Softell grade for interiors: CAE validation for a Jaguar Land Rover project using *Digimat*

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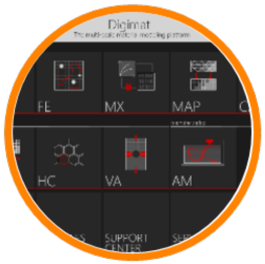
H.Skhiri - e_Xstream Engineering

Material meets Engineering Conference 2019

e-Xstream Engineering

e-Xstream



Digimat

The material & process modeling platform

MaterialCenter

Material Lifecycle Management Platform

MSC Software

Software for Virtual Validation & Optimization of Engineering Designs

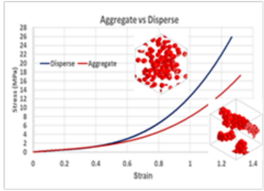
Hexagon

Digital Solutions Smartly Connecting the Physical & Digital Worlds

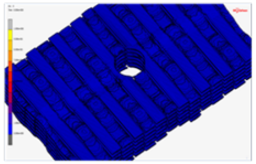
e-Xstream Engineering

10x MATERIALS SOLUTION

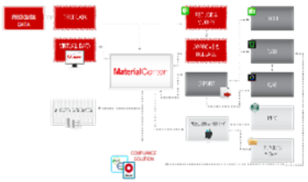
1 Virtual Material Development



2 Virtual Material Testing

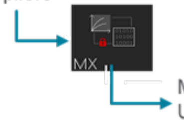


3 Materials Lifecycle Management



4 Material eXchange

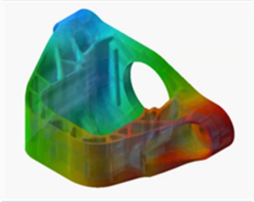
Material Suppliers



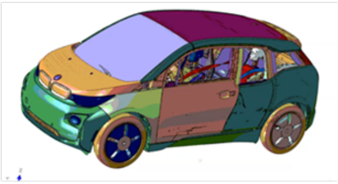
Material Users

5 Compliance & Sustainability

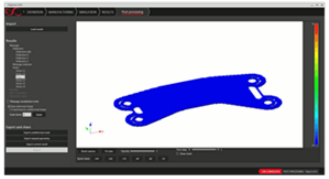
6 Effect of Processing



7 Accurate Material Modelling



8 (Additive) Manufacturing

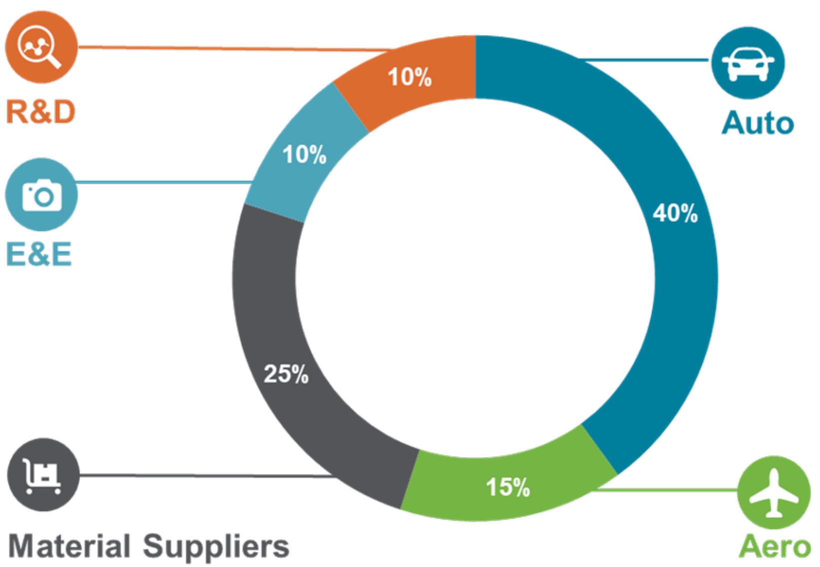


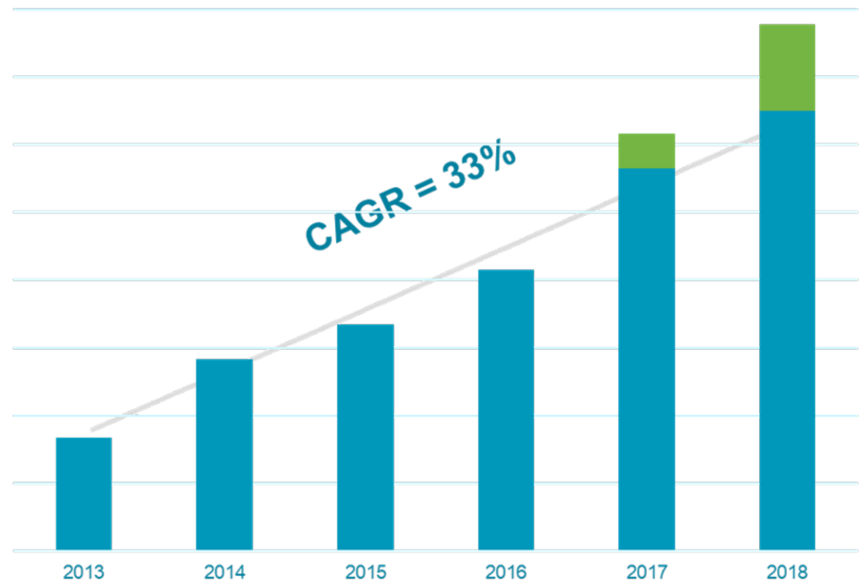
9 Material Intelligence(AI)

10 Digital Continuity & (Material)Twin

e-Xstream : 15 Years of Double Digit Growth!

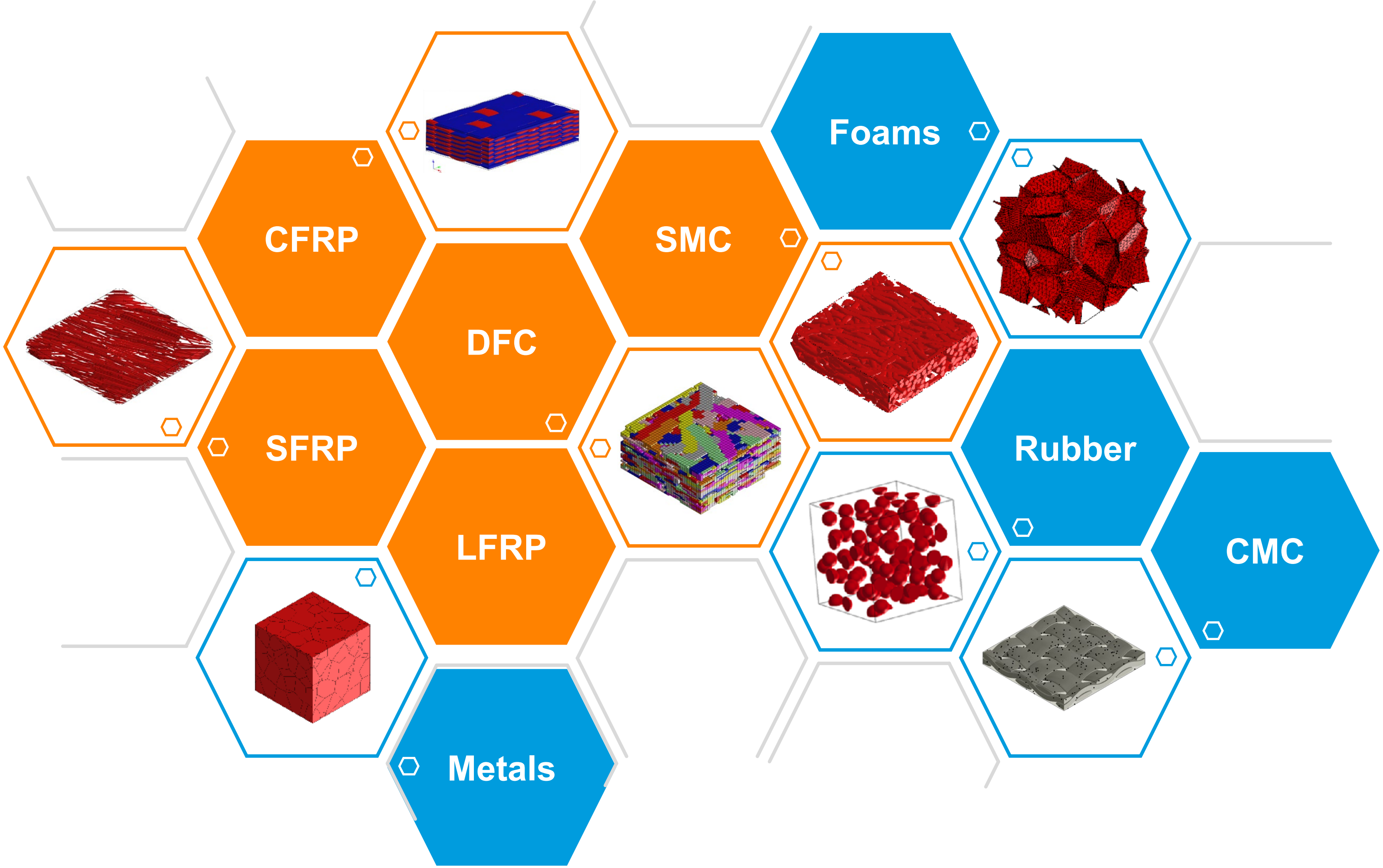
500+ Customers, 3x Revenues growth in the last 5 years



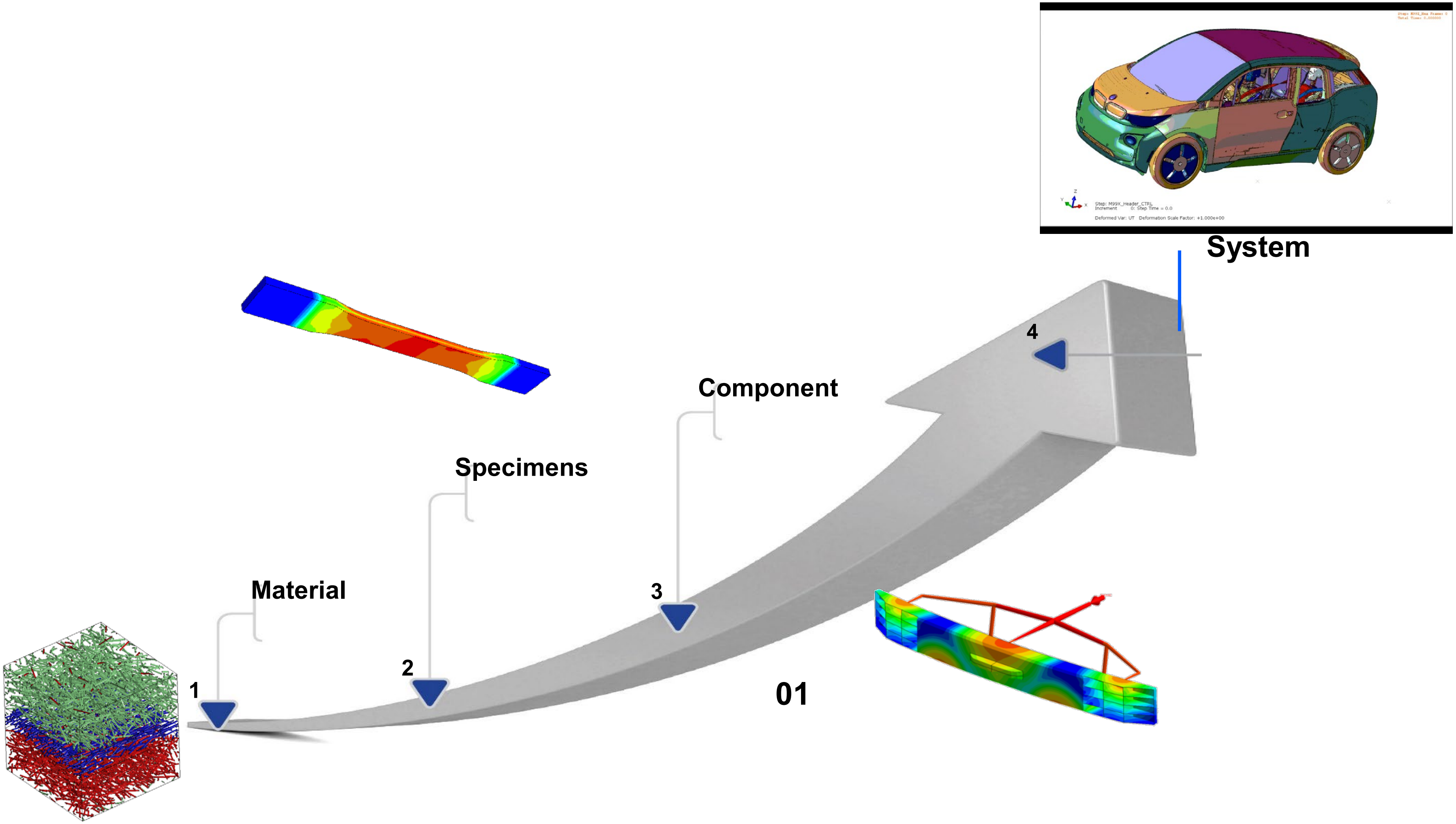


e-Xstream : Accurate, Robust, Fast & Easy Modeling of Material

Accelerated Investments in Addition Material Systems…

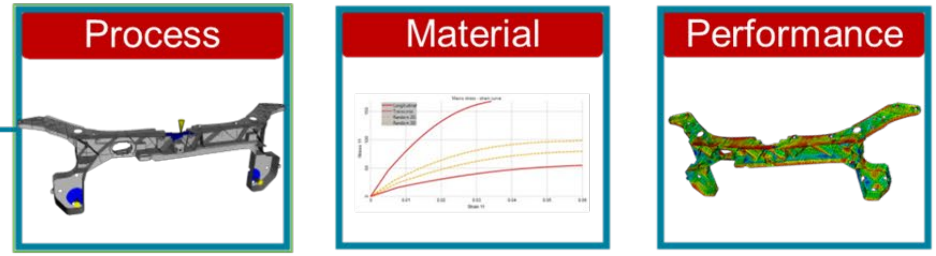


From the material system to the full system



e-Xstream : Material Simulation to Reach Industry Requirements

Bridging the gap between disciplines & scales for faster/cheaper part development



- Select the right material for the right application
- Technical support for design, process optimization and CAE validation
- Shorten development time & reduce cost

Advanced Material Database &Simulation Workflow

Softell material- Goes to amazing extremes so tough yet so soft

- **Innovative Material in a wide range of automotive & non-automotive applications.**
  - High quality product performances
  - Soft Touch
  - Reduced system complexity
  - Lower system cost
  - Support of green objectives

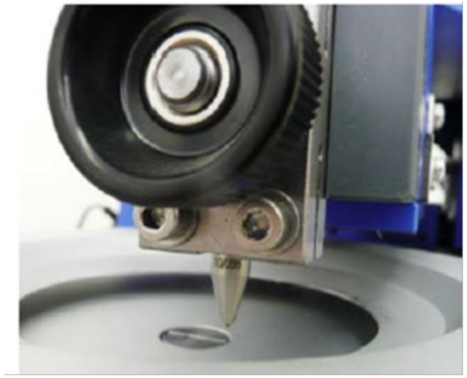
Source: LyondellBasell

Why *Softell* compounds?

