

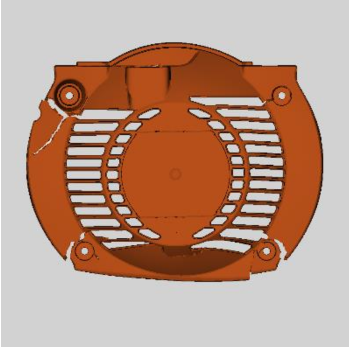
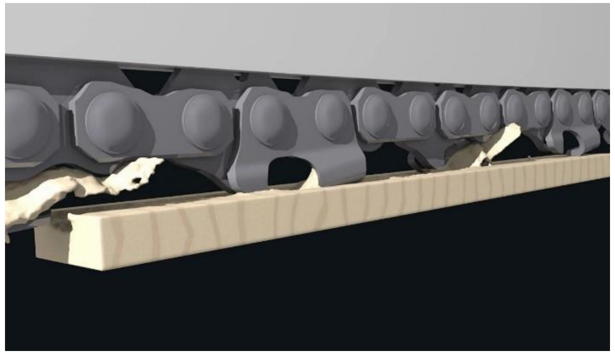


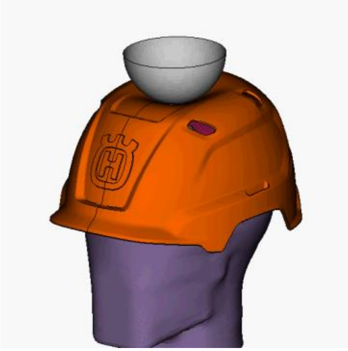
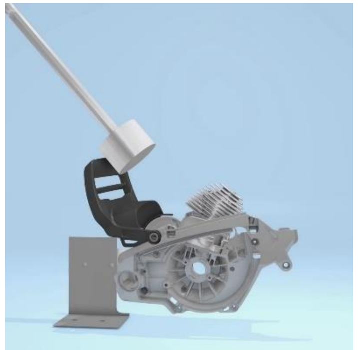
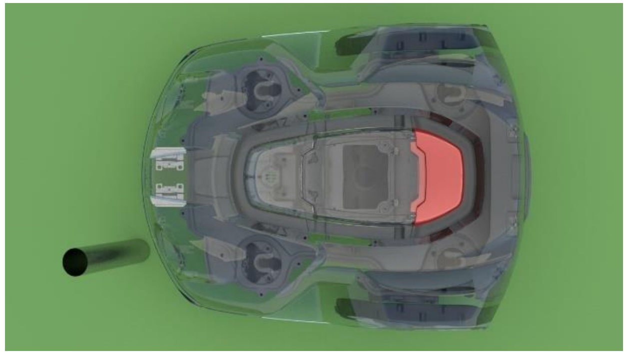

Material characterization in high and low temperatures for safety helmet shock absorption simulations

