Lighter and reliable parts: correct choice of engineering polymers and advanced calculation approach

Part 1

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Global Marketing Manager

Webinar 6th October 2021

OUR APPROACH & MARKETS

RadiciGroup High Performance Polymers has developed and continues to develop **materials**, mainly based on **polyamide**, that can be used in many cases for **metal replacement** in applications with **high technical content**.

MAIN INDUSTRIAL SECTORS

Automotive for new challenges related to the electrification process

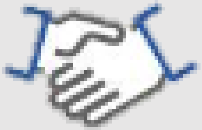
E&E for miniaturization and ever higher safety standards. Replacement of thermosets.

Water management for replacement of additional metals (brass and others)

Industrial and consumer goods for countless applications, which currently use metal

OUR PRODUCT OFFERING, OUR PHILOSOPHY, OUR PRESENCE

Large product portfolio and competence in designing high performance grades



Partnership with strategic customers to develop grades / applications from the initial idea to commercialization

Worldwide application development, technical **support** and R&D

ENGINEERING POLYMER SELECTION CRITERIA

FUNCTIONAL ANALYSIS

RADICI GROUP

APPLICATION REQUIREMENTS » **TRANSLATE INTO GRADE SELECTION**

APPLICATION REQUIREMENTS	TRANSLATE INTO GRADE SELECTION
Define requirements in detail with **development partners**	**Select proper grade**, if available, from the current product range
Consider the **entire life cycle** of the application: from initial idea to expected end of life	Otherwise, **design new grade** to fulfil requirements
Use a **requirement ranking** approach (define priority level)	Provide **short-term and long-term tech data** when necessary

NEW TREND : **DESIGN FOR RECYCLING**

RADICIGROUP HIGH-STIFFNESS GRADE OFFERING

Polymer	Product					
PA6-GF50 HS PA6-GF60 HS	S URV500W S URV600W	HIGH STIFFNESS, STRENGTH	HIGH FLOW			
PA66-GF50 HS	A RV500RW	HIGH STRENGTH				Higher strength, even in the presence of welding lines, versus standard PA66
PA66-GF50	A RV500RKC2	HIGH STRENGTH	WATER MANAGEMENT			
PPA-GF50 HS	Aestus RV500K	HIGH STIFFNESS, STRENGTH	LOW MOISTURE ABSORPTION			Lower moisture absorption sensitivity vs PA6 & PA66
PA610-GF50	D RV500K	HIGH STIFFNESS	LOW MOISTURE ABSORPTION	CHEMICAL RESISTANCE	PARTIALLY BIO	
PA612-GF60	DT RV600RKC2	HIGH STRENGTH	WATER MANAGEMENT, LOW MOISTURE ABSORPTION	STRESS CRACKING RESISTANCE		

RADICIGROUP HIGH-STIFFNESS GRADE OFFERING

PA66-GF50

A RV500RW

HIGH STRENGTH

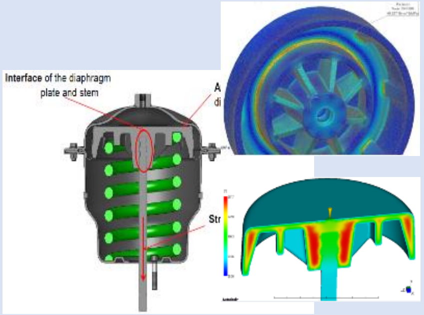
KEY FEATURES VS STANDARD PA66

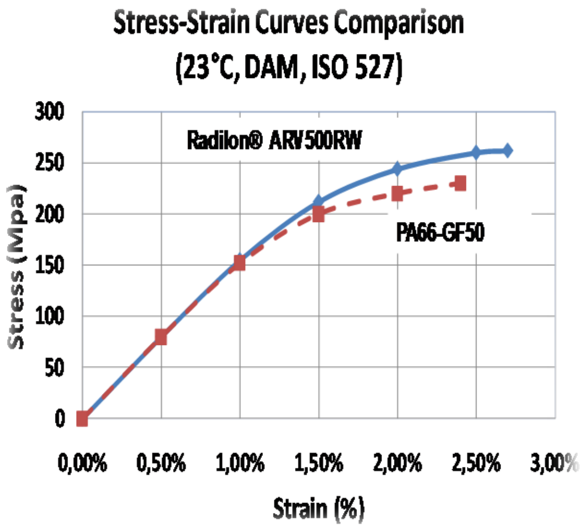
- Improved tensile strength and deformation at break in presence of welding lines
- Higher tensile strength and deformation at break
- Better impact resistance

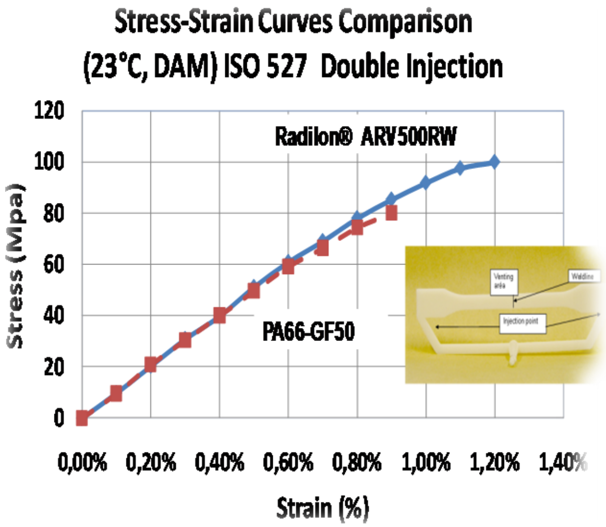
ENGINE MOUNT

INDUSTRIAL VALVE ACTUATION PLATE

ENGINE BRACKET







RADICIGROUP HIGH-STIFFNESS GRADE OFFERING

PA6-GF50 — S RV500W
PA6-GF60 — S RV600W

HIGH STRENGTH

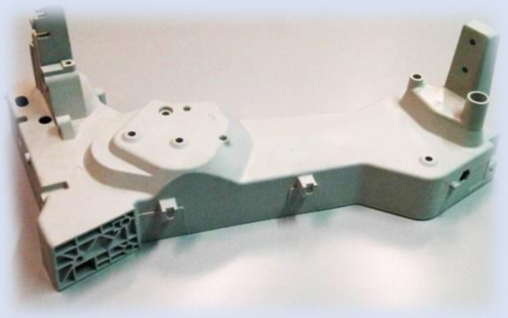
HIGH FLOW

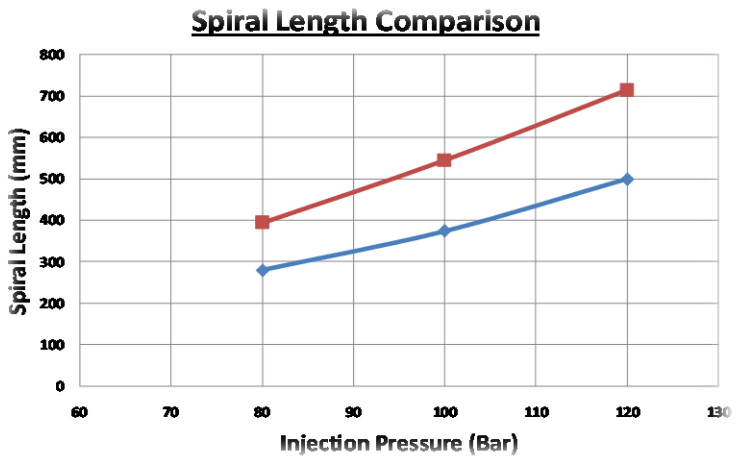
KEY FEATURES VS STANDARD PA66

- Easy flow
- Less fibre breakage and better mechanical property retention after moulding
- Reduced screw abrasion
- Improved design freedom
- Lower barrel temperature
- Higher productivity
- Smaller press size

CHAIR ARMREST

TEXTILE MACHINE CARTER





PA6-GF50

FLOW LENGTH **+40%**

HIGH FLOW RADILON® S URV600LW

RADICIGROUP HIGH-STIFFNESS GRADE OFFERING

RADISTRONG

RADICI GROUP

Polymer	Product				
SPECIAL PA66-GF50-GF60	RDS A RV600W RDS A RV500W	HIGH STIFFNESS	GOOD FLOW	LESS MOISTURE SENSITIVITY VS PA66	SURFACE APPEARANCE
	RDS AR RV500RKC2 (RADISTRONG AROMA)	HIGH STIFFNESS	SUPERIOR GLOSS	GOOD FLOW	
	RDS A RV500UK	HIGH STIFFNESS	SURFACE APPEARANCE	GOOD FLOW	OUTDOOR EXPOSURE

RADICIGROUP HIGH-STIFFNESS GRADE OFFERING

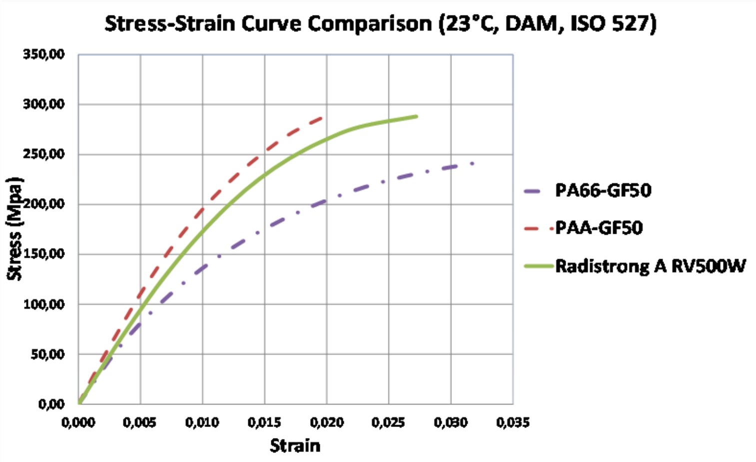
SPECIAL PA66 LOW MOISTURE ABSORPTION SENSITIVITY

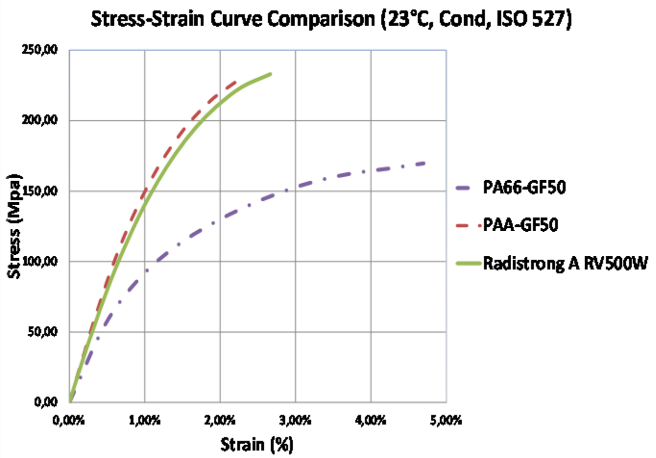
AIR OUTLET BLADES

MOTORBIKE LUGGAGE CARRIER

KEY FEATURES VS STANDARD PA GF GRADES

- Superior mechanical properties
- Lower moisture sensitivity
- Easy moulding
- Excellent surface appearance for standard grades. Superior surface appearance for Radistrong Aroma