- **Tough, yet so soft!**
  - High quality finished part surfaces with soft touch and matt surface without painting
  - Excellent scratch resistance and surface robustness
  - Ductility at low temperature
  - Good noise dampening properties
  - Support “green objectives“ PP component concept allowing easy recycling

Source: LyondellBasell

Soft Touch

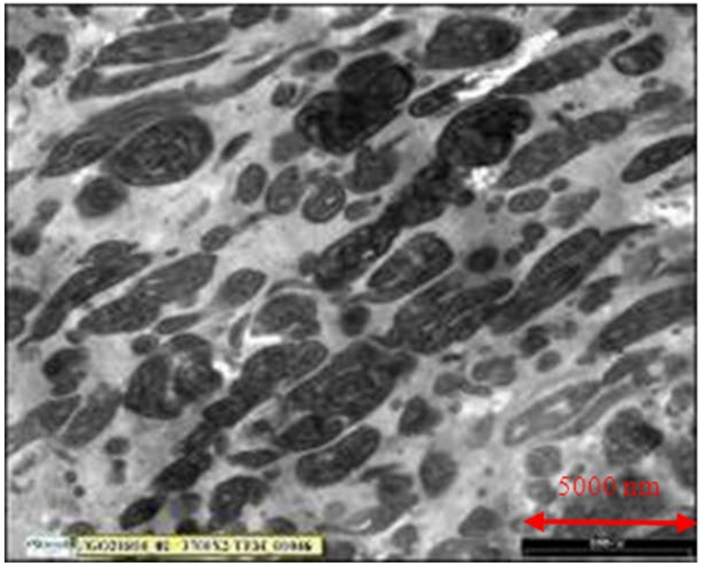


Source: LyondellBasell

Scratch Resistance

What is *Softell* material?

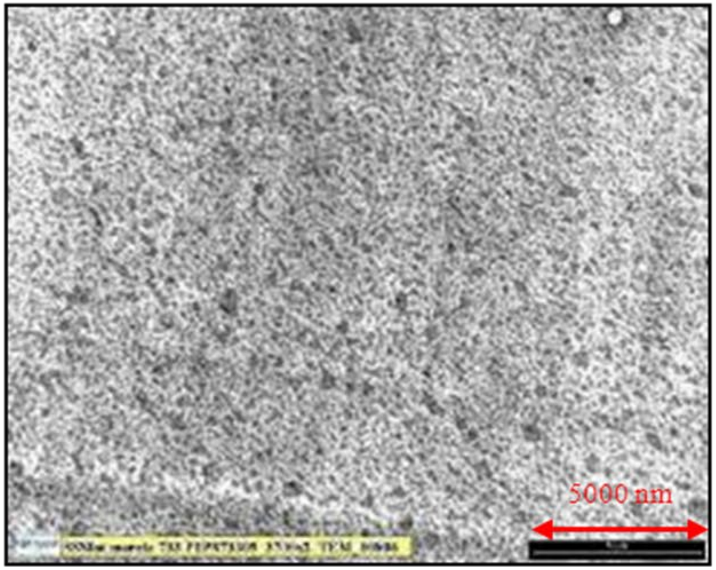
Physical blend of PP & Rubber



Source: LyondellBasell

Compounding process

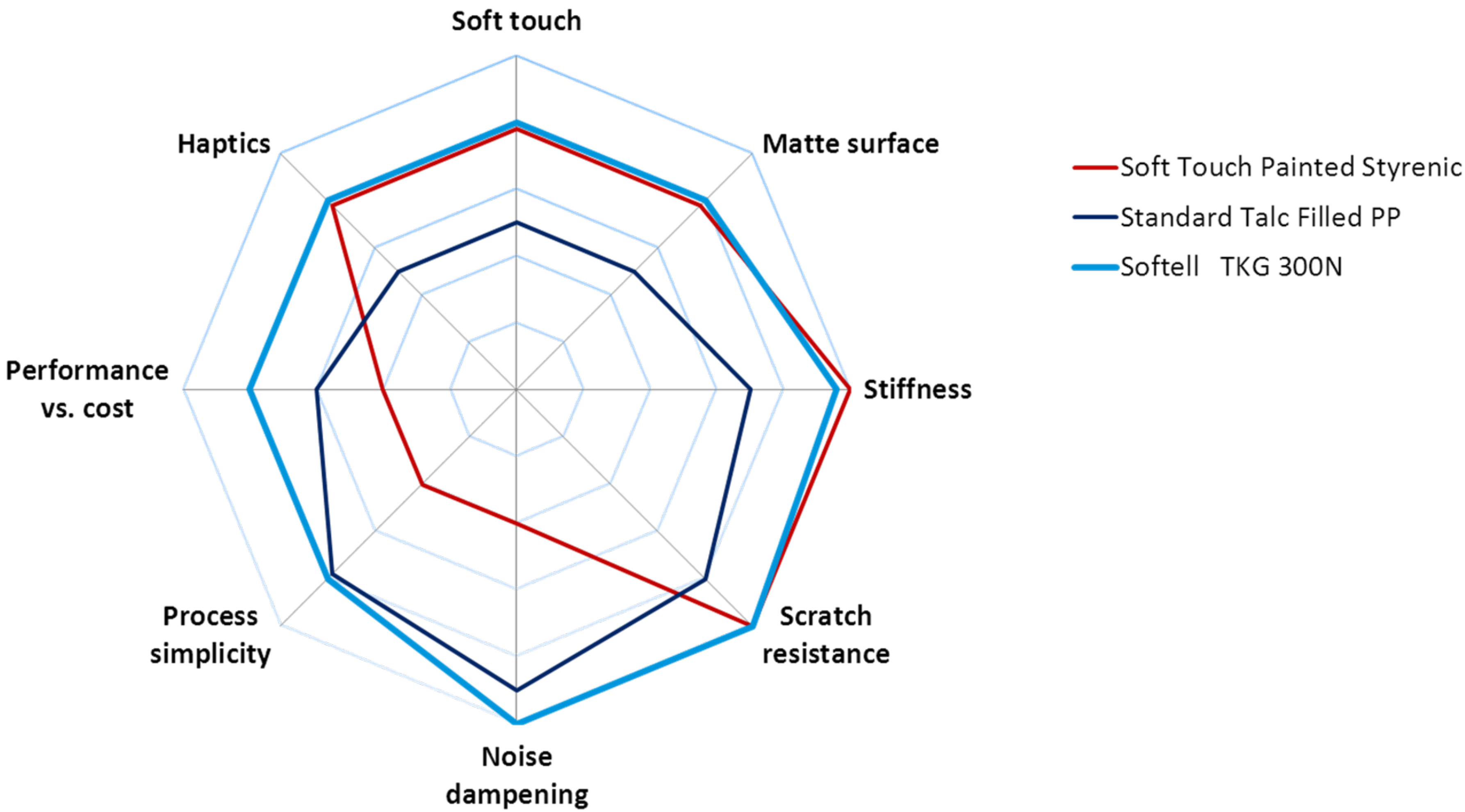
Softell by *Catalloy* process



Source: LyondellBasell

Catalloy polymerization process

Customer value of *Softell* resin blend



LyondellBasell AND Jaguar Land Rover

Metallic Materials at Jaguar Land Rover

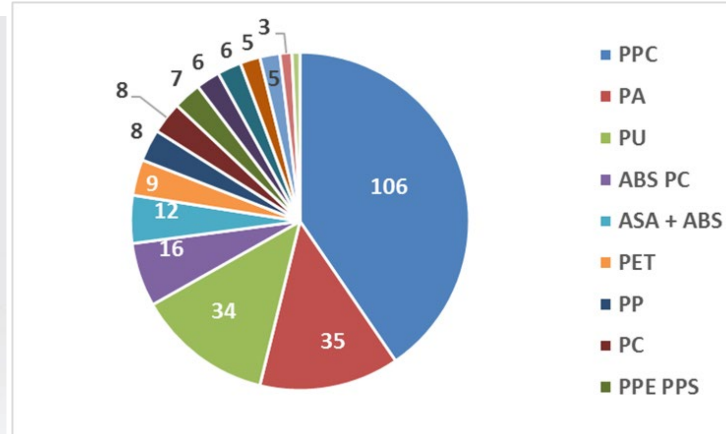
A combination of LyondellBasell Bumper materials in dark techno silver and light silver for the Range Rover Evoque

Source: Jaguar Land Rover

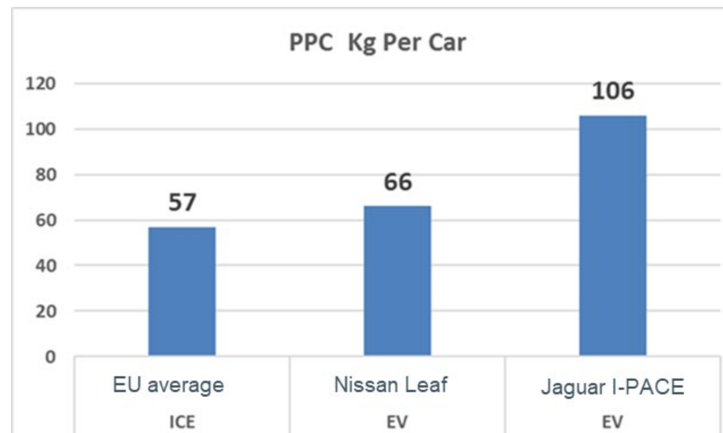
Future New Application Areas for Electric Vehicles

Source: Jaguar Land Rover

Jaguar I –PACE Bonnet Scoop



Source: A2MAC1



Source: A2MAC1

- **The Jaguar I-PACE is using 106 Kgs of PP Compounds**

Softell material at Jaguar Land Rover

Source: Jaguar Land Rover

Source: Jaguar Land Rover

***Softell* TKG 300N now used for many interior applications to replace PC/ABS for glove box doors and seat backs**

Example: Jaguar XE

Source: Jaguar Land Rover

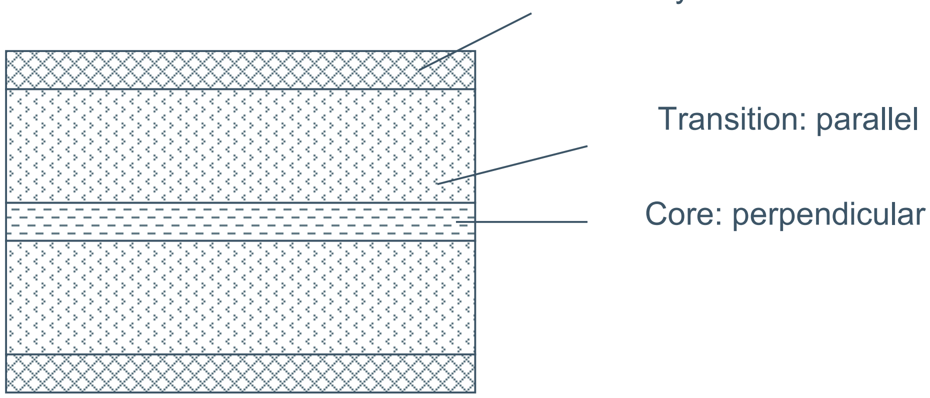
LyondellBasell AND e_Xstream

Process induced Anisotropy

Typical ratio of longitudinal vs. transverse properties of PP-based materials measured on an injection molded 3 mm thick plaque:

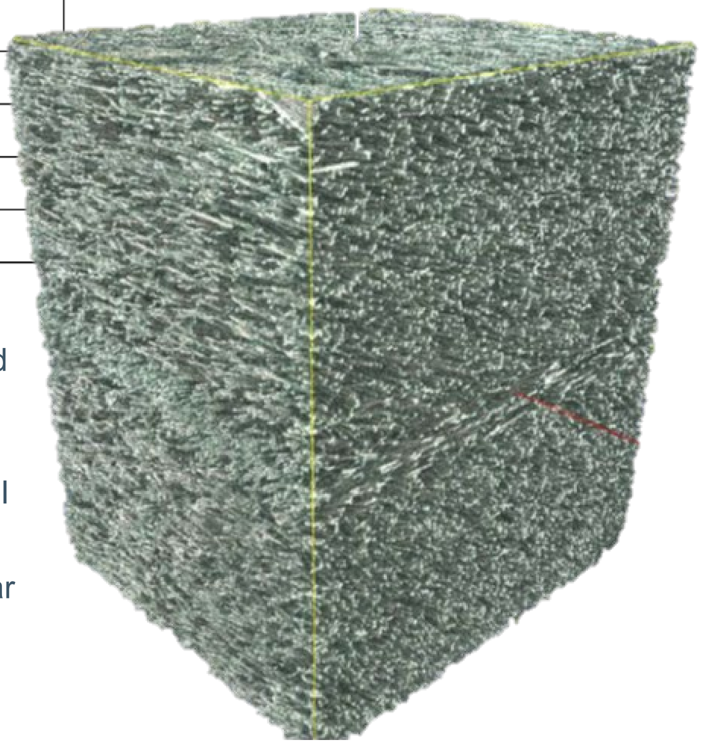
Material type	*Transv/Long Moduli ratio*	**Transv/Long Max stress ratio**
40% SGF-PP homopolymer	0.5	0.56
30% SGF-PP homopolymer	0.63	0.67
10% SGF-PP homopolymer	0.86	0.82
25% SGF-PP Soft PP	0.57	0.68
Impact modified PP/Talc	0.81	0.83
Unfilled PP copolymer	0.93	0.93

Anisotropy is affected by:
- Filler/ reinforcement type
- Filler/ reinforcement amount
- Process parameters



Here: flow lines perpendicular to the sheet

Source: LyondellBasell



Source: LyondellBasell

Process induced Anisotropy

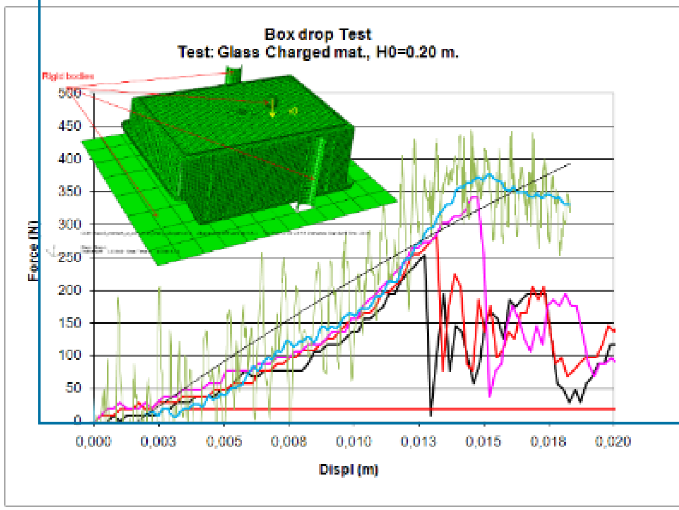
Two main approaches currently available with F.E. analysis

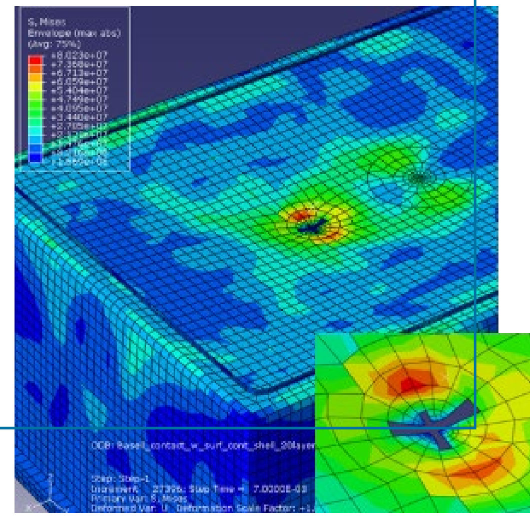
	Micro-mechanical modeling (e.g. e-Xstream Digimat©)	Simplified anisotropic (internal LyondellBasell development)
Material Law	Dedicated, based on Mean field homogenization theories (Digimat by e-Xstream, coupled with most FE codes)	Orthotropic / anisotropic (e.g. Abaqus orthotropic, Ls-dyna MAT_157)
Input from Process Simulation (e.g. Moldflow)	Fiber orientation	Fiber Orientation/ Flow direction
Experimental data	Tensile test in two or more directions	Tensile test in two or more directions

The choice of the approach depends on the specific problem to be studied and on the "boundaries," such as resources, requested accuracy and timing.

Digimat has all the features needed for this project and was therefore chosen.

LyondellBasell and *Digimat*: brief history (1 of 2)





Source: LyondellBasell

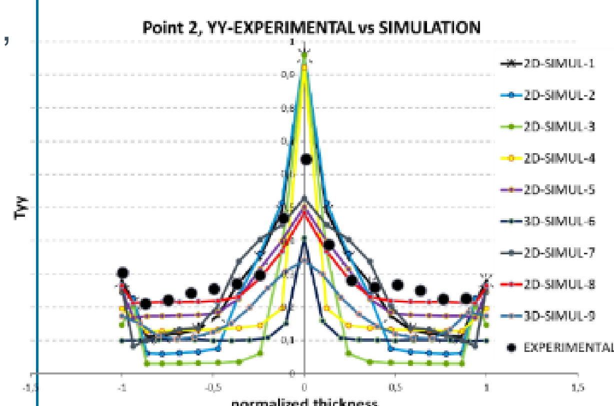
2009: *Digimat* test by e_Xstream on the «Nutini» box (Basell Validation tool)

C.Garcia, M.Nutini, "Fiber Orientation Prediction for Reliable Simulations of Glass-reinforced, Polypropylene-based Components Using DIGIMAT", Digimat Users Meeting, Luxembourg, October 2010

M.Nutini, "An assessment of fiber orientation in GF-PP compounds by assembling the information from testing, mold filling simulation and Digimat-MF through optimization methods", " Digimat Users Meeting, Munich, October 2011

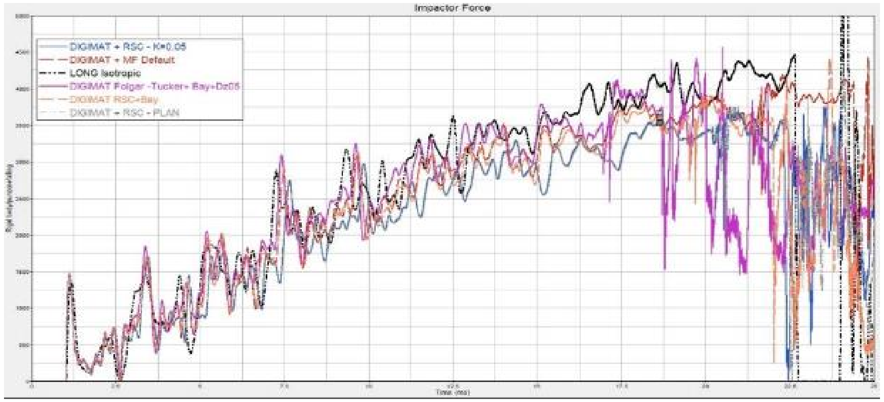
C.Ferrari, C.Garcia, M.Nutini, "Assessment of Fiber Orientation in Injection-Molded SGF-PP items", Connect! Moldflow Users Meeting 2011, Frankfurt, May 2012

2010/2012: Basell validation studies



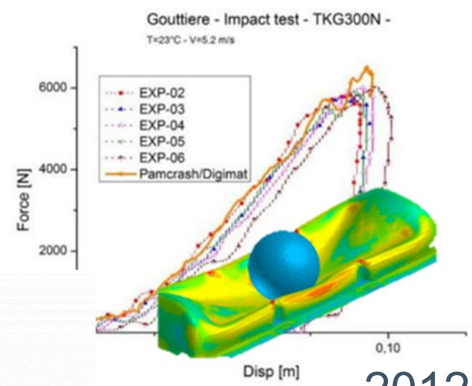
Source: LyondellBasell

LyondellBasell and *Digimat*: brief history *(2 of 2)*



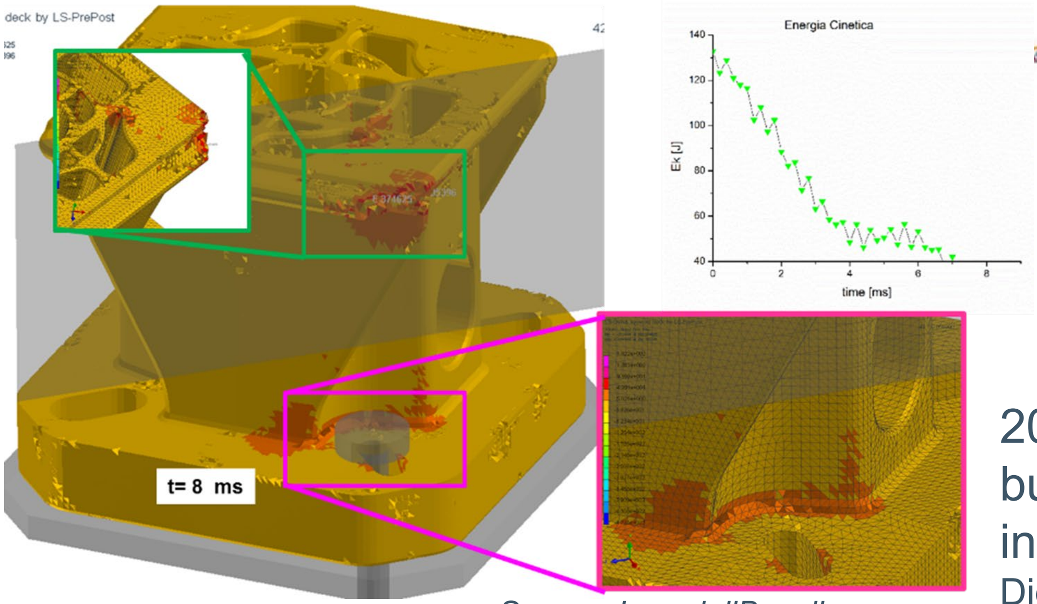
Source: LyondellBasell

2012-2014: Support in the project of a lower bumper stiffener
(Activity with Opel, Materials Meet Engineering, 2012)



Source: LyondellBasell

2012: Support in the project of a door panel
(Activity with Renault, Materials Meet Engineering, 2012)



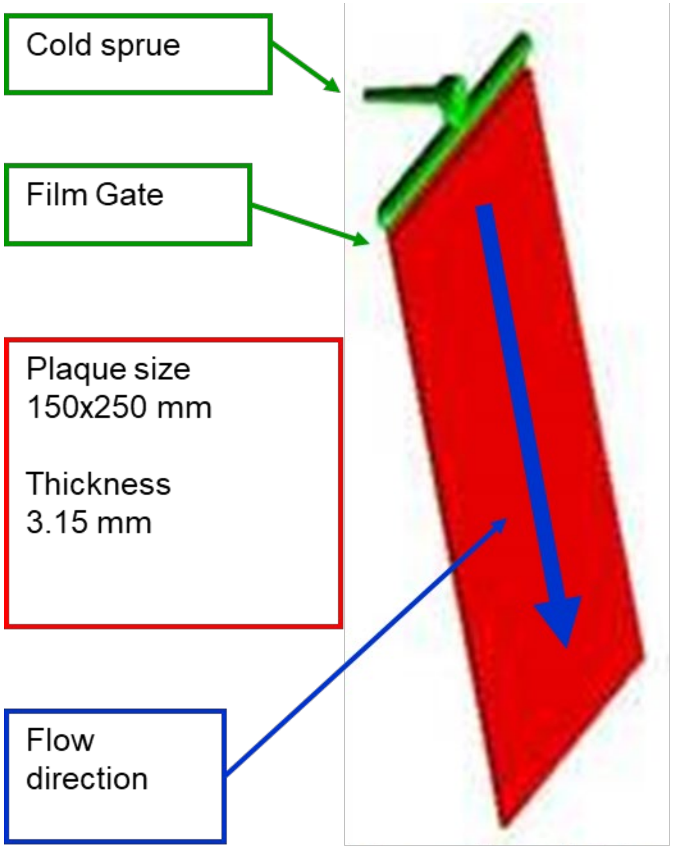
Source: LyondellBasell

2018: Design of a part for building and construction industry (Activity with Polytech, Digimat Tech. Day, 2018)