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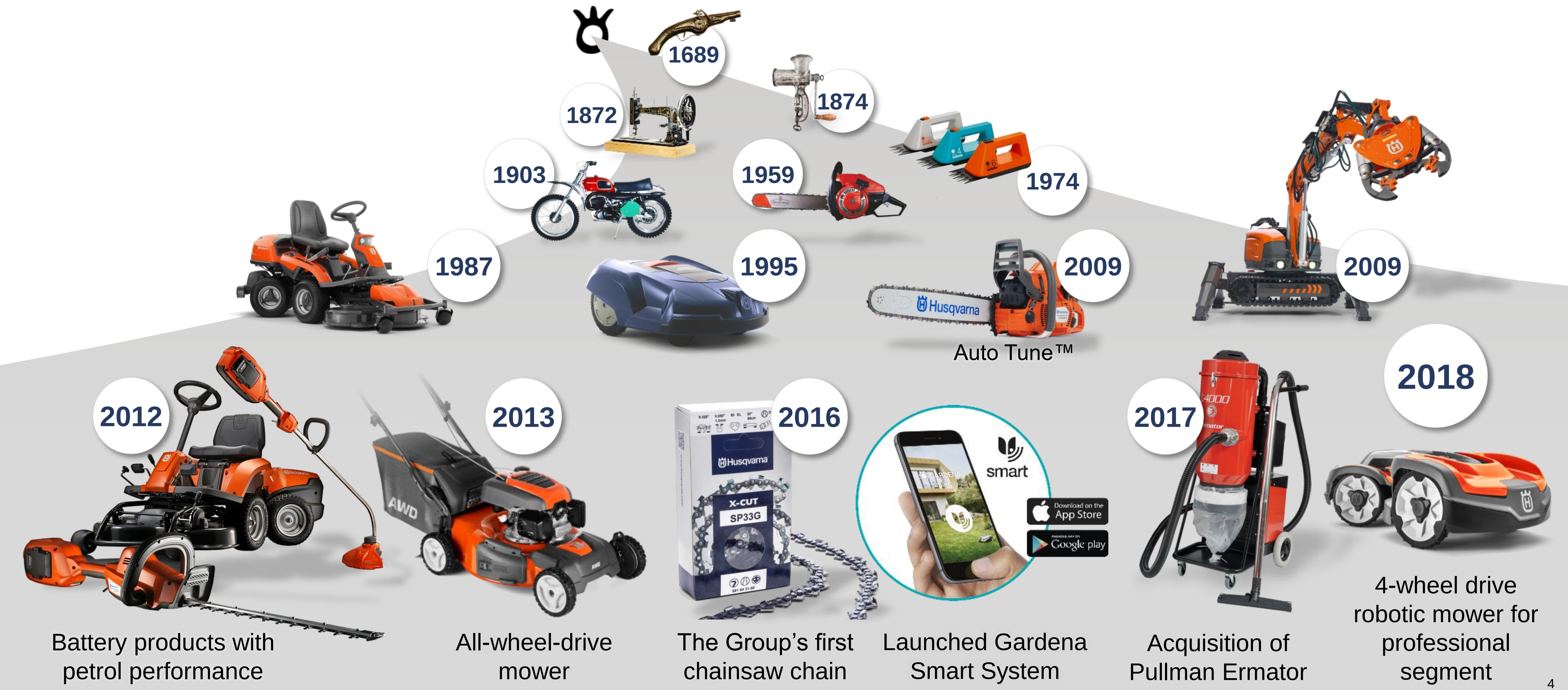
4A engineering GMBH

Outline
• About Husqvarna Group • Motivation and Material test plan • Reverse engineering with Valimat • Helmet component testing • Simulation results • Correlation of simulation model • Conclusions

This is Husqvarna Group

- A global leading producer of outdoor power products including chainsaws, trimmers, robotic lawn mowers and ride-on mowers.
- Net sales in 2018 amounted to EUR 4.1 billion
- Core brands: Husqvarna, Gardena
- Sales in more than 100 countries
- Leadership positions in products for forest, park & garden care, as well as construction
- Main distribution channels are dealers and retailers, and with growing on-line presence
- Approximately 13,000 employees in 40 countries
- The share is listed on Nasdaq Stockholm

330 years of innovation



Forest helmet, Technical

Helmet shell

Material: LG Chem, ABS HI100H

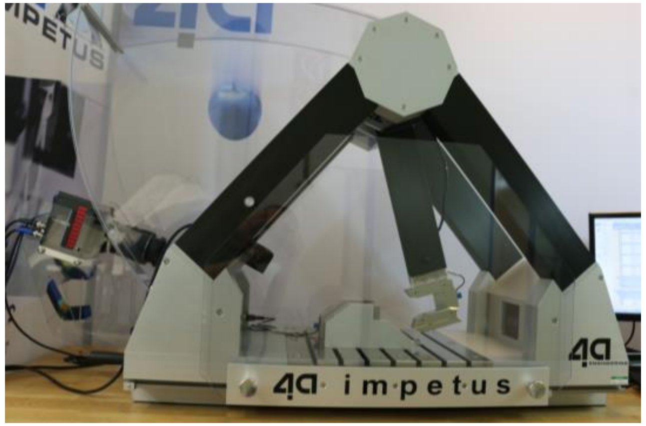
The performance of the helmet is highly dependent on the material properties in different temperatures. If the helmet shell is too soft in heat there will be a direct contact between the head and a falling object with high contact forces as a consequence. The helmet must on the other hand not become too stiff in cold conditions to limit the maximum force transmitted to the head and neck.