RADICIGROUP FLAME RETARDANT OFFERING

RADIFLAM

RADICI GROUP

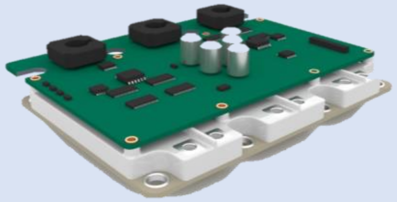
Polymer	Product			
PA6-GF35	S RV350HF	GOOD MECHANICAL PROPERTIES	HALOGEN- & RED PHOSPHOROUS-FREE	
PA66-GF25-35	A RV250-350HF	GOOD MECHANICAL PROPERTIES, CREEP RESISTANCE	HALOGEN- & RED PHOSPHOROUS-FREE	
PA66-GF35	A RV350AF	EXCELLENT MECHANICAL PROP.	RED PHOSPHOROUS	
PA66-GF50	A RV500AF	EXCELLENT MECHANICAL PROP. HIGH STIFFNESS	RED PHOSPHOROUS	
PPA-GF30	Aestus RV3 00HF	EXCELLENT MECHANICAL PROP. AND HIGH STIFFNESS HALOGEN- & RED PHOSPHOROUS-FREE	LOW SENSITIVITY TO MOISTURE ABSORPTION	HIGH MELTING TEMPERATURE

YC AVAILABLE

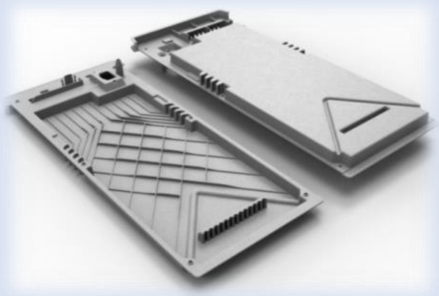
RADICIGROUP FLAME RETARDANT OFFERING

EV BATTERY HOUSING

IGBT BASE



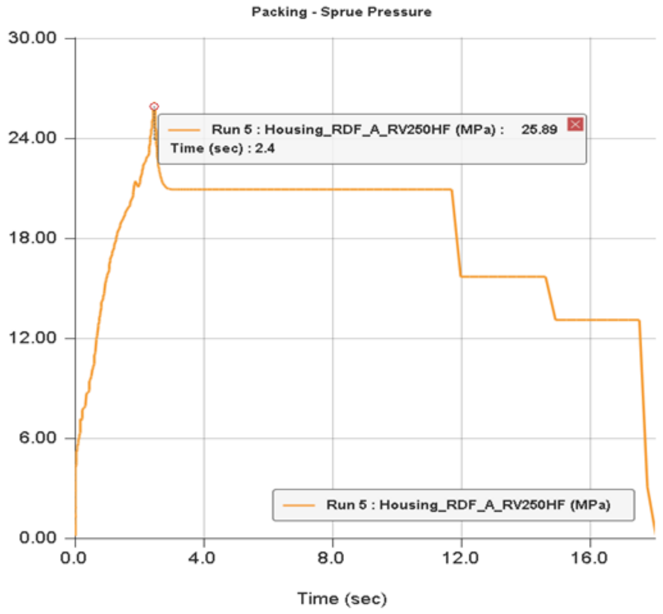
ELECTRONIC APPLIANCE HOUSING

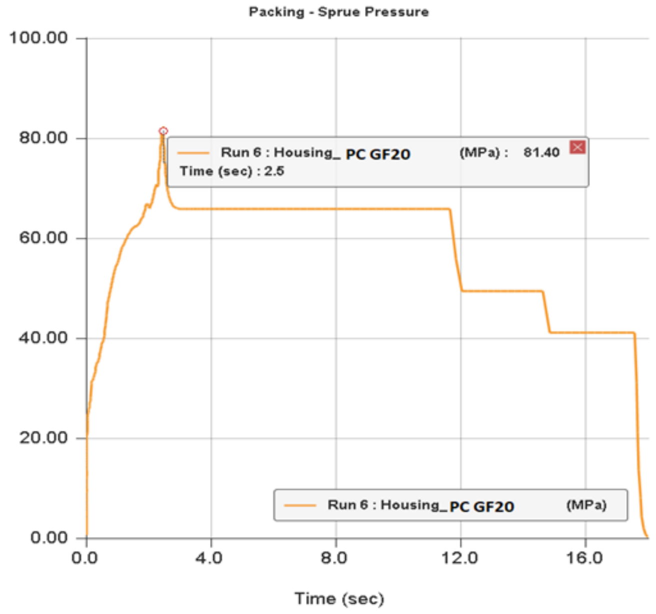


KEY FEATURES VS STANDARD PA GF GRADES

- UL-V0 certified grades
- Different technologies available, including halogen- and red phosphorous-free
- Improved laser markable grades available
- Good mechanical properties and chemical resistance

The pressure required to fill the cavity for the PC-GF20-FR product is almost 4 times higher than that required for Radiflam A RV250HF (PA66-GF25-FR – halogen- and red phosphor.-free)

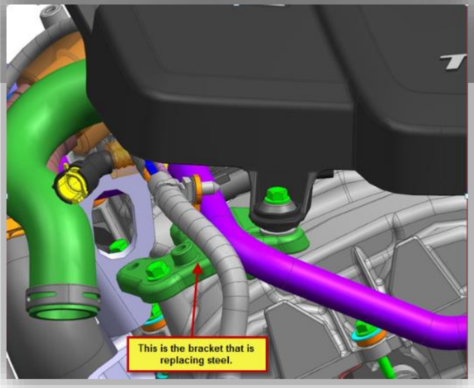




METAL REPLACEMENT PROJECT

RADICI GROUP

COMPONENT : UNDER THE BONNET BRACKET



Material selected:
Radilon® A RV500RW 339 Ner
(Special PA66-50% GF, heat stabilized; improved tensile strength at break, deformation at break and impact; higher mechanical resistance in the presence of welding lines)

Development time: 8 months approx.
Based on input from functional analysis, an innovative material already present in the product range was chosen.

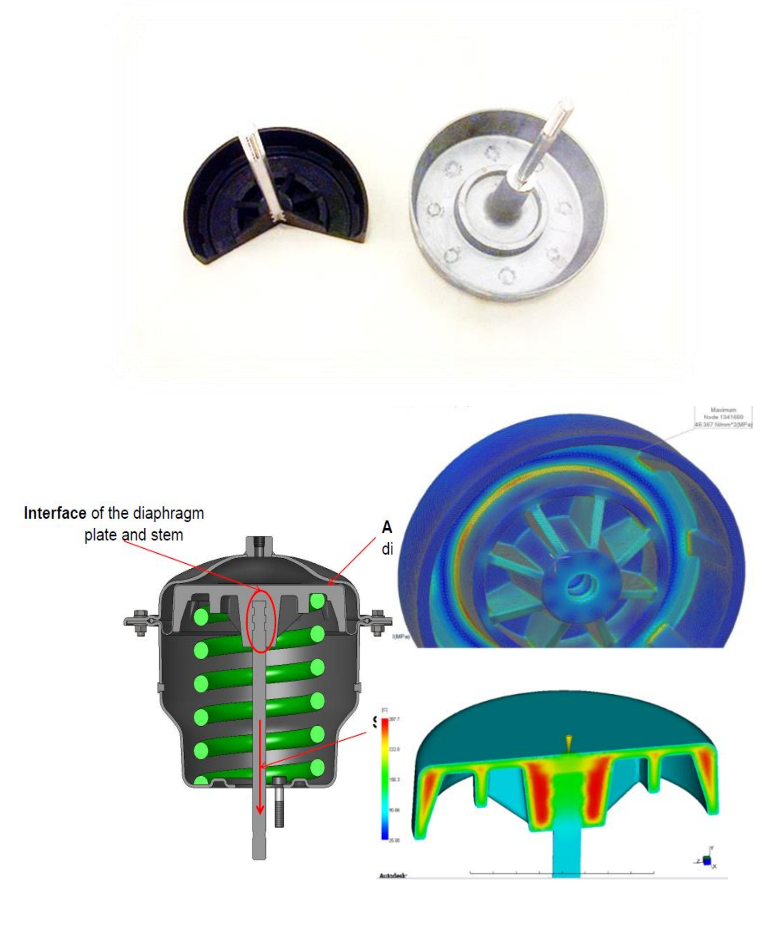
METAL REPLACEMENT PROJECT

COMPONENT: INDUSTRIAL VALVE ACTUATION PLATE
OBJECTIVE: ALUMINIUM SUBSTITUTION

Key requirements: mechanical + fatigue performance, low deformation, tolerances respect

Material: **Radilon® A RV500RW 339 BK**

Advantage vs metal: 40% cost saving
No machining needed
Reduced assembly time
Better surface appearance (improved membrane life time)



METAL REPLACEMENT PROJECT

COMPONENT: CYLINDRICAL CELL HOUSING

Key requirements: stiffness, strength, creep resistance, vibration resistance, flame retardancy, no halogens

Material: **Radiflam® A RV250HF**

Advantage vs metal: cost saving
No machining needed
No corrosion

RADICI GROUP

HIGH PERFORMANCE POLYMERS

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Lighter and reliable parts: correct choice of engineering polymers and advanced calculation approach

Part 2

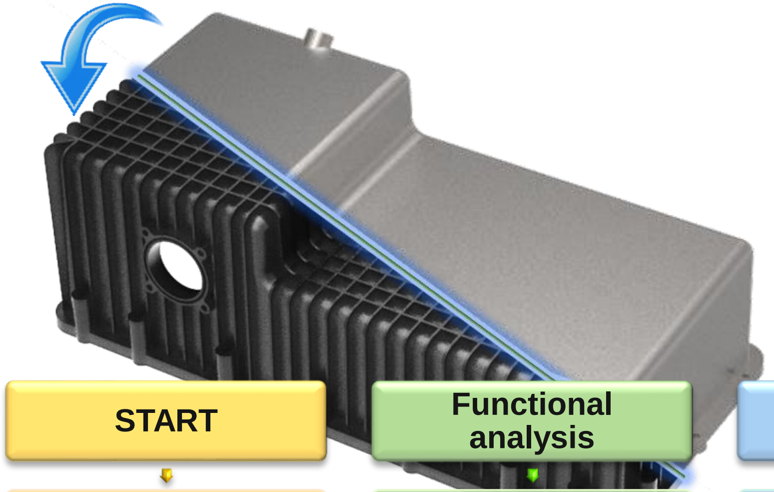
Carlo Grassini
CAE Global Team Leader

Webinar, 6th October 2021

Metal Replacement: Key concept

› Change **MATERIAL**, maintain **FUNCTIONALITY,** gain **ADVANTAGES**

"Metal to **Technopolymer**"



Not "volume refilling" but a **re-engineering process**!