Modelling *Softell* material for Impact Simulation

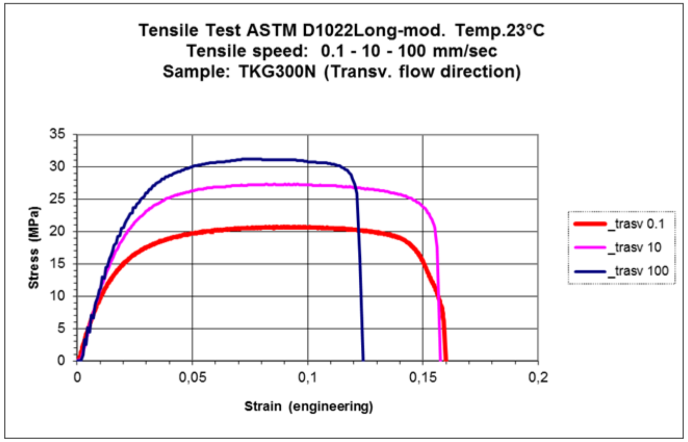
Softell material*:* Experimental data

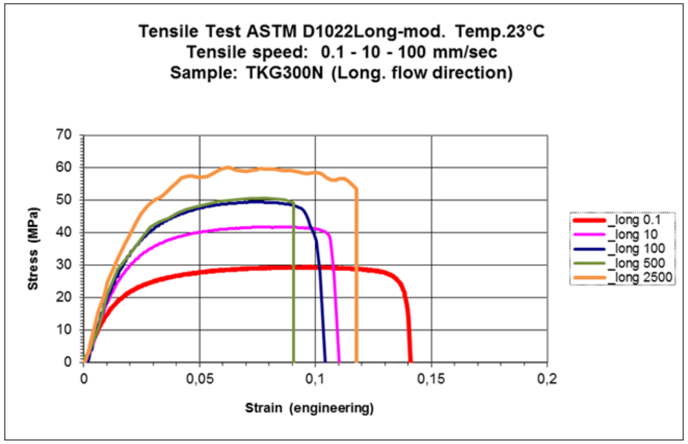
- **LyondellBasell testing method for GF-PP: mechanical properties are better measured on specimens cut from injection-molded plaques.**
  - The material orientation in the plaque is similar to the one existing in the real components, while in injection molded specimens the orientation is emphasize
  - It is possible to cut specimens along any desired direction with respect to injection flow. Here specimens cut at 0° and 90° with respect to the flow direction in the mold have been used



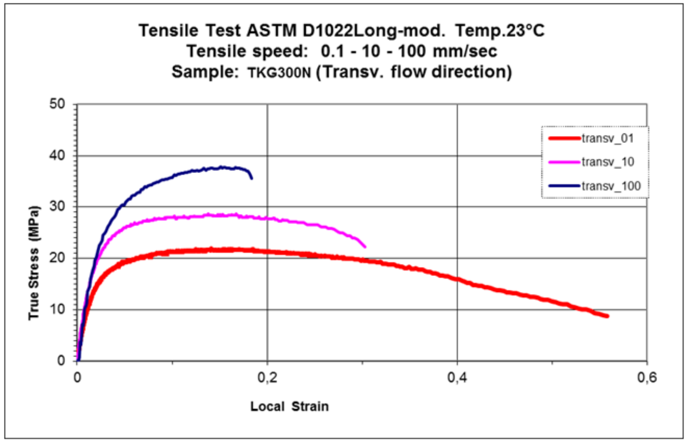
Source: LyondellBasell

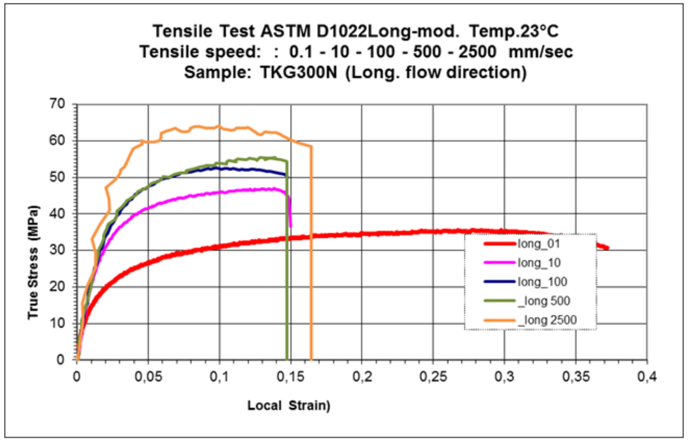
Softell material*:* Experimental data





Engineering curves



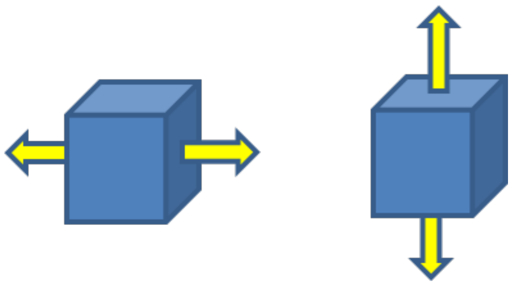


Curves from Local strain measurement

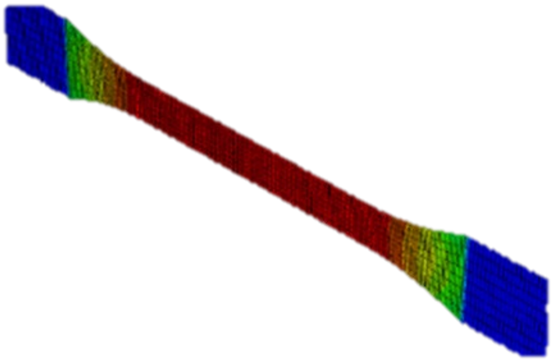
Source: LyondellBasell

Building up a *Digimat* material card

- **Determination of Elastic Parameters**
  - Based on average fiber orientation
  - Pure uniaxial loading
  - Determination of elastic parameters
  - First Guess of Plasticity-related parameters



- **Tensile test validation: tuning of plasticity parameters**
  - Based on distributed fiber orientation
  - Not-pure uniaxial loading (striction and volume change)
  - Tuning of Plasticity-related parameters
  - Introduction and validation of a failure criterion



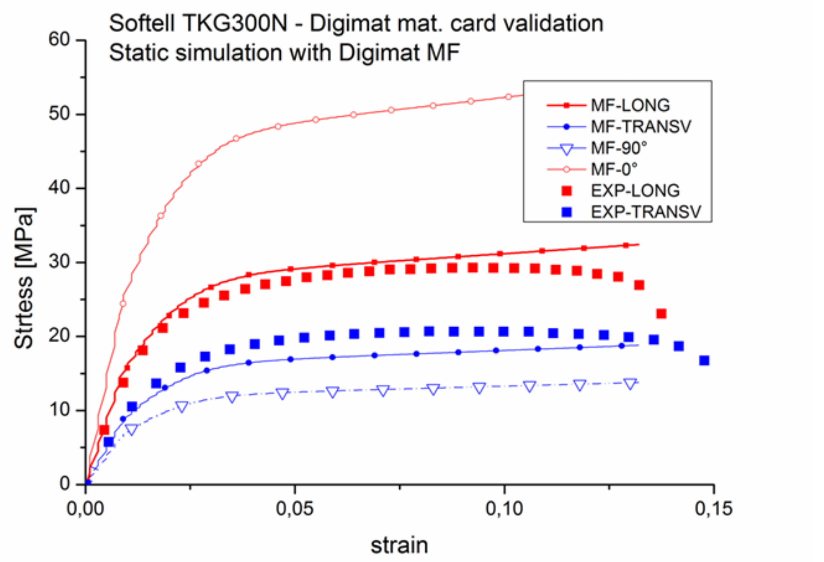
Source: LyondellBasell

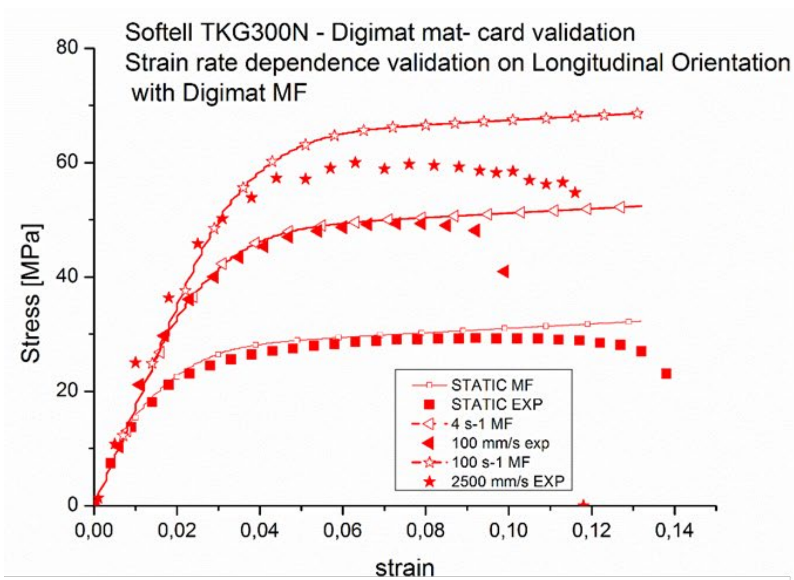
Exponential and linear law,

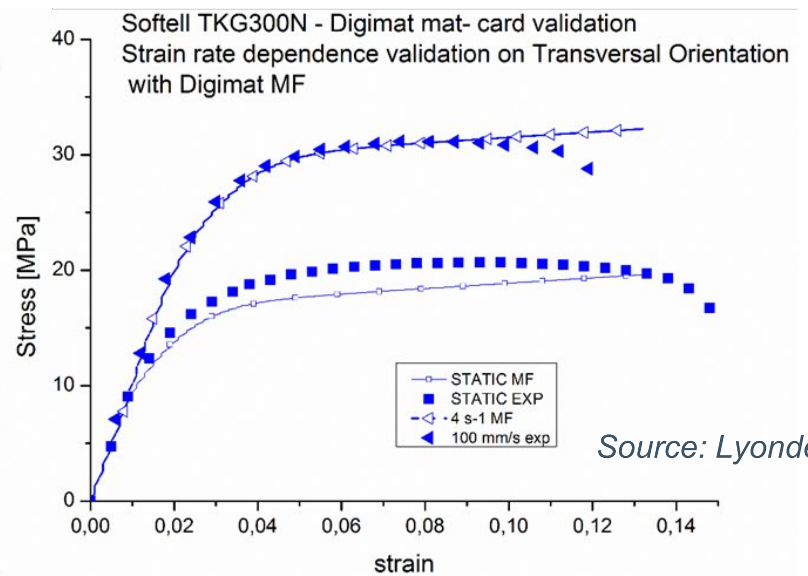
$R(p) = kp + R_1[1 - \exp(-mp)].$

Material card preparation and validation on the tensile test

- **STATIC**
  - Identification of the parameters for static behavior modelling, including extreme /untested orientations, via *Digimat* MF and then FEM simulation
- **DYNAMIC**
  - Identification of the parameters for dynamic behavior modelling, via *Digimat* MF







Source: LyondellBasell

Introducing a failure criterion

- **Preferred choice: Tsai-Wu interactive criterion**
  - Anisotropic
  - Compression/tension sensitive
  - Interactive
  - Strain/rate dependent

Tsai_Wu 3D, stress-based

Failure indicator:

f_A is such that $\mathcal{F}_A(\boldsymbol{\sigma}/f) = 1$, with

$$\mathcal{F}_A(\boldsymbol{\sigma}) = \frac{\sigma_{11}^2}{X_t X_c} + \frac{\sigma_{22}^2+\sigma_{33}^2}{Y_t Y_c} + \frac{\sigma_{12}^2+\sigma_{13}^2}{S^2} + \frac{4\sigma_{23}^2}{Y_t Y_c} - \frac{\sigma_{11}\sigma_{22}+\sigma_{11}\sigma_{33}}{2X_t X_c} - \frac{2\sigma_{22}\sigma_{33}}{Y_t Y_c} + (\frac{1}{X_t} - \frac{1}{X_c})\sigma_{11} + (\frac{1}{Y_t} - \frac{1}{Y_c})(\sigma_{22}+\sigma_{33})$$

Tsai_Wu 3D, strain-based

Failure indicator:

f_A is such that $\mathcal{F}_A(\epsilon/f) = 1$, with

$$\mathcal{F}_A(\epsilon) = \frac{\epsilon_{11}^2}{X_t X_c} + \frac{\epsilon_{22}^2+\epsilon_{33}^2}{Y_t Y_c} + \frac{(2\epsilon_{12})^2+(2\epsilon_{13})^2}{S^2} + \frac{(2\epsilon_{23})^2}{Y_t Y_c} - \frac{\epsilon_{11}\epsilon_{22}+\epsilon_{11}\epsilon_{33}}{2X_t X_c} - \frac{2\epsilon_{22}\epsilon_{33}}{Y_t Y_c} + (\frac{1}{X_t} - \frac{1}{X_c})\epsilon_{11} + (\frac{1}{Y_t} - \frac{1}{Y_c})(\epsilon_{22}+\epsilon_{33})$$

when the normal to the plane of isotropy corresponds to axis 1,

$$\Lambda(\dot{\varepsilon}) = \Lambda_0 \left[1 + \left(\log \frac{\dot{\varepsilon}}{\dot{\varepsilon}_{\text{ref}}}\right)^{1/p}\right],$$

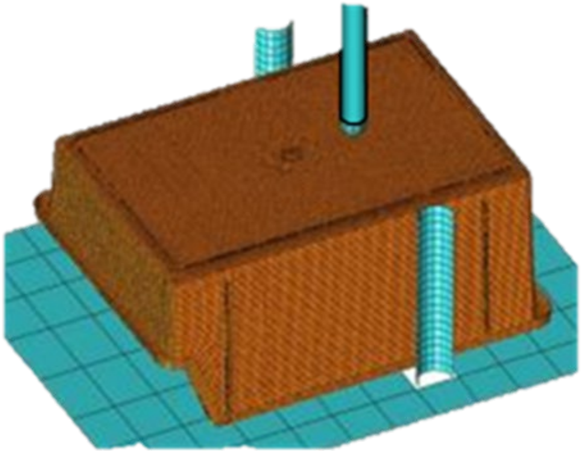
The material elongations at break are the parameters to be tuned and validated

lyondellbasell
Advancing Possible

1st Validation: LyondellBasell test case

1st validation: LyondellBasell test case

- "Dart Test: Test on LyondellBasell Box
  - Drop test
  - Several parameters used.
  - "Test1" (in the graph) is the test chosen
  - Impactor Mass: 5.186 Kg
  - Impactor diameter 20 mm
  - Falling height: 0.6 m
  - Force vs. displacement recorded



