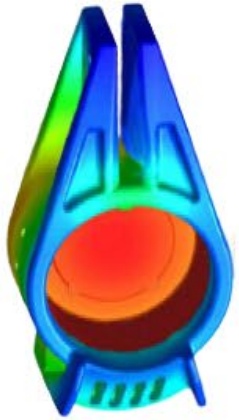
DIGITAL MODELING

Initial creation of a digital twin is used to represent the composite part design and provide confirmation that requirements have been understood.



OPTIMIZATION

Analytical tools are used to optimize the part design to meet the application demands and see how design choices impact results.



PROCESS SIMULATION

Advanced simulation tools are used to see how design choices impact manufacturability.

PROTOTYPING

First parts are produced to verify manufacturability and validate part performance.

COMMERCIAL PRODUCTION

APQP framework, production quality tooling, and automated equipment allows for a seamless transition to commercial production.

Thank You

Questions?

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