- ✓ **Lightweighting**
- ✓ Form design **freedom**
- ✓ Function **integration**
- ✓ Reduction of **post-manufacturing aesthetics**, colouring
- ✓ Total effective **cost**

START	Functional analysis	Redesign	CAE validation	Prototyping	Scale-up
Identification of part(s) to be replaced	Identification of part requirements	Function integration	**Processability** (injection moulding)	Rapid prototyping / Soft tooling /…	Definitive tooling
Preliminary cost analysis	Identification of desired material properties	Plastic design (guidelines)	Mechanical performance (**Structural**)	Functional tests on prototypes	Functional tests on pre-series
Definition of targets and goals	Preselection of material and technology	Design for manufacturing, for assembly…	Design modifications (iterative process)	Validation and fine-tuning	Validation and production
	Comparative cost analysis				

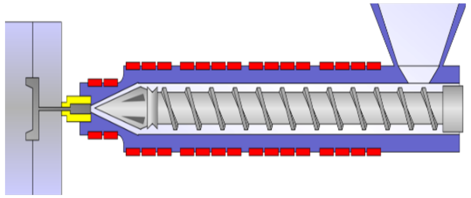
CAE Service

RadiciGroup HPP CAE Service role

- Perform **CAE simulations,** when requested, in support of applications involving RadiciGroup special thermoplastic compounds, using state-of-the-art software tools and methods available on the market, with the scope of:
  - Assessing project feasibility
  - Validating material selection and part (re)design
  - Evaluating solutions for issues occurring in prototyping or regular production
- Coordinate with R&D, external suppliers and software producers, so as to ensure that fresh and reliable **material cards** for RG-HPP products are made available for use by simulation communities.
- Communicate with customers' **CAE experts** in order to facilitate a positive exchange of information in material selection and modelling, when RadiciGroup grades are involved in components or assembly simulations.

RadiciGroup HPP CAE simulation skillset

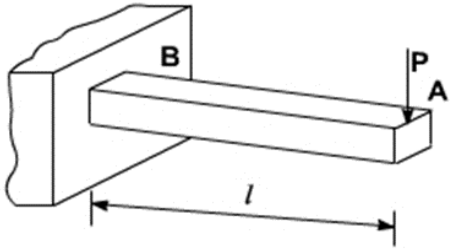
Process



- Injection moulding process simulation
- Flow, packing, cooling, warpage
- Prediction of process-related output and defects

Moldex3D

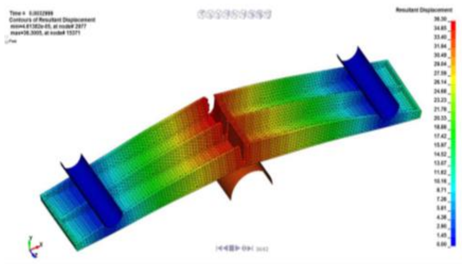
Structural Static



- Linear and non-linear, multi-body contact
- Stiffness, strength, failure
- Modal and harmonic
- Fatigue and creep long-term evaluation
- Thermal and thermo-mechanical

Marc
MSC Apex

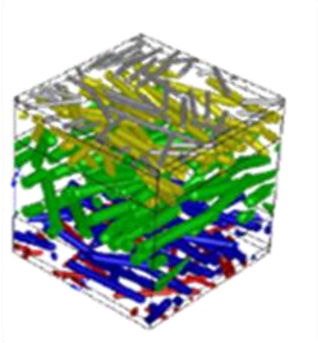
Structural Dynamic



- Transient dynamic simulations
- Explicit and implicit solver
- High-speed impact, crash simulation
- Special manufacturing (e.g., TPC)

LS-DYNA

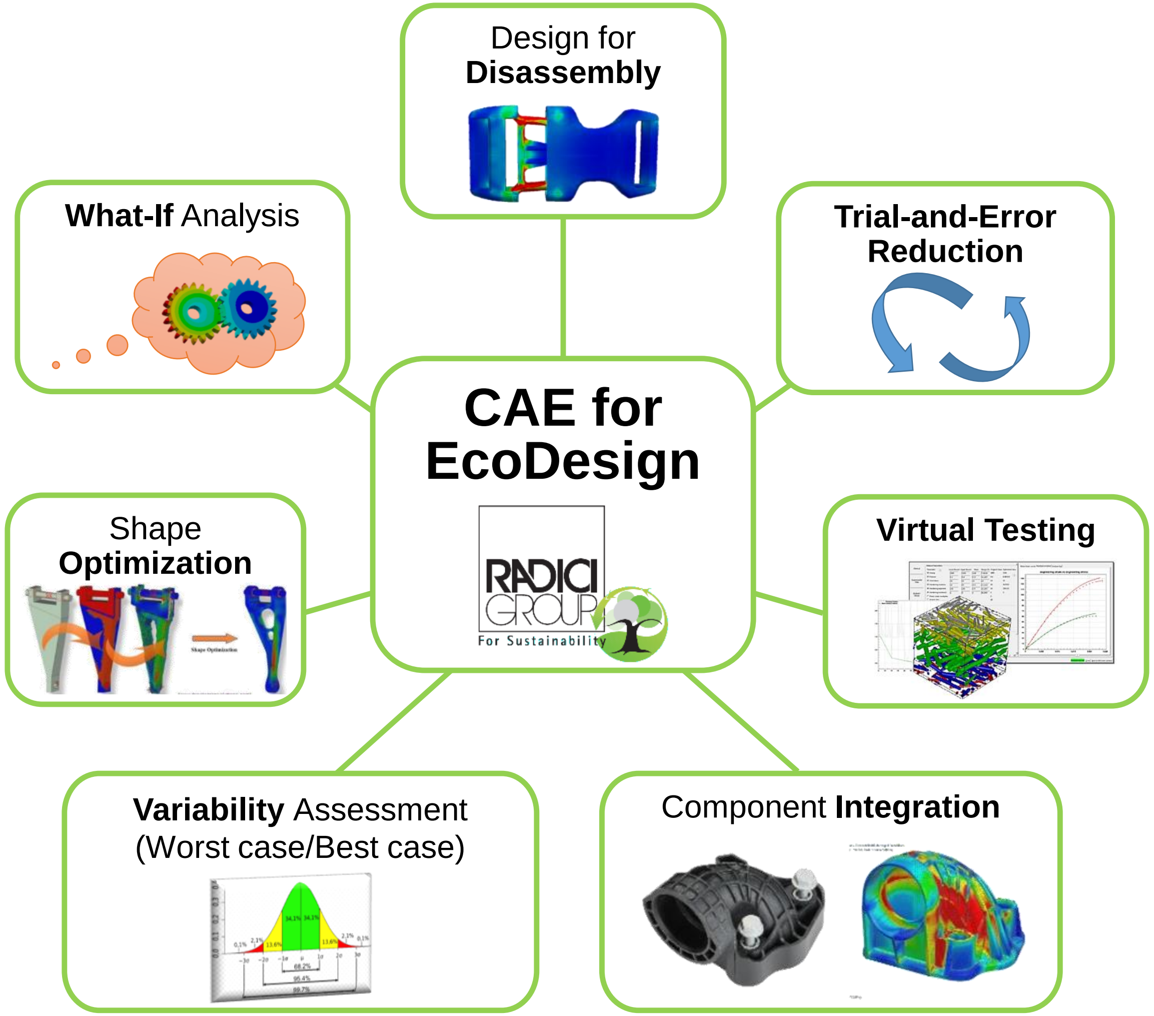
Integrated



- Linking process to structure
- Anisotropic behaviour, GF orientation, welding lines, warpage
- Multi-scale material modelling
- Available for static, dynamic and long-term analysis

Digimat

CAE for EcoDesign

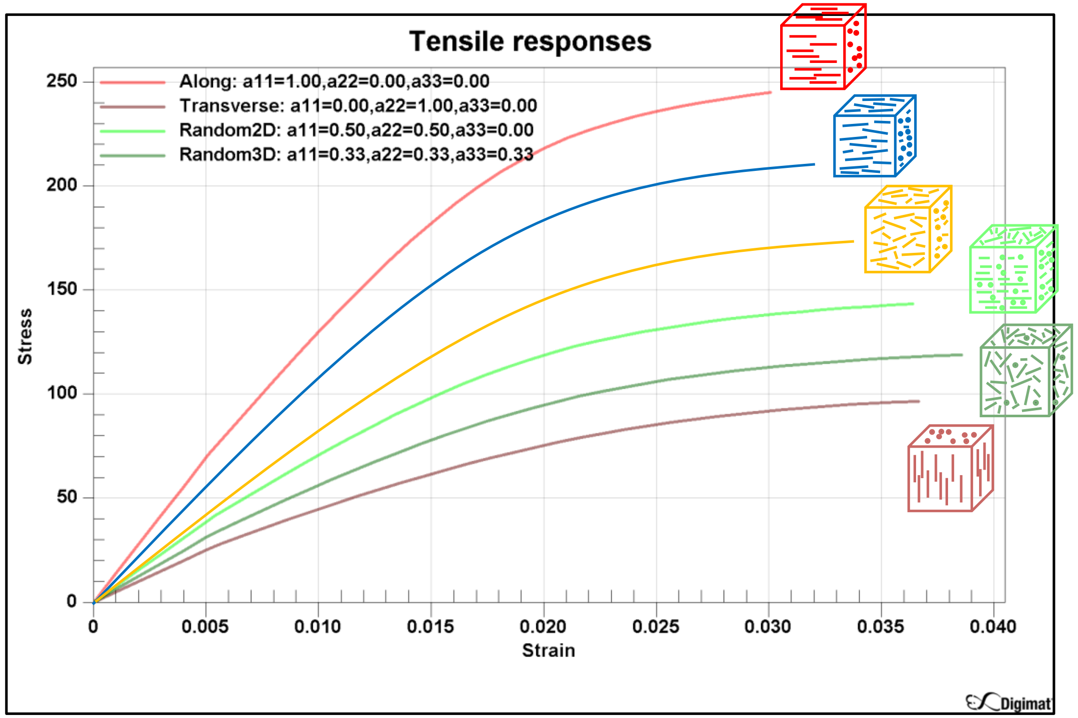


- **Design for disassembly**: to easily dismantle the item at end of life, making it easy to recover recyclable parts.
- **Minimizing trial-and-error**, saving time and material for disruptive trials and prototyping.
- **Formulation** of new materials made quicker by the use of multi-scale **virtual testing**.
- Possible reduction in the number of components by **integrating** with few multi-functional parts.
- Assessing **variability**, which is intrinsic to recycled materials, evaluating best/worst cases.
- **Optimizing** the shape of items by fully exploiting the potential of materials.
- Exploring **alternative solutions** (what-if?).