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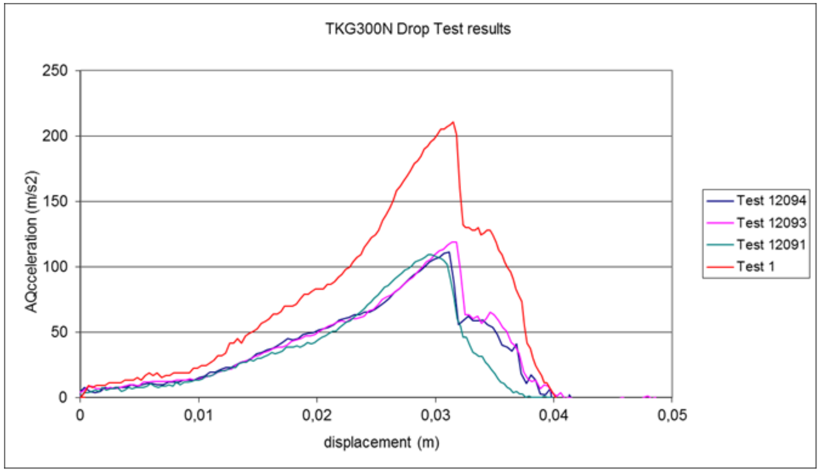
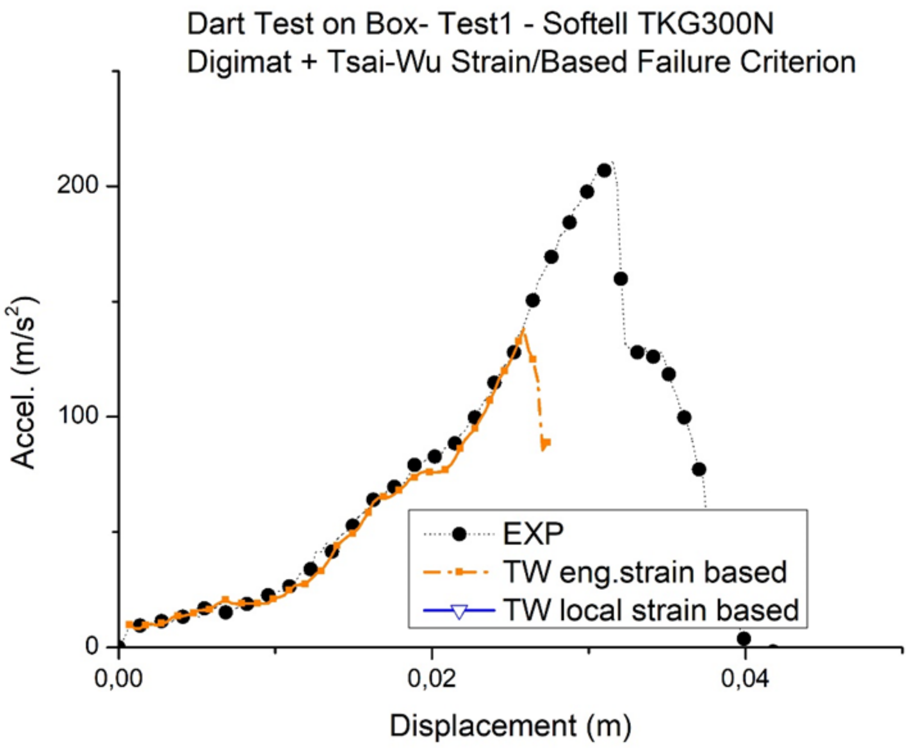


Source: LyondellBasell

1st validation: LyondellBasell test case

■ Results

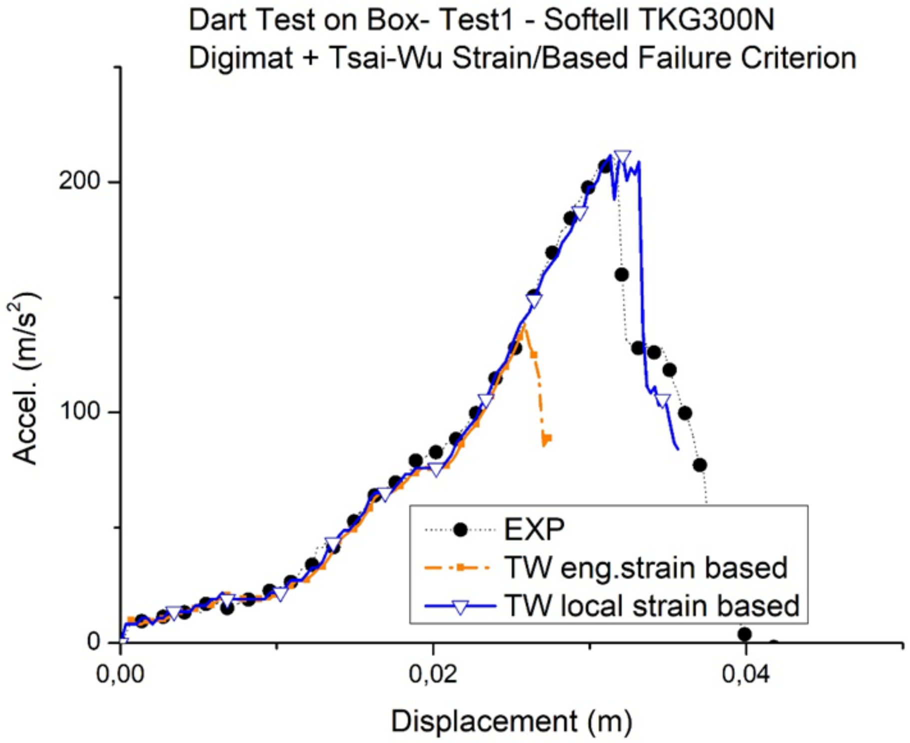
- Good reproduction of the Force vs. Displacement: elasticity, plasticity and viscoplasticity parameters in the Material Card are OK
- Premature rupture onset with the Tsai-Wu strain-based failure criterion built on the engineering strains
- Fracture propagation strongly influenced by the mesh; unrealistic fracture surfaces are obtained



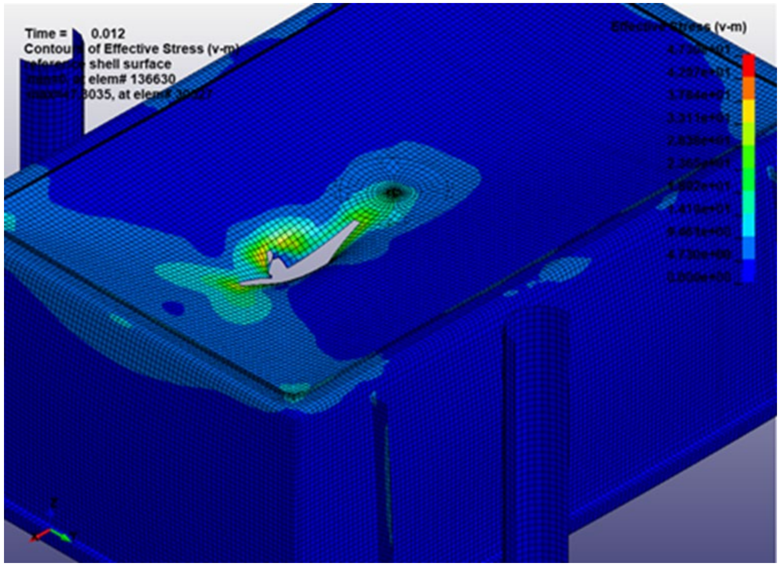
Source: LyondellBasell

1st validation: LyondellBasell test case

- **Modification: Tsai Wu based on LOCAL strain**
  - The introduction of local strains definitely improves the prediction of the onset of failure
  - Still unrealistic fracture surfaces are obtained



Source: LyondellBasell



Source: LyondellBasell

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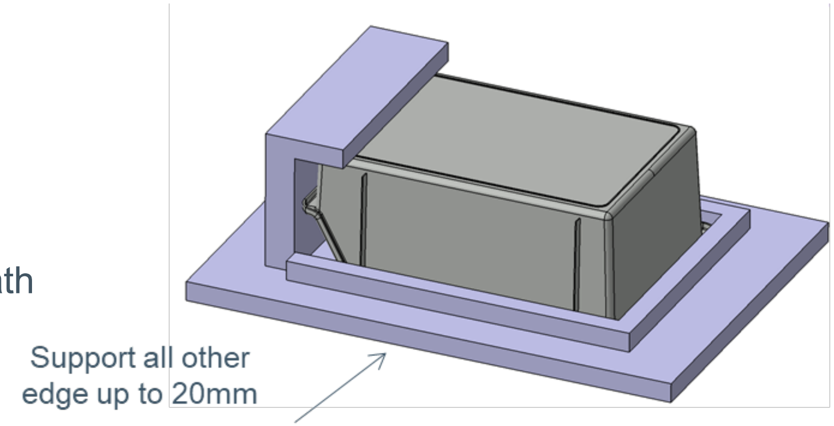
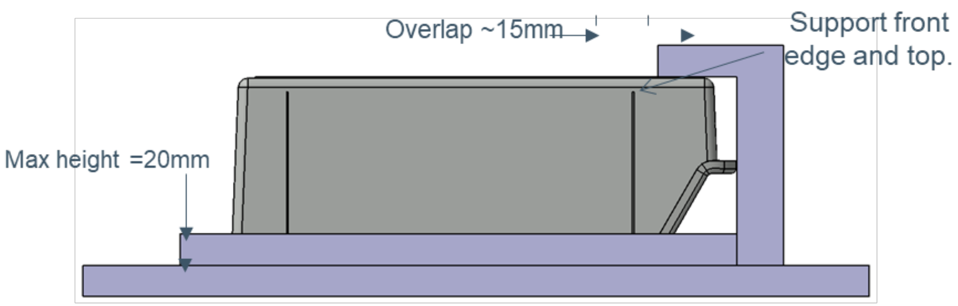
Advancing Possible

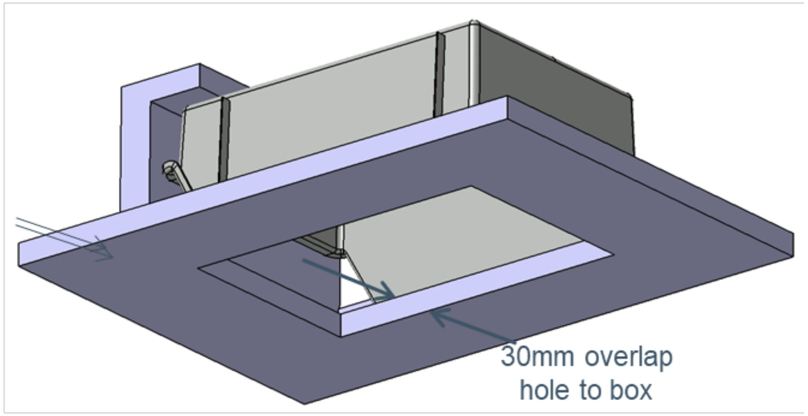
2nd Validation: Jaguar Land Rover test case

Jaguar Land Rover test case: layout

- During some of the impacts the front edge of the box will have a tendency to lift. To reduce variability of the results all edge will be constrained in the following configuration.
- If possible the rig will contain a hole underneath to capture deformation pattern will optical measurement cameras.

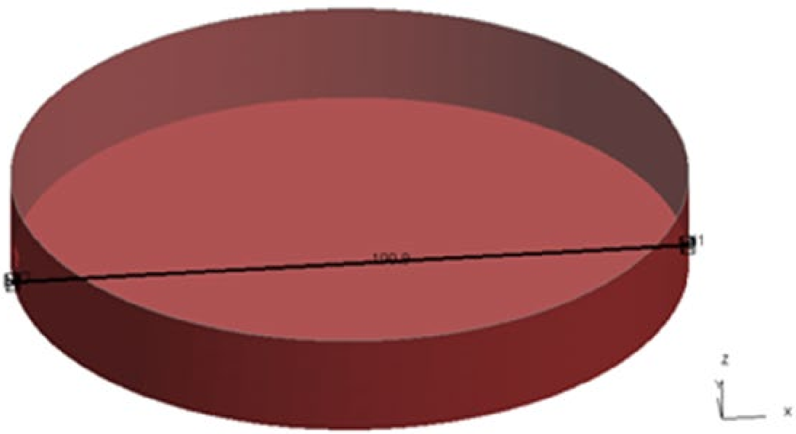
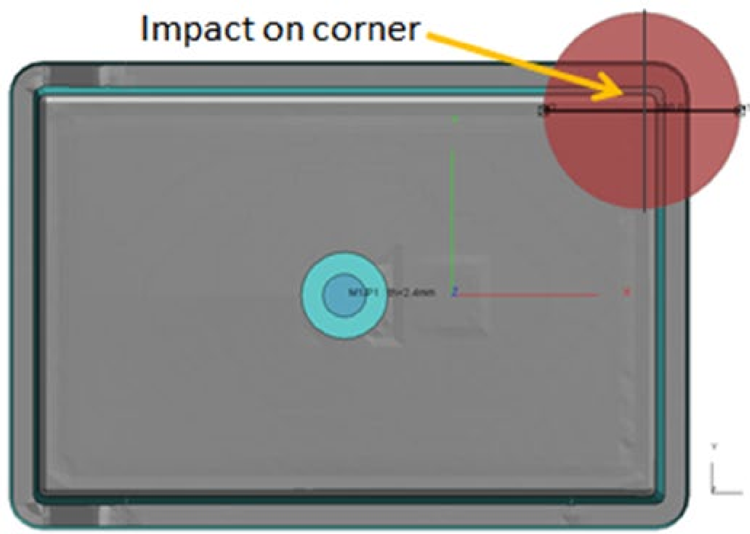






Source: Jaguar Land Rover

Jaguar Land Rover test case: layout

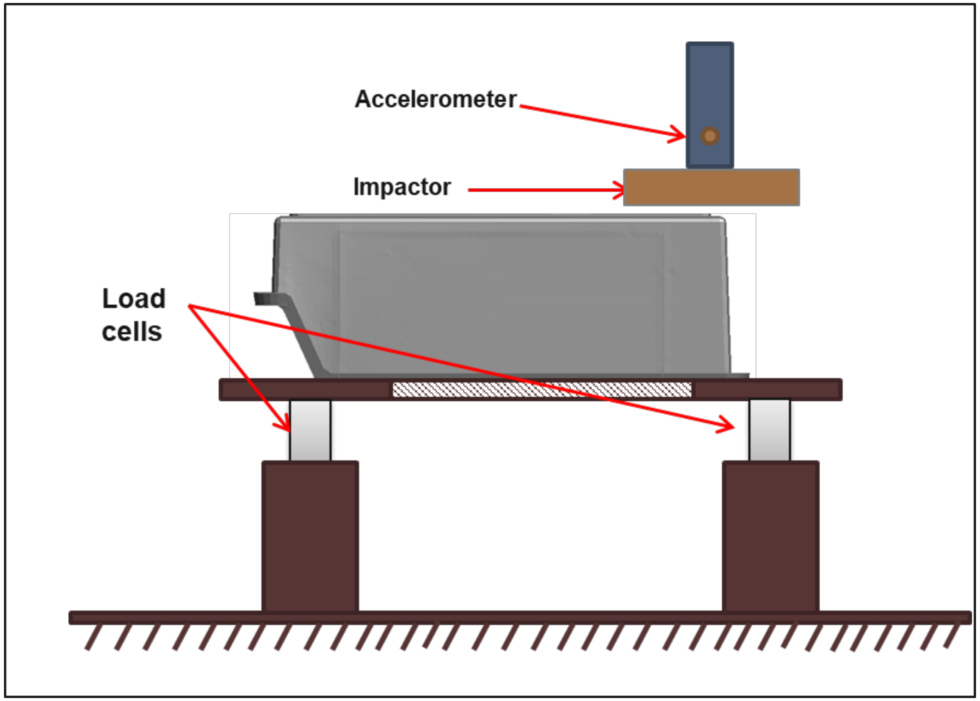
Impactor Type	Location
Flat Disk Impact and Quasi Static Test – Box Corner Crush	
~100mm flat disk impactor 	

Source: Jaguar Land Rover

Jaguar Land Rover test case: layout

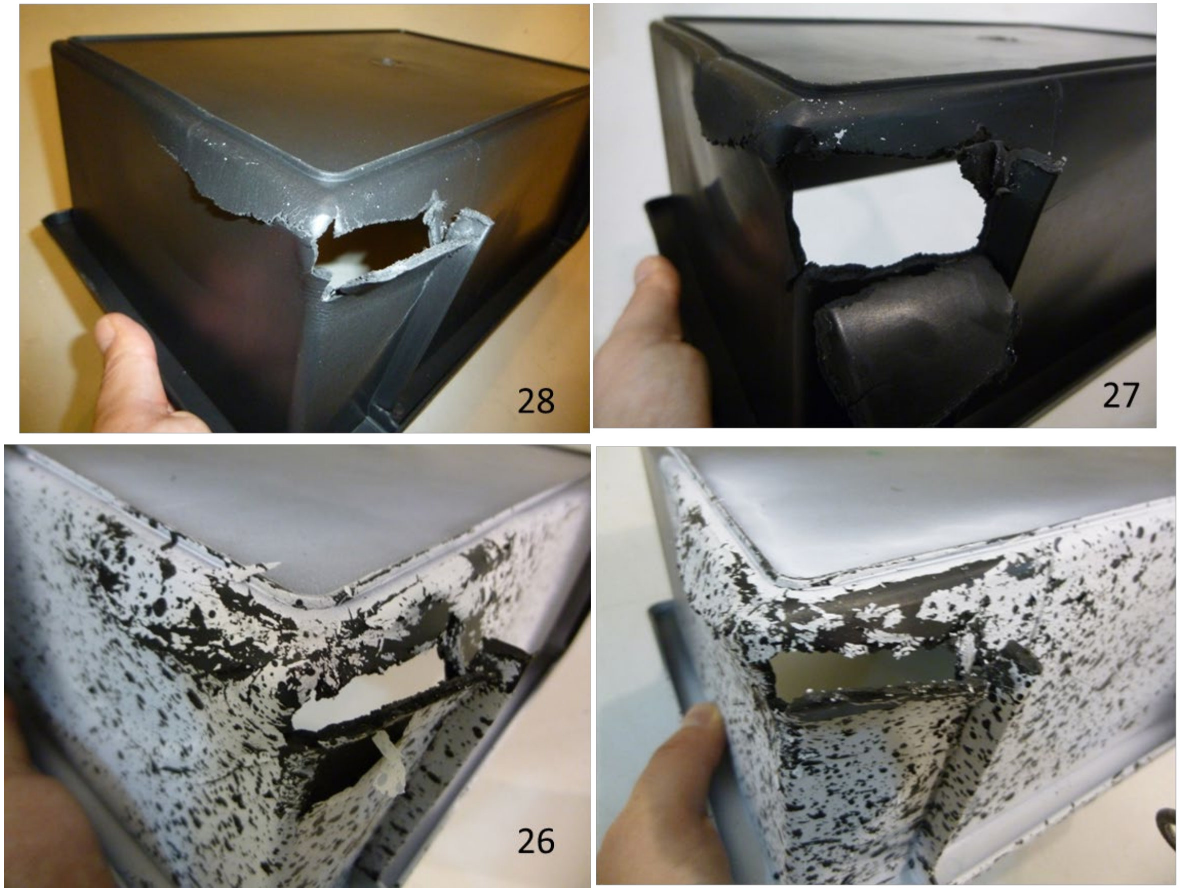
Drop test

- Drop rig total mass = ~10kg
- Drop Energy = ~150J
- Impact Velocity = 5.5m/s
- Equivalent Drop Height = 1500mm
- Impact Acceleration Recorded
- Loadcell under fixture or on impactor
- Displacement laser
- Optical Measurement cameras



Source: Jaguar Land Rover

Jaguar Land Rover test case: results



Source: Jaguar Land Rover

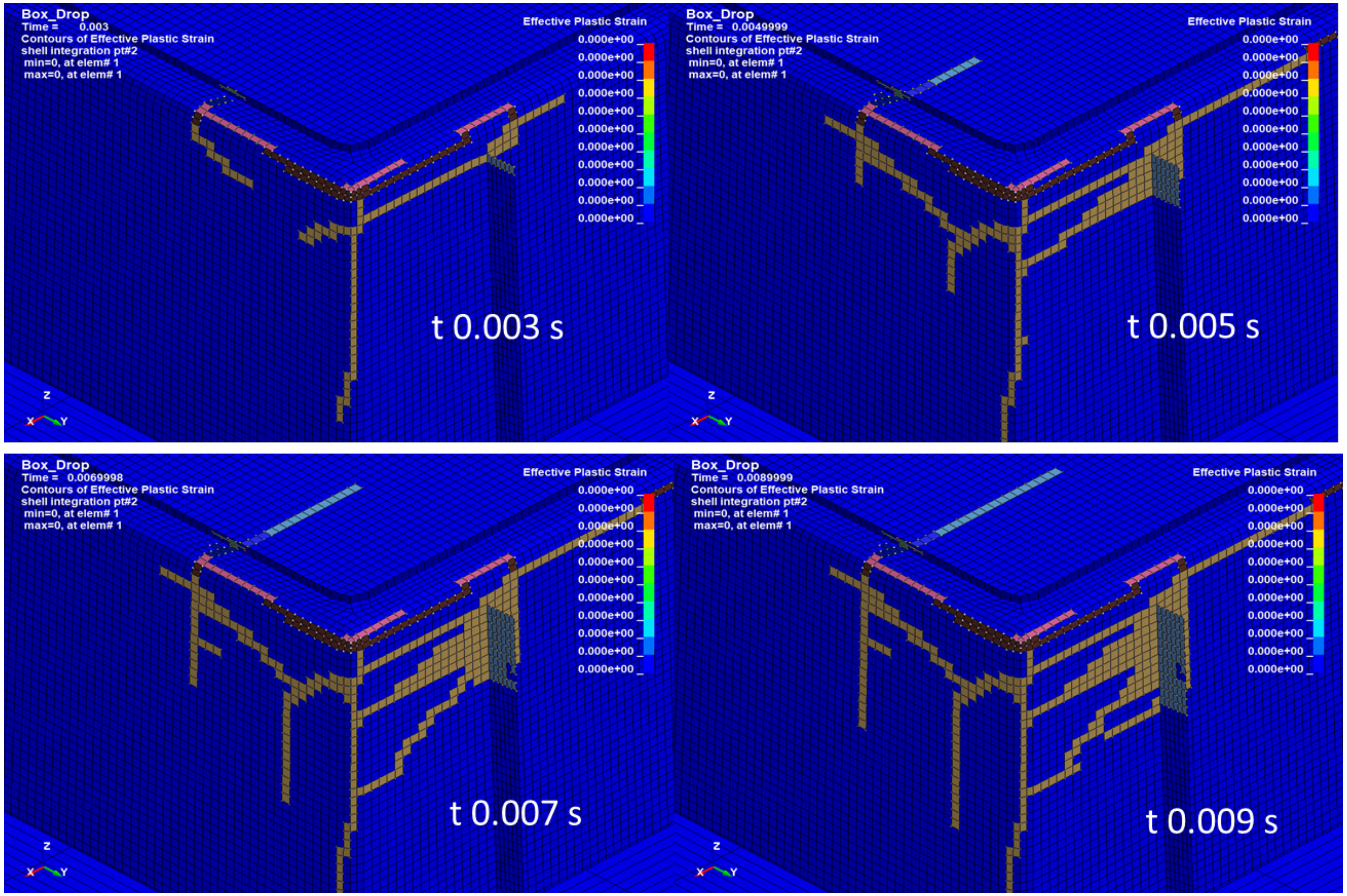
Four replications carried out under same testing conditions

Jaguar Land Rover test case: results

Simulation details

- *Digimat* 2017 (available and installed version) used with Ls-dyna
- Fiber orientation from JLR or varied (Folgar/Tucker, ARSC) from Moldflow
- Mesh size 2.5 mm (average)
- Element formulation 16
- Other parameters varied (Plasticity, mass scaling, FPGF and *Digimat* failure parameters, etc.)

Jaguar Land Rover test case: first simulation results

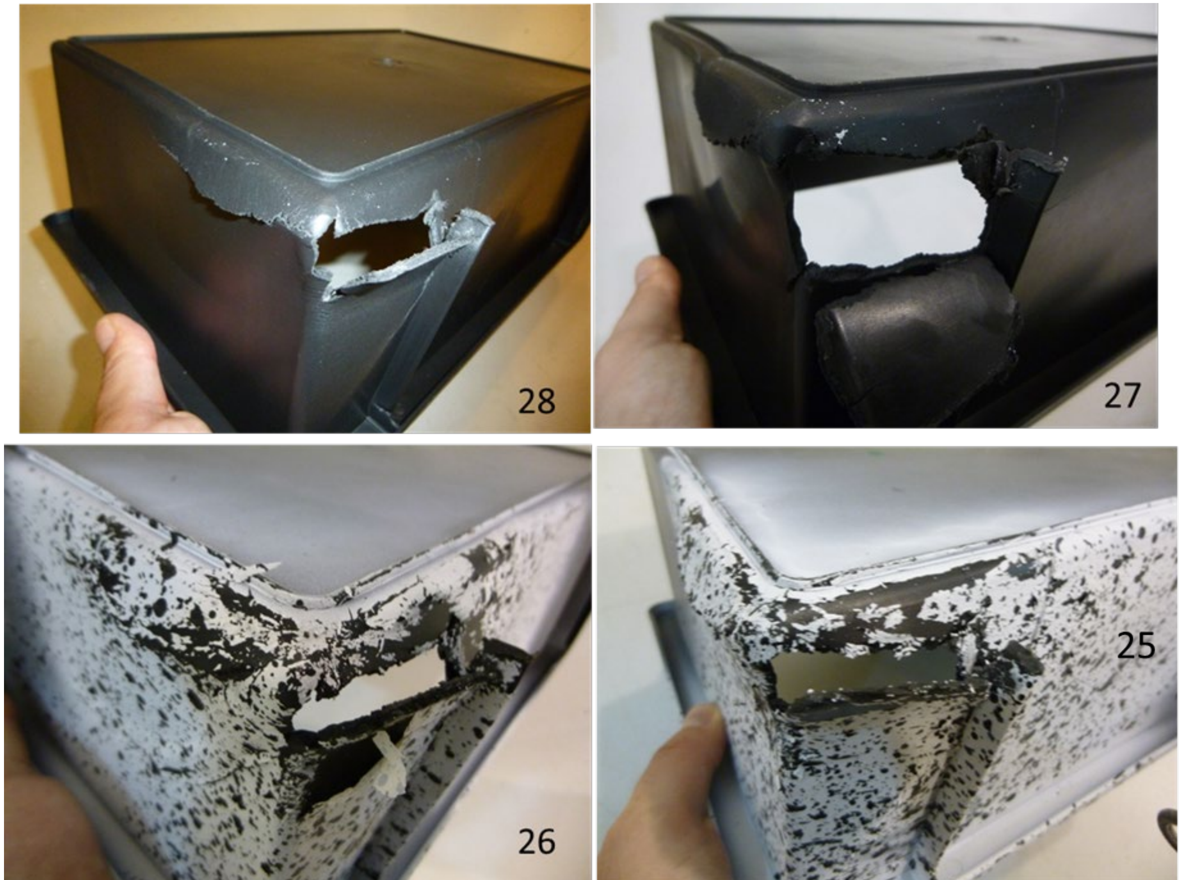


Plots of failed (deleted) elements

Source: LyondellBasell

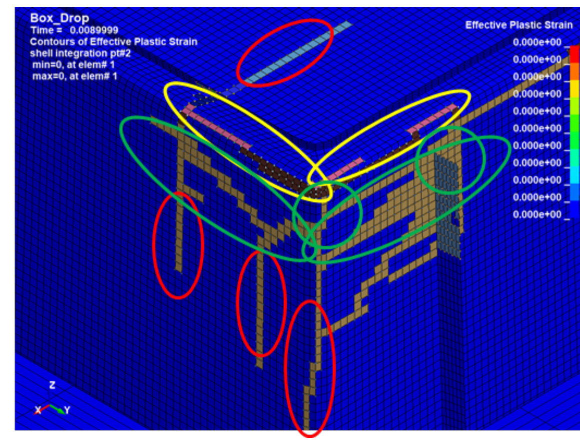
First results show unrealistic failure prediction, mainly related to fracture propagation