Integrated approach to simulation

› **Short glass-fibre reinforcement** fibres have a significant aspect ratio (>20)

› Mechanical properties of GFRP heavily depend on the **orientation of fibres** with respect to loading direction (anisotropy): **PROPERTIES = f(MICROSTRUCTURE)**

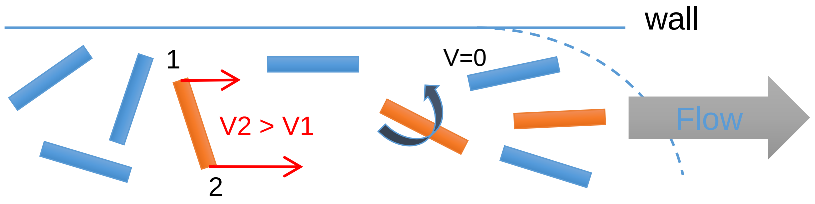


Integrated approach to simulation

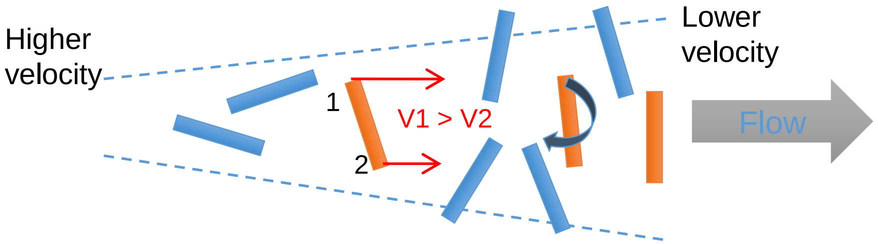
RADICI GROUP

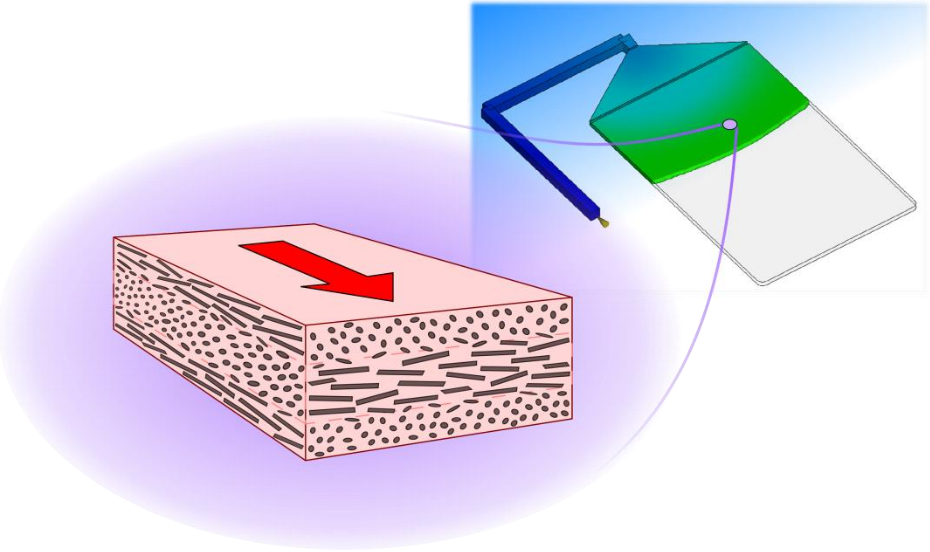
- The fibre orientation is a consequence of the phenomena which occur during the **mould filling phase**. Thus, these phenomena are related to the part's geometry and transformation process: **MICROSTRUCTURE = f(PROCESS)**
- **Therefore PROPERTIES = f(PROCESS)**

Shear Flow → Fibre // Flow direction

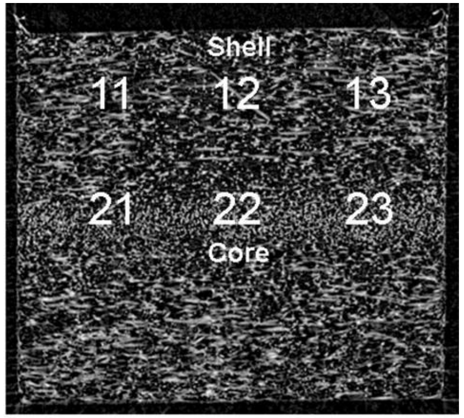


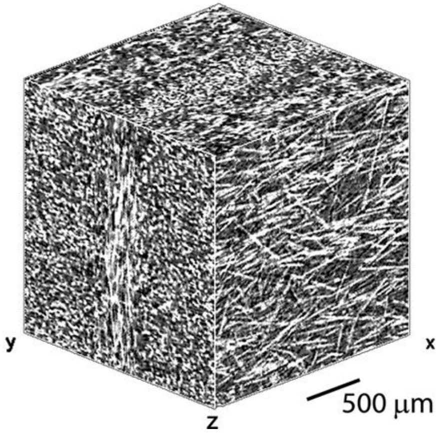
Expansion Flow → Fibre ⊥ Flow direction





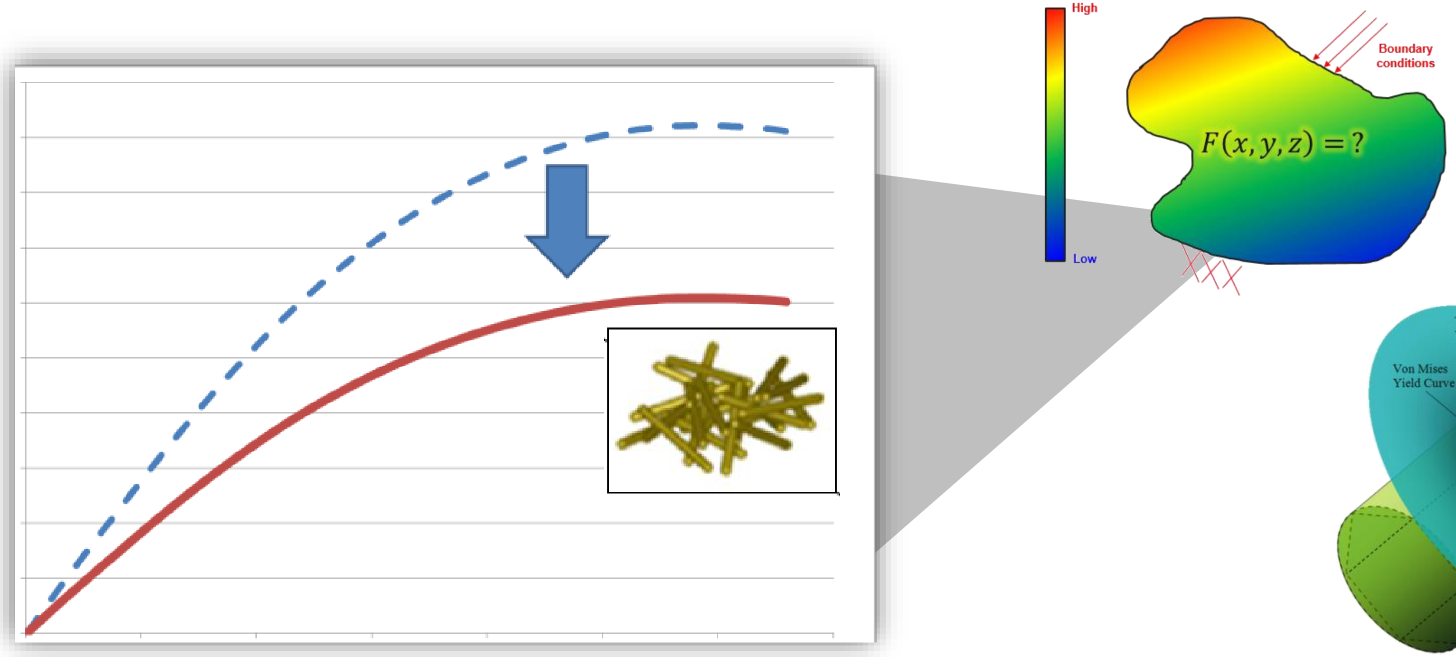
Typical "sandwich" microstructure of an injected plate

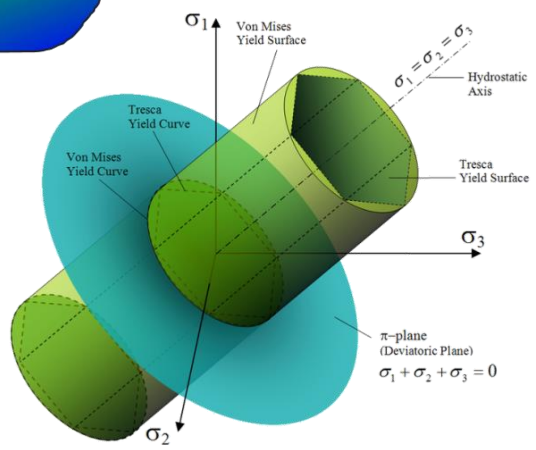




“Classic” CAE: Pseudo-isotropic approximation

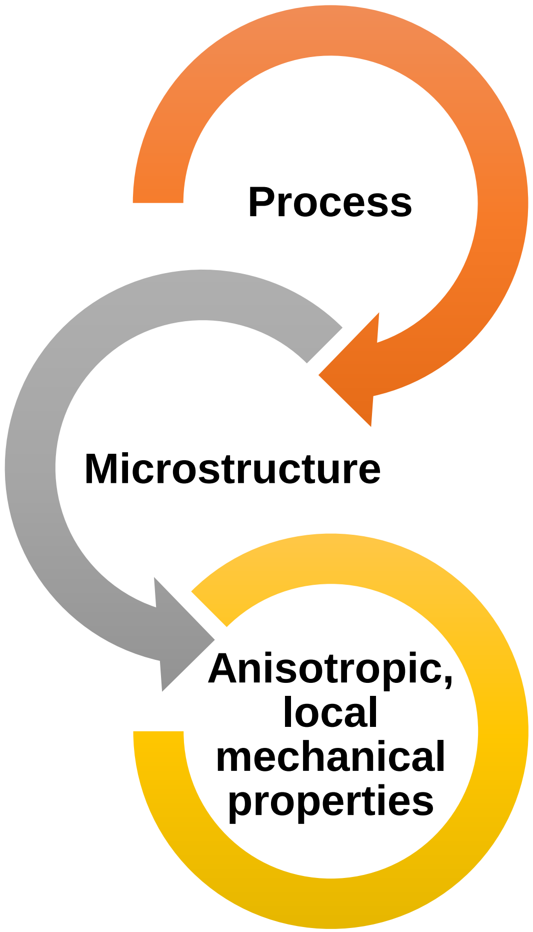
- Simplifying assumption: material is treated as homogeneous and isotropic, with characteristics equivalent to fibres oriented in a random manner.
- This is practically done by **rescaling** ISO-527 data (from TDS), obtained on very oriented specimens, with an appropriate **penalty factor**, calculated based on the analyst’s experience.





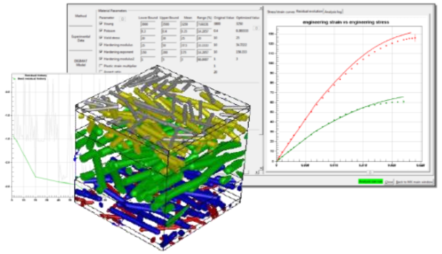
In pseudo-isotropic analysis, **Von Mises equivalent stress** is typically used as the failure criterion, vs. uniaxial **stress at break** in tension.