Jaguar Land Rover test case: first simulation results



Source: Jaguar Land Rover

Predicted fracture patterns
- Green circles: OK
- Red circles: BAD (propagation?)
- Yellow circles: BAD (mesh not accurate)

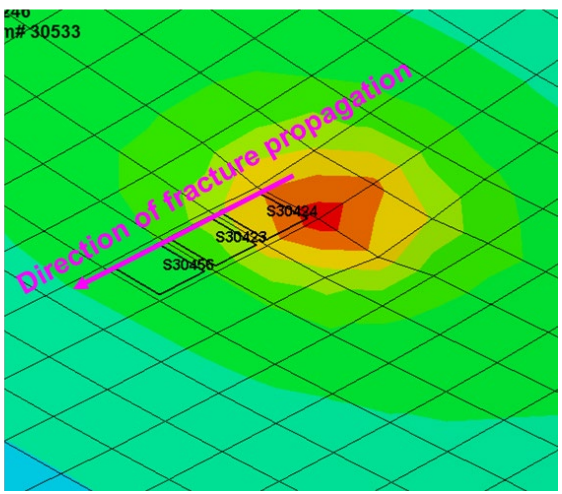


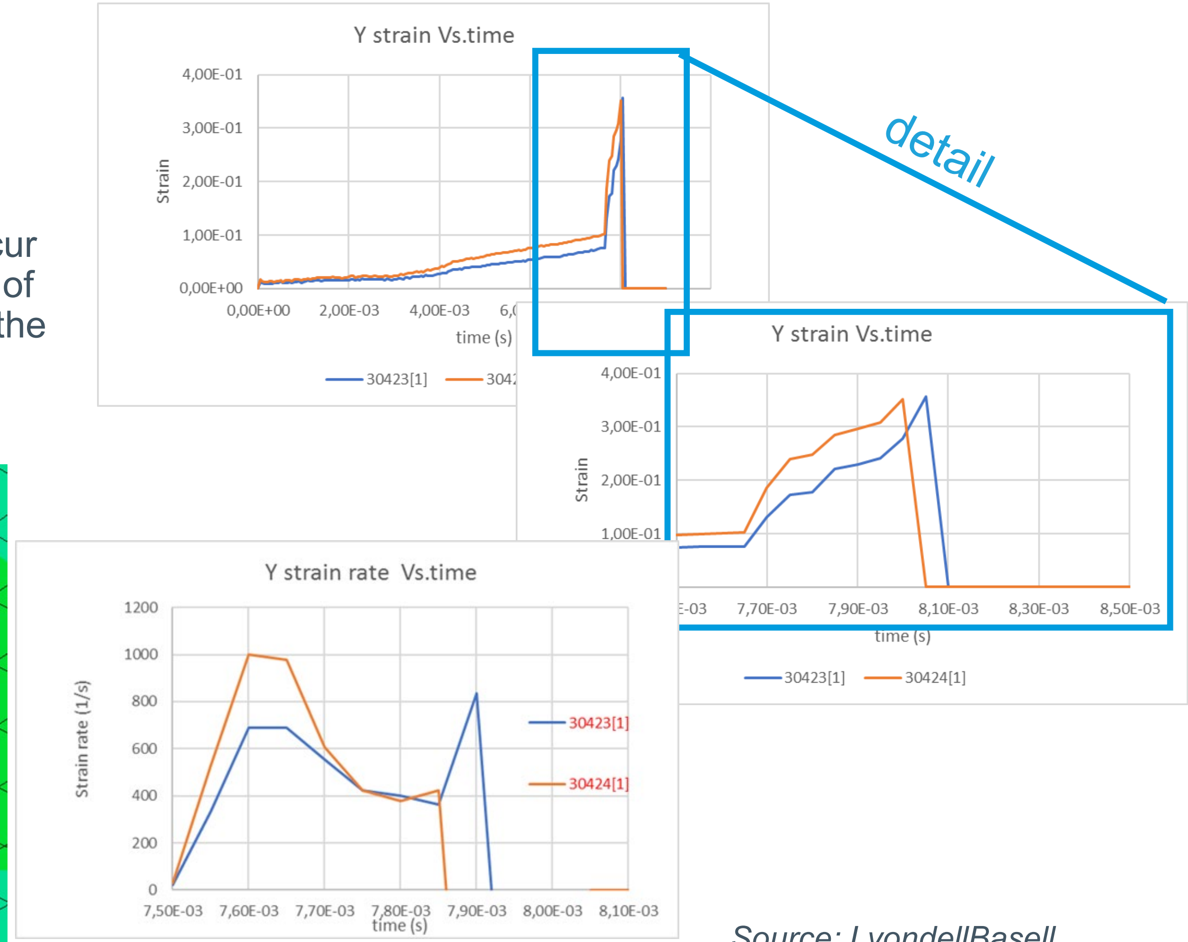
Source: LyondellBasell

First results show unrealistic failure prediction, mainly related to fracture propagation

Jaguar Land Rover test case: modifications

- **Amendments and modifications: analysis and Interpretation of fracture propagation**
  - Strain/ Strain rate peaks occur after the sudden elimination of an adjacent element due to the Failure Criterion functional reaching the threshold.



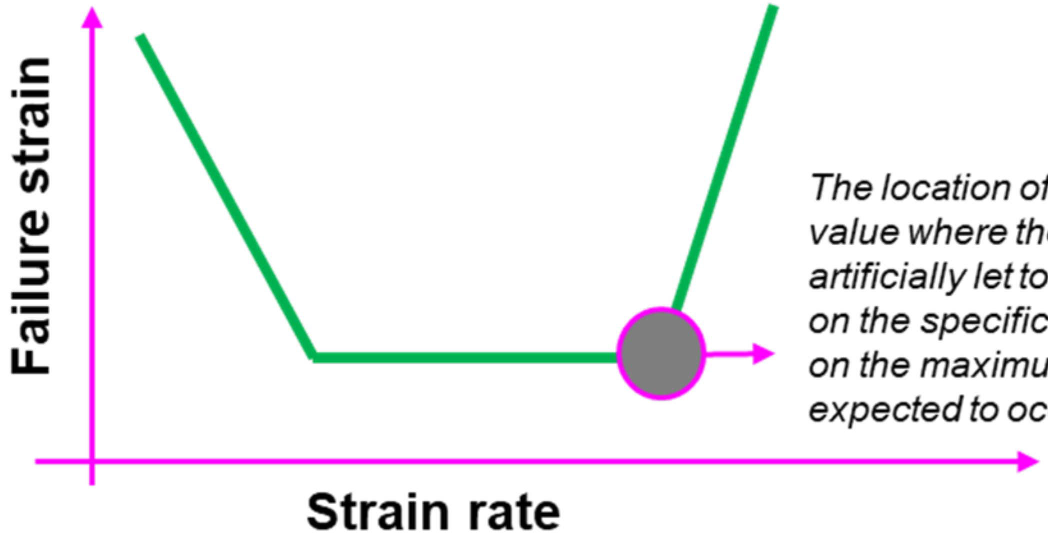


Source: LyondellBasell

Strain rate peaks occurring after element elimination mislead the failure criterion

Jaguar Land Rover test case: modifications

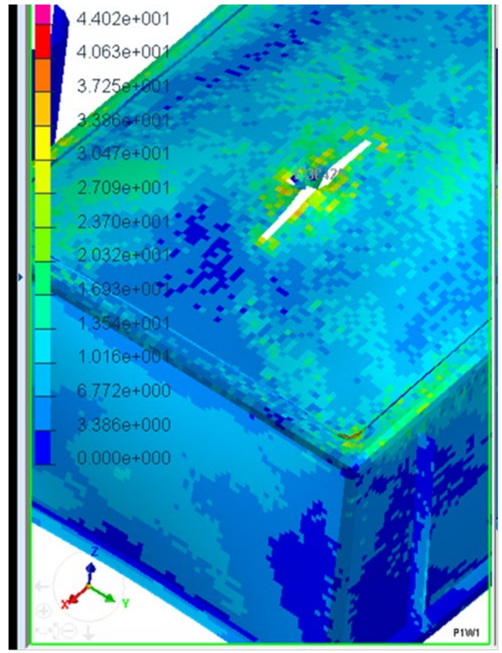
- **Amendments and modifications:**
  - “Washtube” shape for Failure strain vs. Strain rate to overcome falure criterion activation after contiguous element elimination
  - Additionally: improvement in the mesh (location of the main rib)

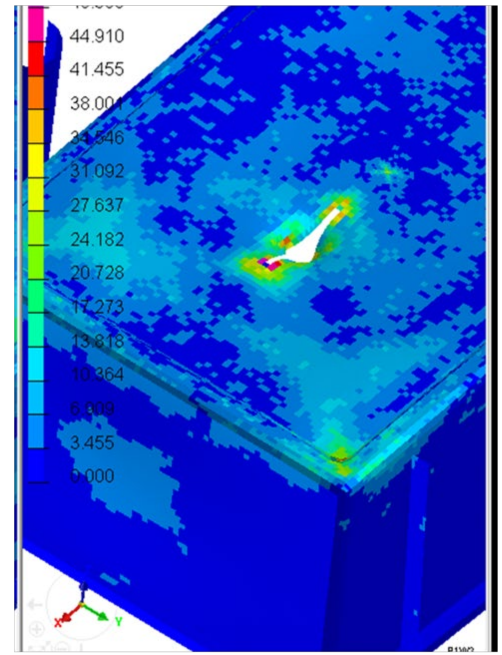


The location of the strain rate value where the Failure strain is artificially let to increase depends on the specific case simulated, i.e. on the maximum strain rate expected to occur in the real case.

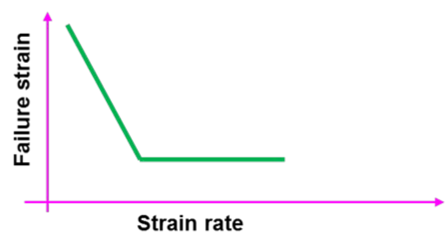
Verification of the improvement on LyondellBasell test case

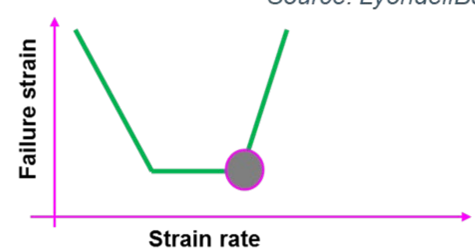
- **Results:**
  - "The modification seems to improve the prediction of the final fracture pattern on LYB Dart Test 1





Source: LyondellBasell





Source: LyondellBasell

Verification of the improvement on Jaguar Land Rover test case

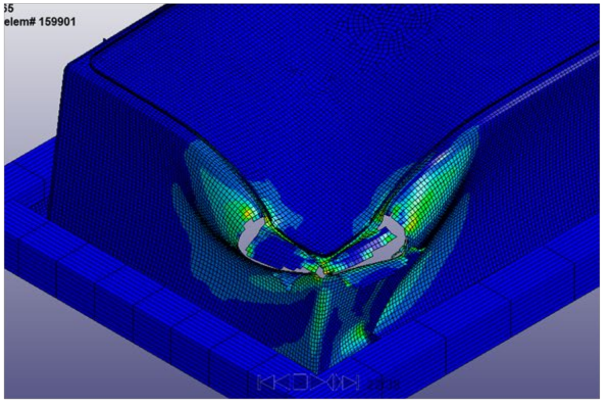
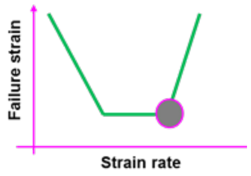
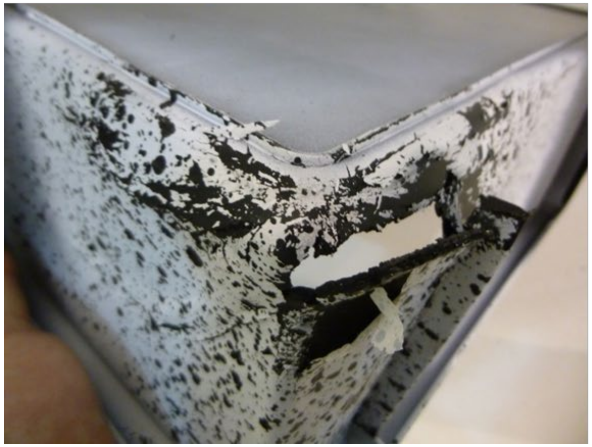