Advanced CAE workflow: Integration

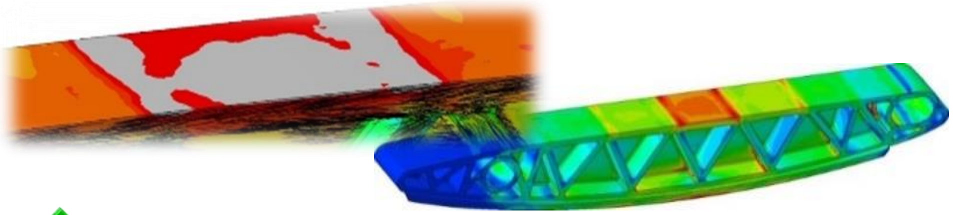


Injection simulation:
Warpage,
GF orientation, weld lines…

FEA model



Advanced material
modelling

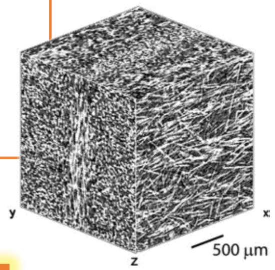


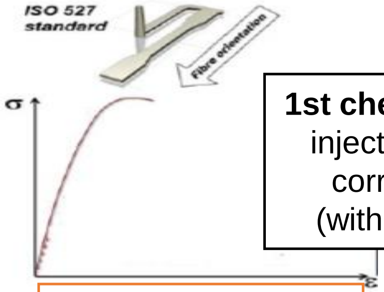
INTEGRATED NONLINEAR FEM ANALYSIS

Higher **ACCURACY** and **RELIABILITY** in predicting elasticity and failure
More in-depth understanding of **MATERIAL BEHAVIOUR**
Reduced **OVER-ENGINEERING** and use of high **SAFETY FACTORS**
Less need for **PROTOTYPE TESTING**

Advanced CAE workflow: Modelling and check

Microstructure of specimens: microtomography scan (µCT) analysis





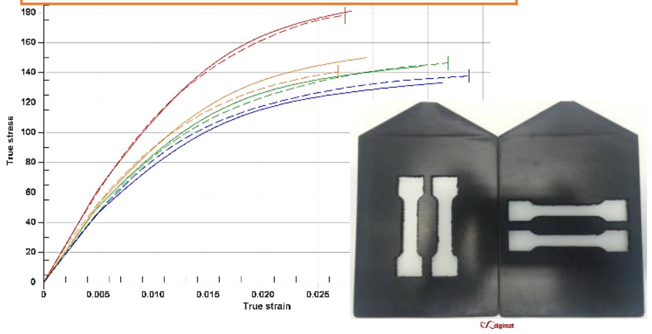
1st check: ISO527-1A
injected specimens correspondence
(with **Digimat-MF**)

Tensile experimental data
@ 0°, 30°, 45°, 90°
@T and RH

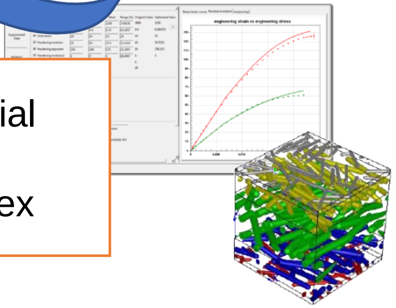
Reverse-engineering
Digimat-MX
calibrating / fitting the model to experimental data

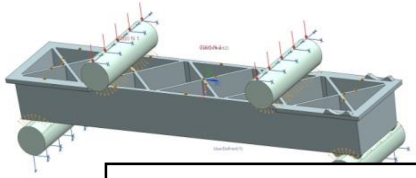
Verification
and
Validation

AVAILABLE FOR ENGINEERING USE!



Micromechanical material model equations
e.g., J2-EP + Failure Index

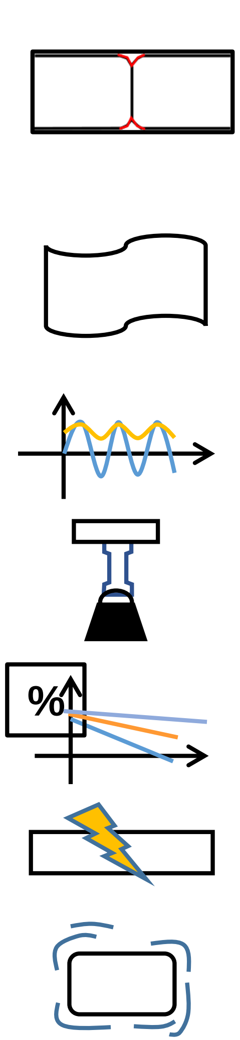




2nd check: 4PB
"Demonstrator" beam
reproduction
(with **Digimat-RP + Marc**)

Advanced CAE workflow: more fields of simulation

- **Weld lines** – taking into consideration strength reduction according to formation conditions
- **Warpage** – applying the deformation induced by injection moulding to the structural mesh
- **Fatigue** – prediction of Critical N to failure on the part
- **Creep** – deformation under continuous steady load
- **Thermal / Chemical ageing**
- **High-speed loading** (crash, impact…)
- **Vibrations / Damping**



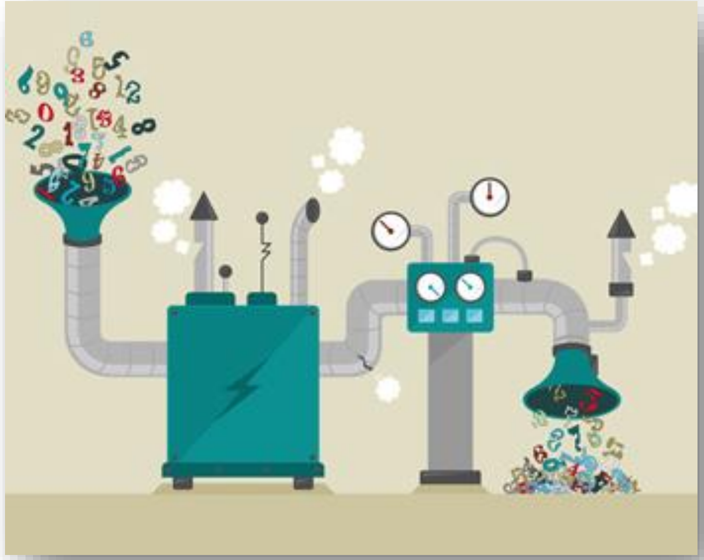
Process-induced local properties
(other than GF orientation)

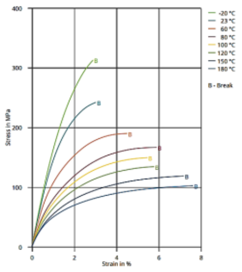
Long-term behaviour of materials

Dynamic behaviour of materials

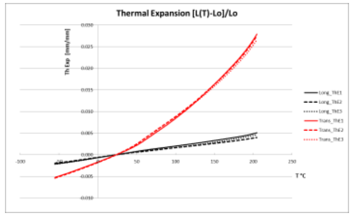
Providing reliable and controlled CAE material cards

- For our customers who prefer to carry out their own CAE studies internally, we provide **accurate characterizations** and **material cards for** many **RadiciGroup HPP materials** and support CAE engineers in choosing the optimal parameters for their applications.
- If the specific data needed are not yet available for the desired grade, we can set up a **collaboration plan** to implement a dedicated testing campaign.

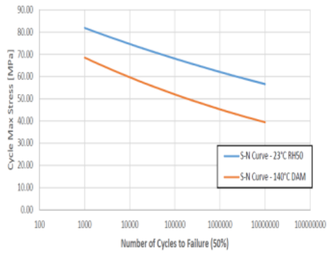




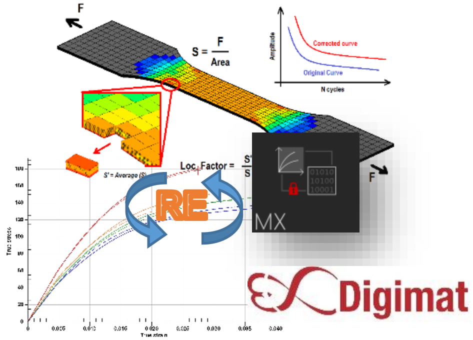
σ-ε curves various T, RH (static structural)



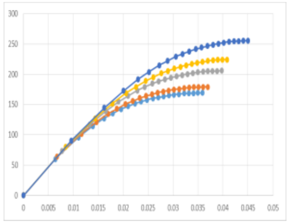
CLTE // and ⊥ (thermo-mechanical)



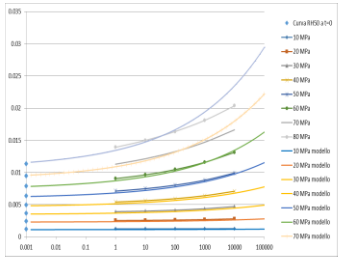
Fatigue Wohler curves



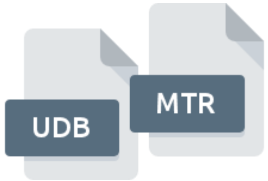
Anisotropic models EP, VEVP, SREP, creep, fatigue (integrated simulation)



σ-ε curves various dε/dt (dynamic, crash)



Creep ε vs t curves



Material cards for process simulators

Providing reliable and controlled CAE material cards

RADICI GROUP

- For **process simulation**: 116 material cards currently available in the public databases for the most known software solutions.

AUTODESK® MOLDFLOW® Moldex3D CADMOULD® 3D-F SIMULATION SOLIDWORKS PLASTICS

- For **integrated simulation**: 268 material cards for 21 different grades available in MSC Digimat form.

Digimat

- For **structural simulation**, the data can be made available any time, based on available stress-strain curves in various conditions.

Case history: Housing for LED street lamp

RADICI GROUP

- Substitution from **aluminium** (die-cast) to **engineering polymers** (injection-moulded).

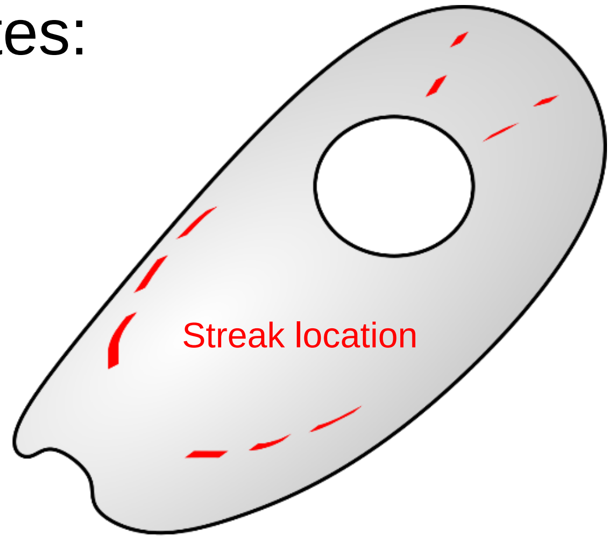
- Material: **RADISTRONG A RV500UK** Black, White, Grey versions
PA66 special blend, high fluidity, 50% glass-fibre reinforced.

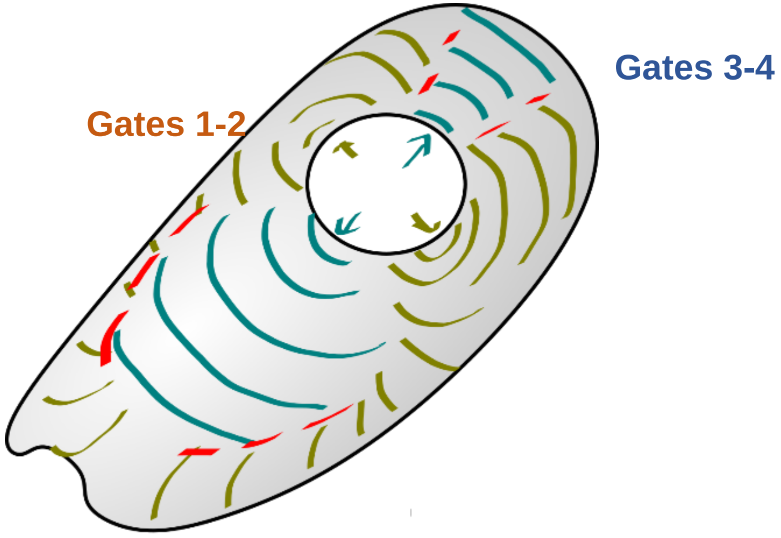
- Various process and structural CAE evaluations aimed at evaluating filling behaviour and assessing flow path, in order to optimize mechanical and aesthetic performance.