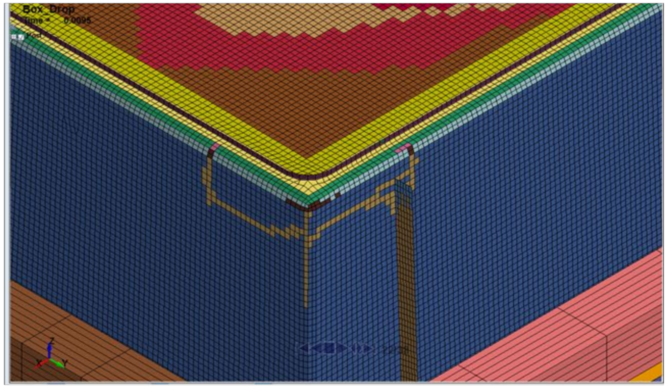
Image during the transient



Source: LyondellBasell



Source: Jaguar Land Rover

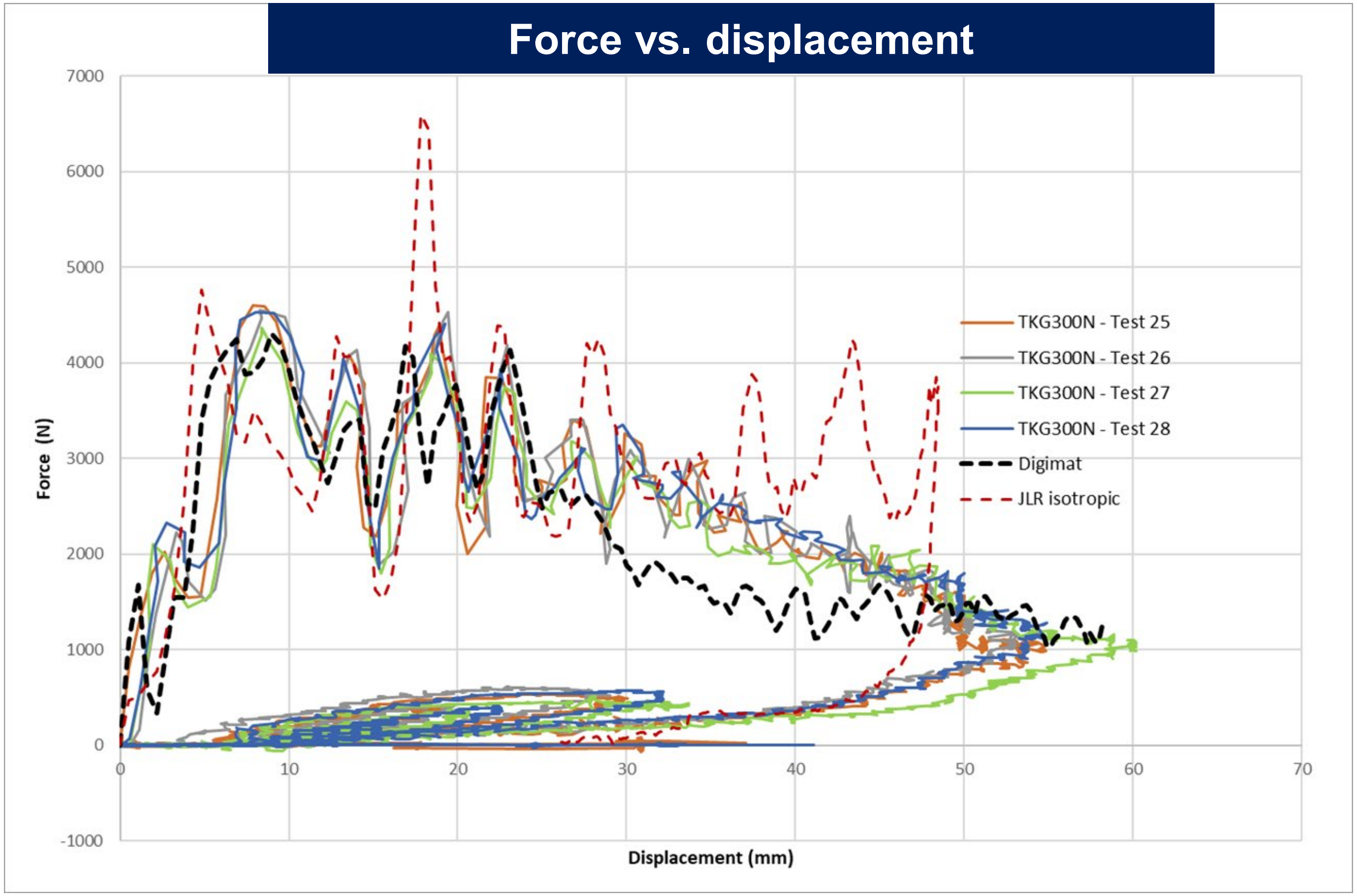


Predicted failed elements

Source: LyondellBasell

Failure onset and fracture propagation are better predicted when proper dependence on strain rate is assumed for the failure criterion

Jaguar Land Rover test case: force vs. displacement



Source: LyondellBasell

- **Digimat predicts reasonable values in agreement with experimental curves**

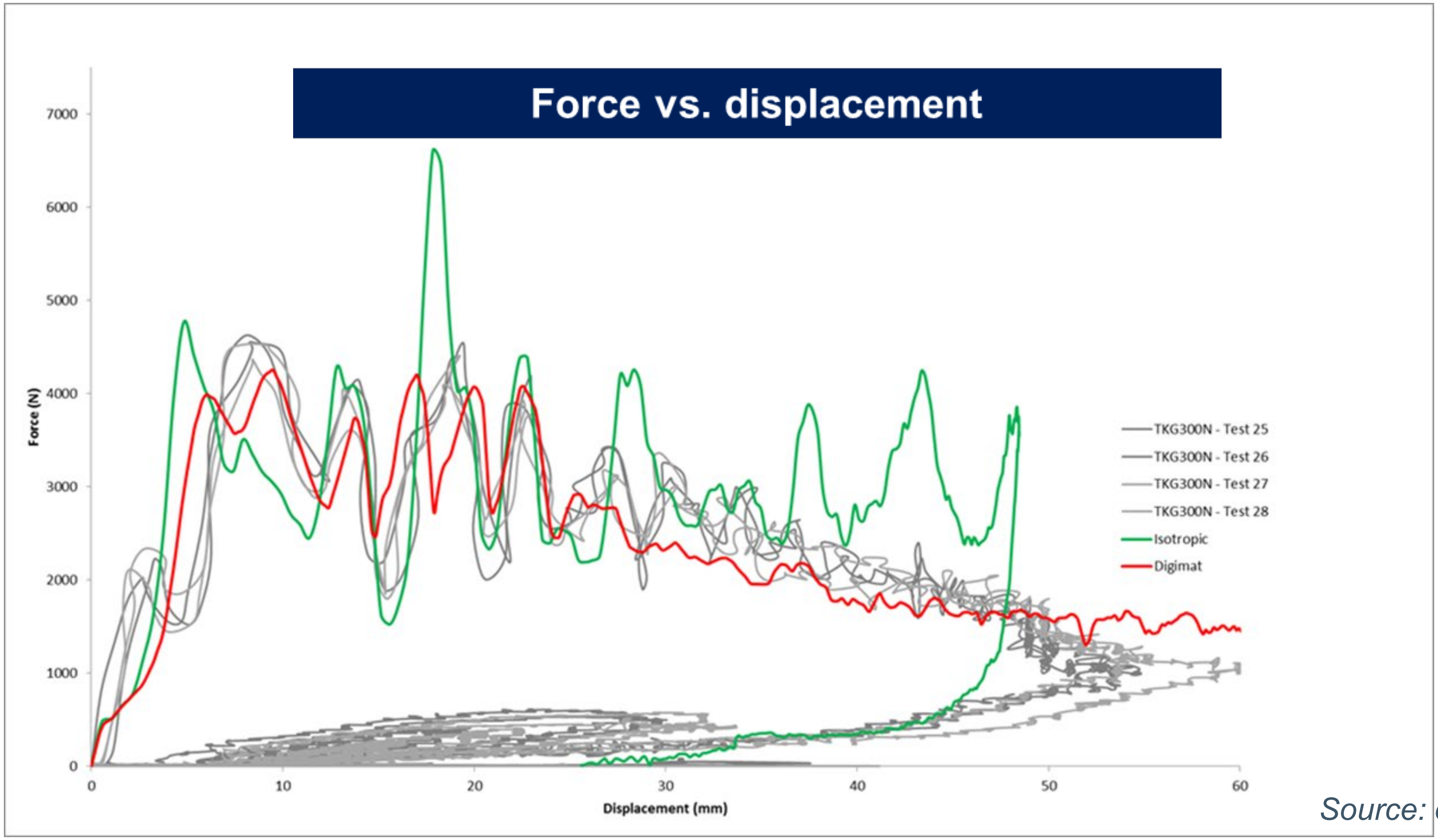
First conclusion

- The experimental data on two test cases were used to validate the material card for *Softell* grade
- The final predictions of force vs. Displacement curves in the two tests are definitely acceptable and aligned with the experimental evidence
- The Tsai-Wu failure criterion based on strain formulation performed well, provided that the strains were measured locally and a proper strain-rate dependence.
- This was conceived to block the activation of the criterion due to the strain rate peaks deriving from the deletion of failed elements
- Impact on parts made of *Softell* grades can be properly simulated with *Digimat*
- Can we do something better and in an easier way with *Digimat* 2018 and 2019 versions?

Impact on parts made of *Softell* grades can be properly simulated with *Digimat*

Can we do something better and in an easier way with *Digimat* 2018 and 2019 versions?

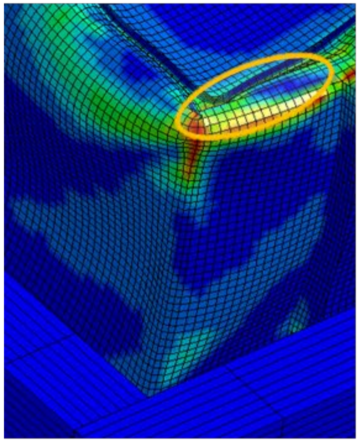
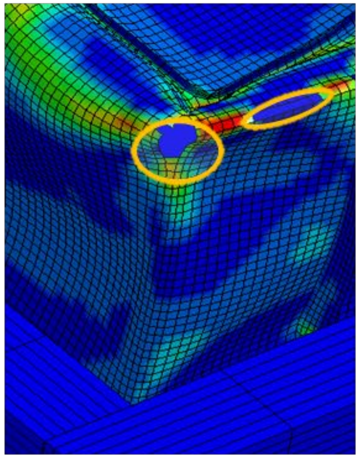
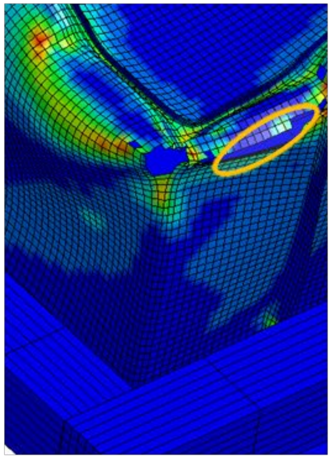
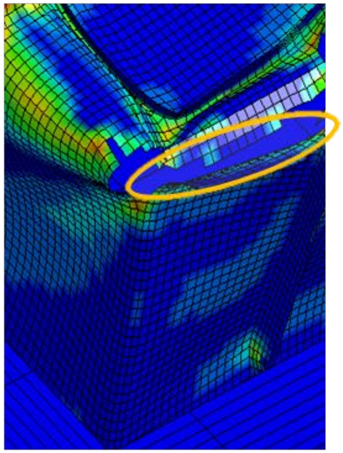
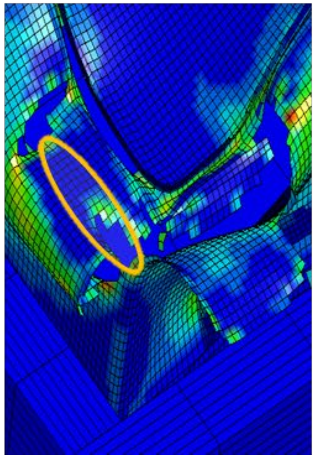
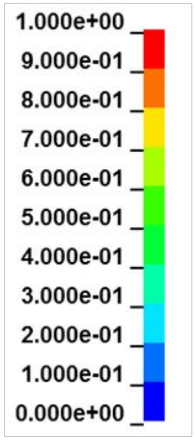
- **“*Ls-Dyna* 9.1.0 & *Digimat* 2018.1**
  - The strain rate filtering parameter is a new to filter spurious oscillations of strain rate values during strain rate dependent FEA runs
  - Applicable to failure models using a (V-)EVP material model



Source: e_Xstream

Can we do something better and in an easier way with *Digimat* 2018 and 2019 versions?


Source: Jaguar Land Rover

Source: e_Xstream

- **Failure indicator is a *Digimat* output to detect the critical zone supposed to fail in the part**
- **When the value exceeds 1 this means that the element is deleted if no damage is included in the material law**

Conclusion

Impact on parts made of *Softell* grades can be properly simulated with *Digimat*

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