Illustrative image only

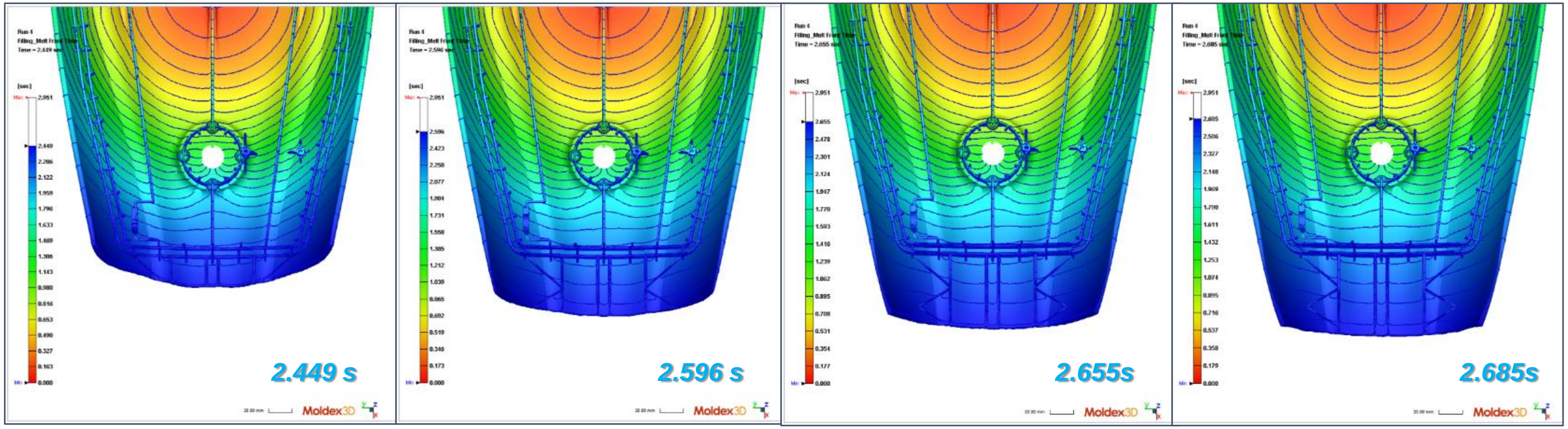
Problem solving: Aesthetic issue

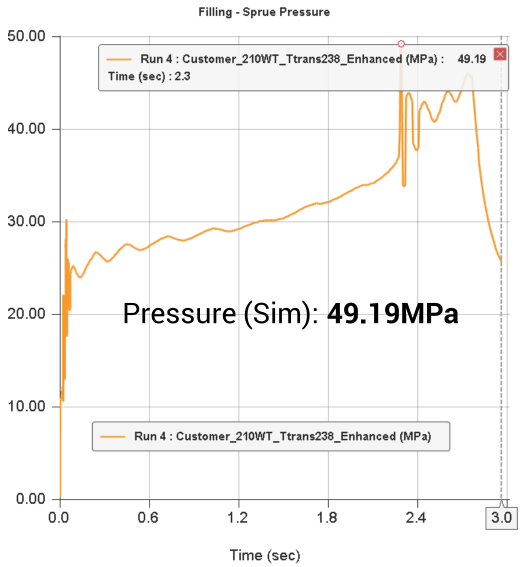
- In the first prototype trials, we needed to deal with an aesthetic issue involving white-coloured **RADISTRONG**.
- In a particular zone on the cover, grey/yellowish flow streaks sometimes appeared during injection moulding. This was *not* predicted by the earliest simulations.
- By performing the Moldex3D simulation using the advanced **VE Solver + Fibre Coupling solver**, we noticed that the streak locations coincided with boundary lines between flows from different gates:

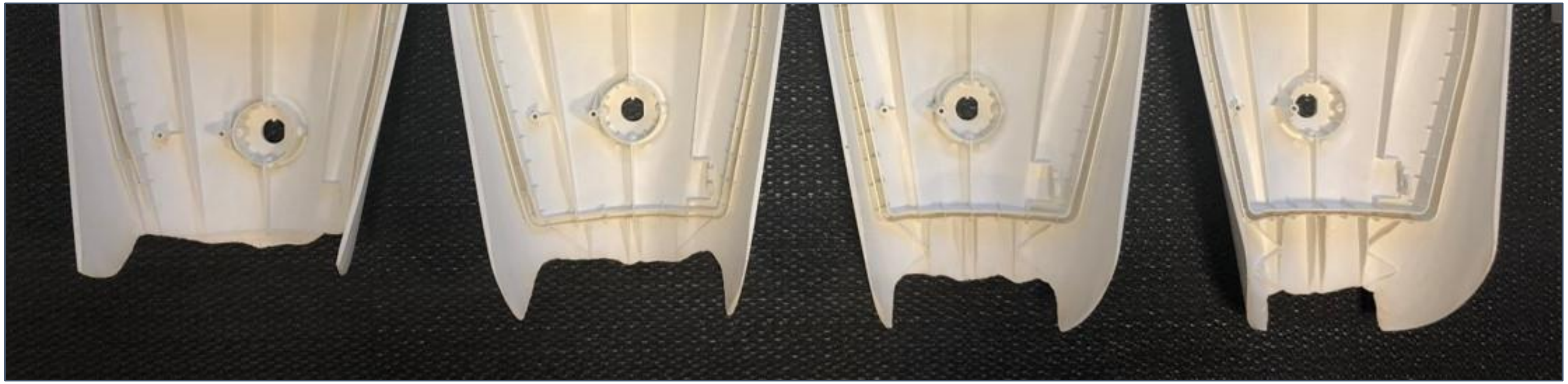




Problem solving: Aesthetic issue – Standard solver



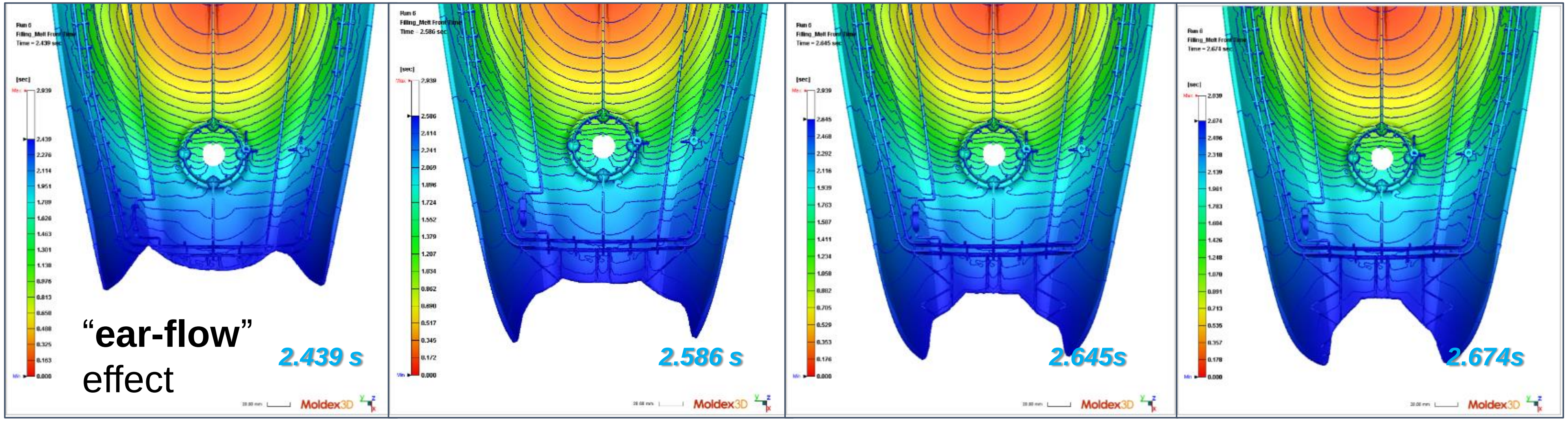


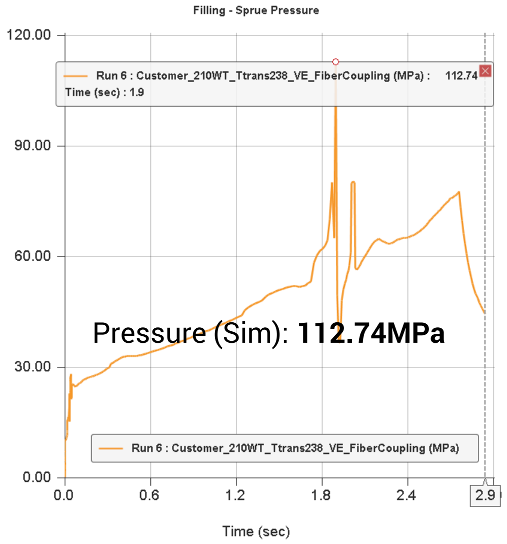


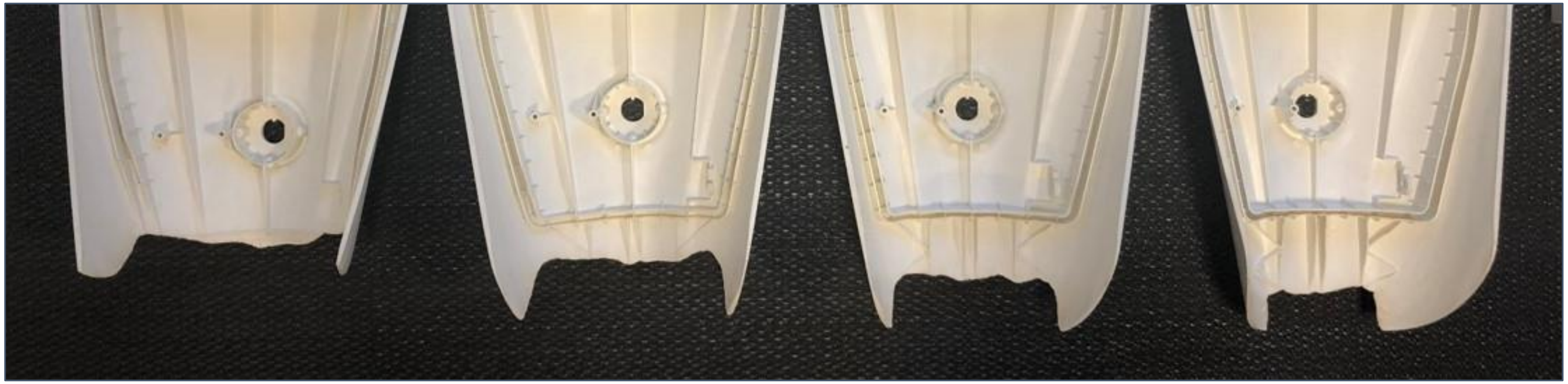
Max Pressure (Real): **120MPa**

Courtesy of ACERBIS SpA

Problem Solving: Aesthetic issue – VE + Fiber coupling







Max Pressure (Real): **120MPa**

Courtesy of ACERBIS SpA

Case history: Drain grate

Cast iron

RADILON S RV350W 333 BK

PA6 GF35, heat stabilized, black

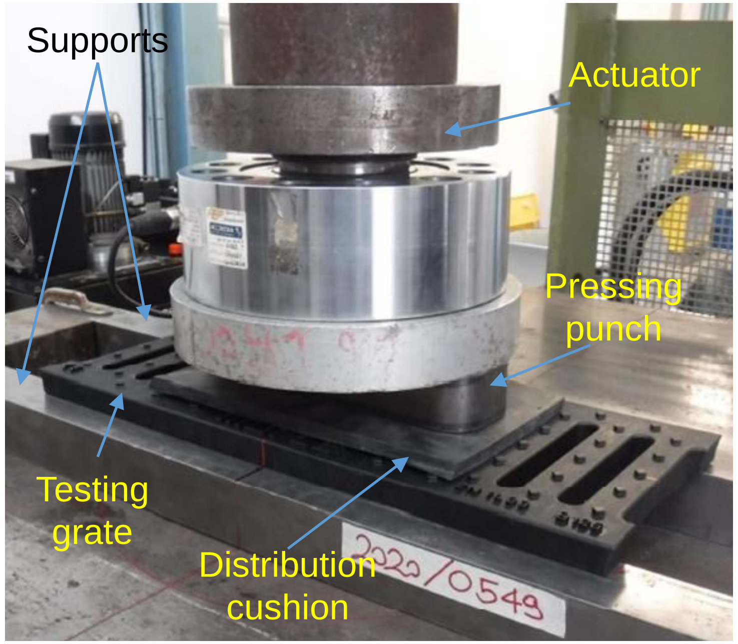
Courtesy of:

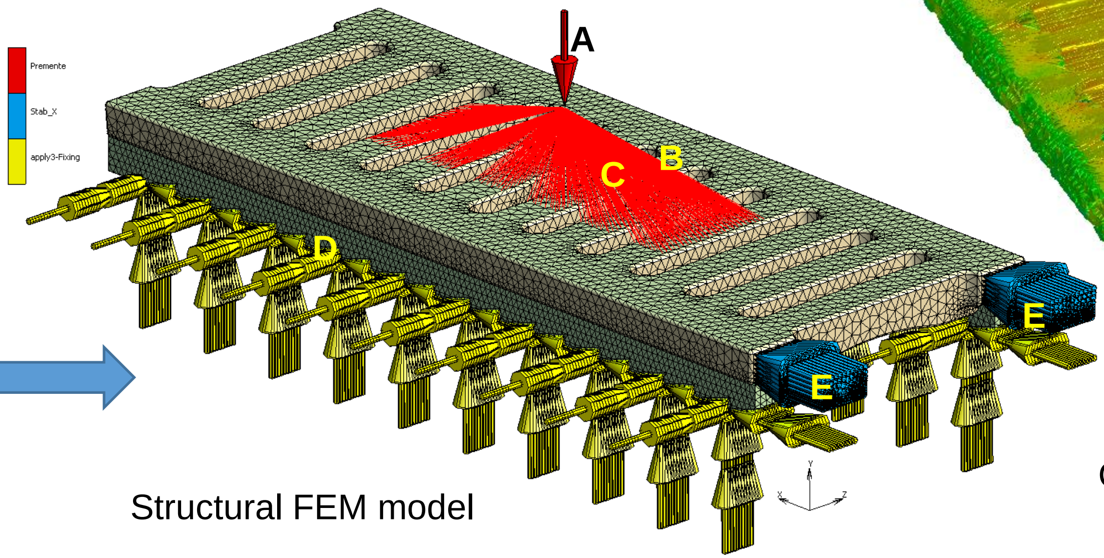
ACO

Replacement of a classic cast-iron grate by a grate made of **engineering thermoplastics** allows for:

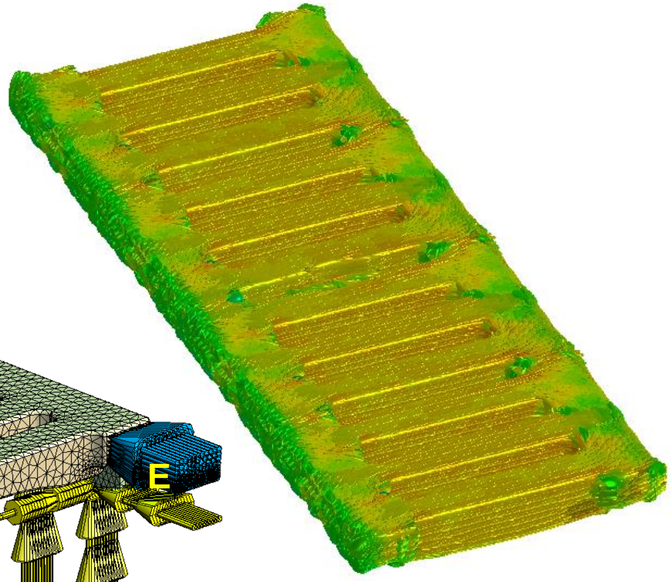
- ✓ **Weight saving of more than 60%**, with a significant reduction in logistics and transportation cost, CO_2 emissions…
- ✓ **Local EU supply**, with a shortened supply chain, reduced lead time and transportation risks
- ✓ No risk of **metal theft**
- ✓ Engineering polymers resist **corrosion**, also in challenging environments (e.g., sea salt)

Drain grate validation test: CAE simulation set-up



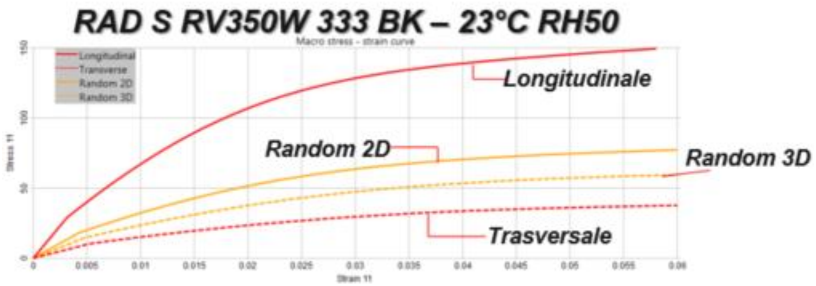


Structural FEM model


Glass-fibre distribution (from process simulation)

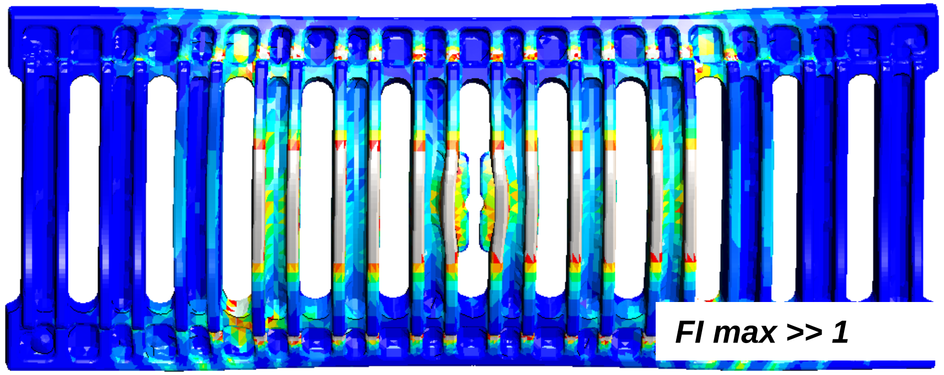
The component had to withstand a validation test with a bending force of up to **75 kN**.

We performed an **advanced, integrated structural simulation** in order to predict the performance with **RADILON** and suggest possible design improvements.

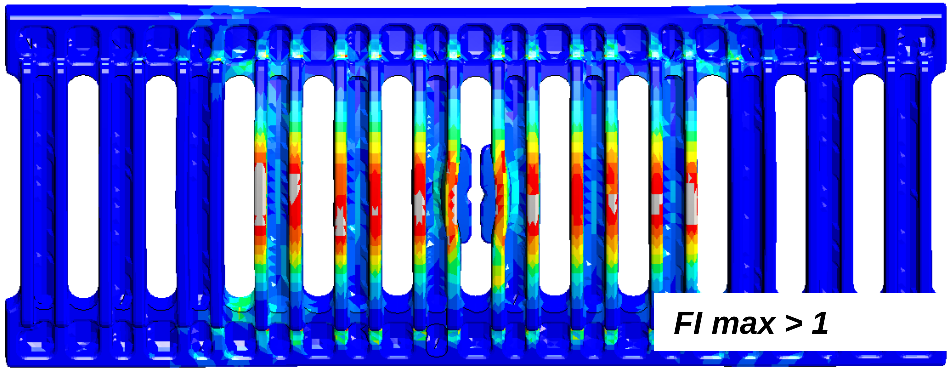


Drain grate validation test: Versions

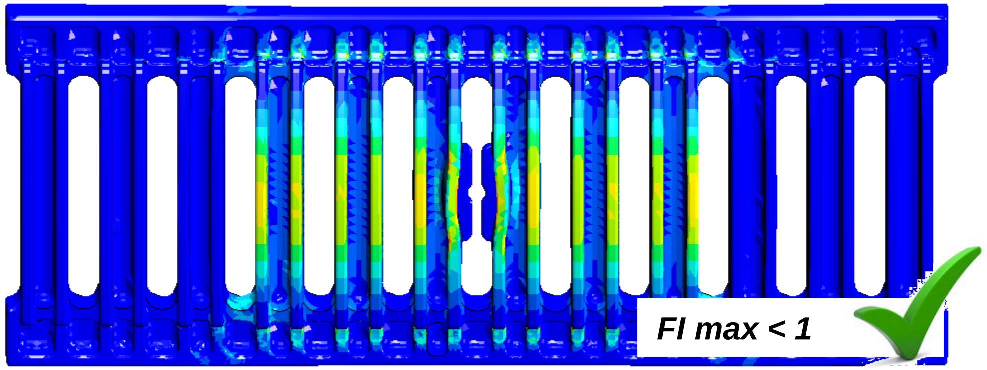
ORIGINAL DESIGN - @75 kN



FIRST REVISION - @75 kN



SECOND REVISION - @ 75 kN

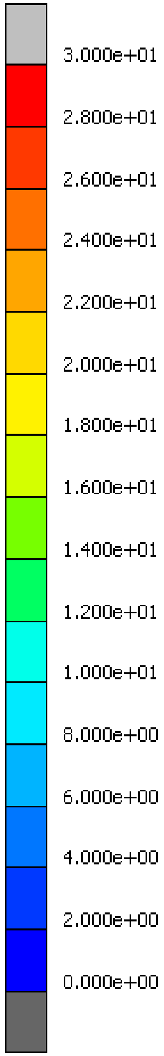


Failure indicator map

Above red -> FI >1

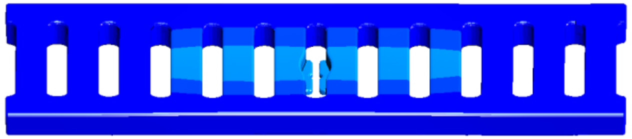
The part can be subjected to failure

Drain grate validation test: Versions

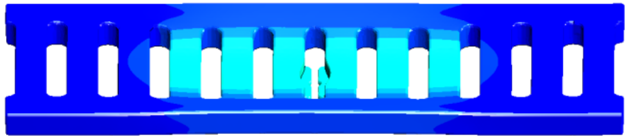


ORIGINAL DESIGN

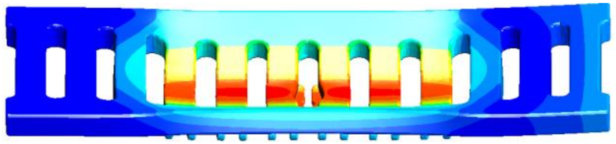
t = 0.45
Displ. Max = 5.1 mm



t = 0.7
Displ. Max = 11.9 mm

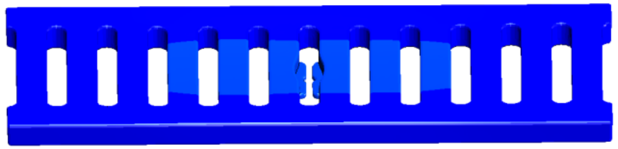


t = 1
Displ. Max = 29.3 mm

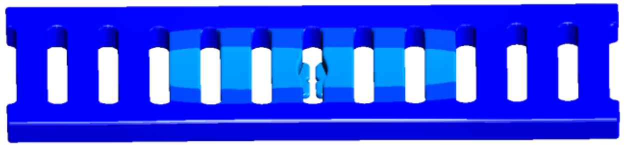


FIRST REVISION

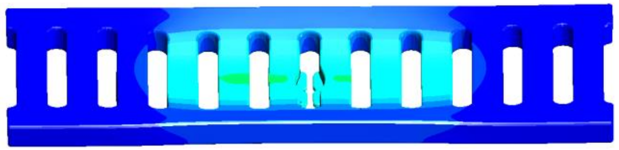
t = 0.45
Displ. Max = 5.1 mm



t = 0.7
Displ. Max = 7.1 mm

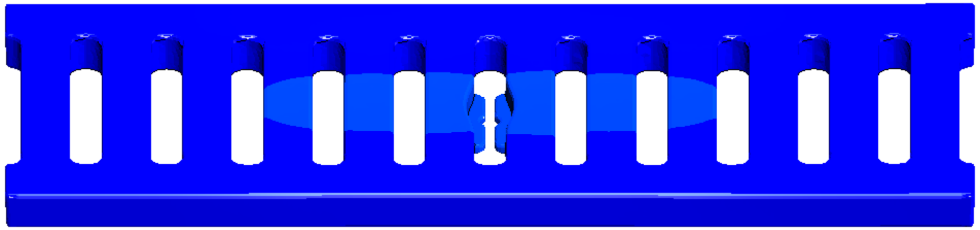


t = 1
Displ. Max = 12.3 mm

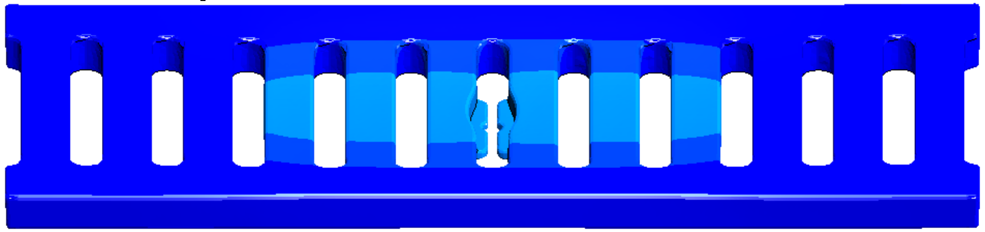


SECOND REVISION

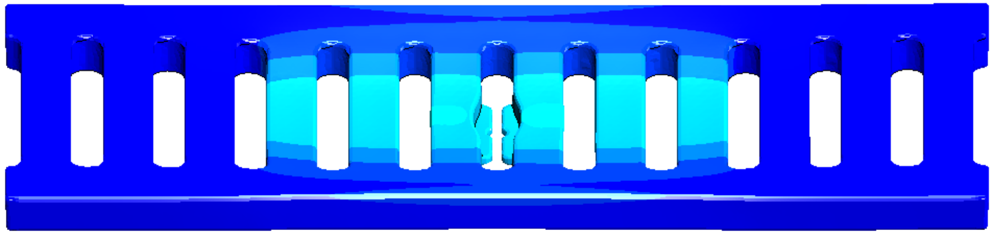
t = 0.45; ***Displ. Max = 2.5 mm***



t = 0.7; ***Displ. Max = 5.5 mm***

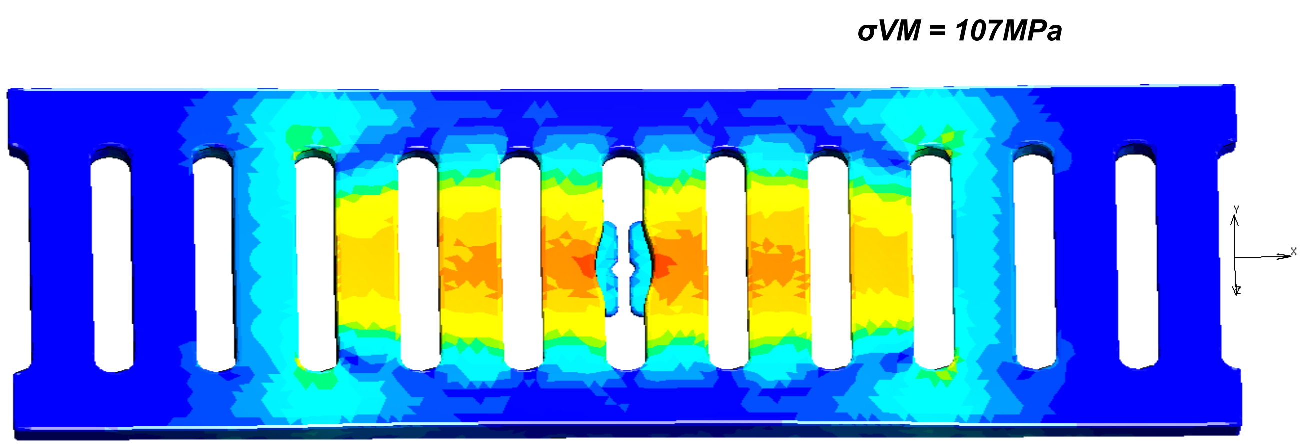


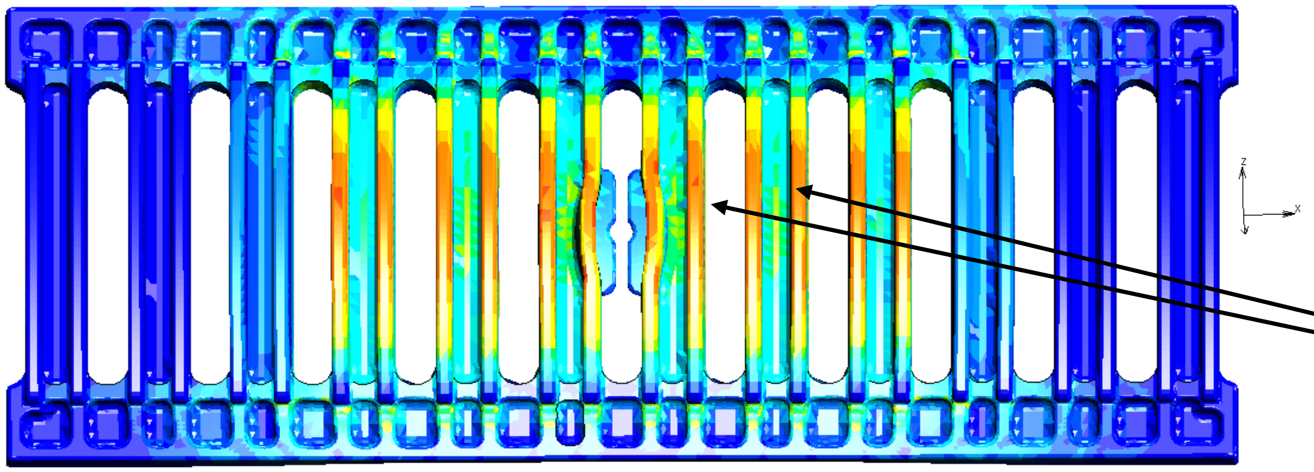
t = 1; ***Displ. Max = 8.5 mm***

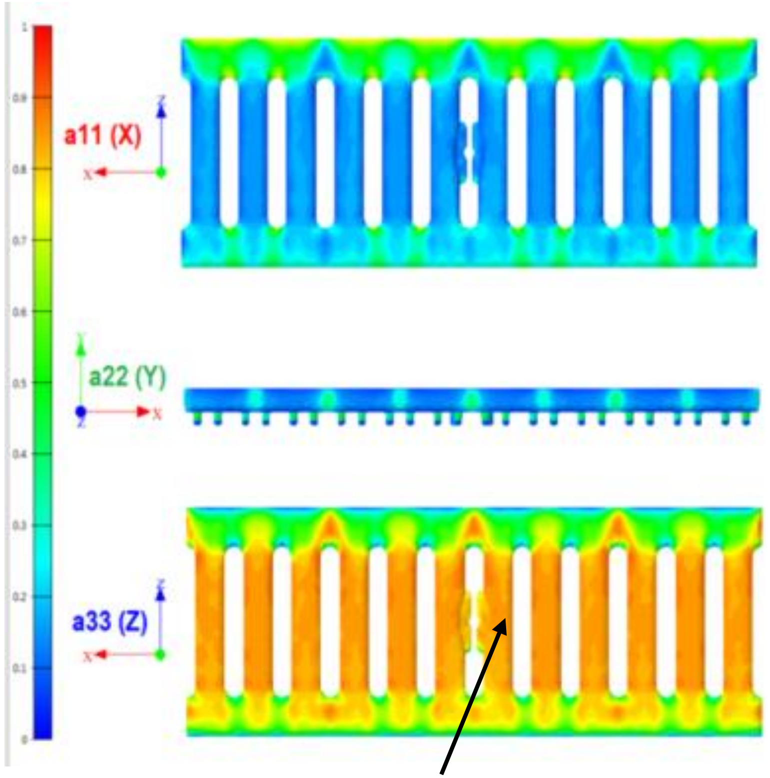


Drain grate validation test: GF orientation effect

SECOND REVISION







The regions and directions of maximum stress are compatible with a <u>favourable glass-fibre orientation</u> in injection moulding. This with equal VM stress brings the Failure Index into an acceptable range.

Conclusions and final remarks

- In today’s competitive scenario, being able to accurately **predict** the structural behaviour of items made of **technopolymer**, starting from the earliest phases of **design**, is essential for timely and successful projects.
- **Metal replacement** and **lightweighting** are challenges that require careful and in-depth design work in order to be effective.
- An **advanced approach to CAE**, which combines a deep understanding of **material** science, accurate know-how in **technology** and a faithful representation of working **structure**, is the key to achieve such precision.
- Through close collaboration with its customers, **RadiciGroup High Performance Polymers** is able to provide state-of-the-art support and expertise to reach demanding targets in performance-driven projects.

Disclaimer notice

The information provided in this documentation, including results coming from CAE analysis, material properties measured on standard specimens, third-party and literature data and any kind of scientific and technical advice explicitly or implicitly adduced, is supplied in good faith and according to our knowledge at the date of its publication.

Although every reasonable effort is made to ensure the maximum meaningfulness and adherence to reality of the calculations, the method unavoidably involves the use of approximations at many levels, including material properties, model geometry, actual operating conditions, physical laws governing the behaviour of the system, and the nature itself of the F.E.M. mathematical method. Because of all this, results obtained in a computer-aided analysis can differ from actual results observable in reality, even to a significant extent.

Therefore, the data provided must be taken as indications and do not constitute legally binding statements or specification limits. They must not be used alone as the basis of design and are not at all substitutive of tests on real prototype parts. They are rather to be considered as guidelines which help in planning and conducting the experimentation in a more effective way.

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Q&A