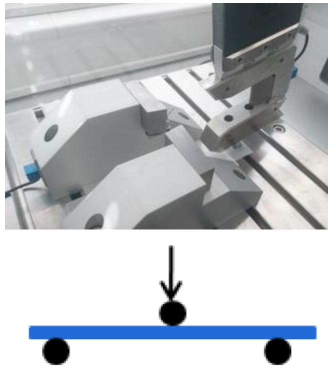
A UV expire indicator fastened on the outside signals when it is time to exchange the helmet for a new one.

Material testing

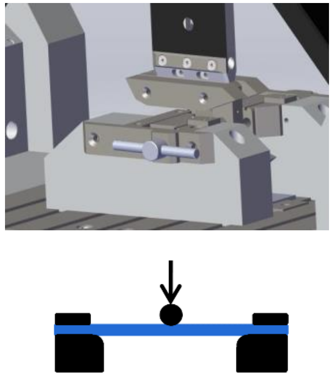
Material testing

Tests at 4A engineering with the Impetus pendulum rig. MAT_24 material model based on static and dynamic flexural tests.

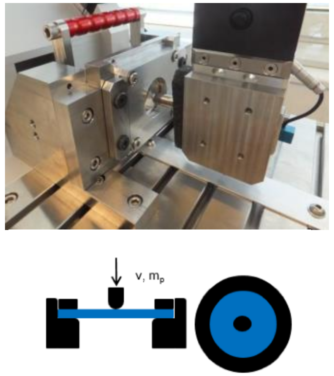




Static and dynamic
3-point bending test



Dynamic clamped 3-point
bending/tension test



Dynamic puncture test

Material testing at -30°C

3-point bending tests

Test type	Initial velocity [m/s]	Support distance [mm]	Pendulum mass [kg]	Thickness [mm]	Initial strain rate* [1/s]	Temperature [°C]	Orientation [°]
Static	0.001	40	0	2.0	0.0075	-30	90
Static	0.001	40	0	2.0	0.0074	23 / -30	0
Dynamic	1	40	1.58	2.0	7.4	23 / -30	0
Dynamic	4	40	1.58	2.0	29.7	-30	0
Dynamic	4	20	1.58	2.0	52.8	-30	0

* Calculated initial strain rate

Clamped 3-point bending test

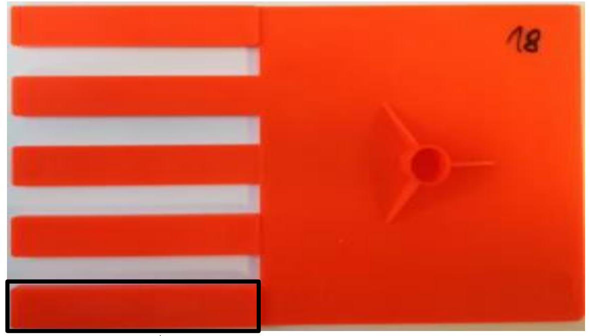
Test type	Initial velocity [m/s]	Support distance [mm]	Pendulum mass [kg]	Thickness [mm]	Initial strain rate* [1/s]	Temperature [C]	Orientation [°]
Dynamic	4	40	1.58	2.0	-	-30	0

Puncture test

Test type	Initial velocity [m/s]	Support distance [mm]	Pendulum mass [kg]	Thickness [mm]	Initial strain rate* [1/s]	Temperature [C]	Orientation [°]
Dynamic	3	42	3.22	2.0	-	-30	0

Material testing at -30°C

Different wall thicknesses & screw bossing



3.5 mm thick

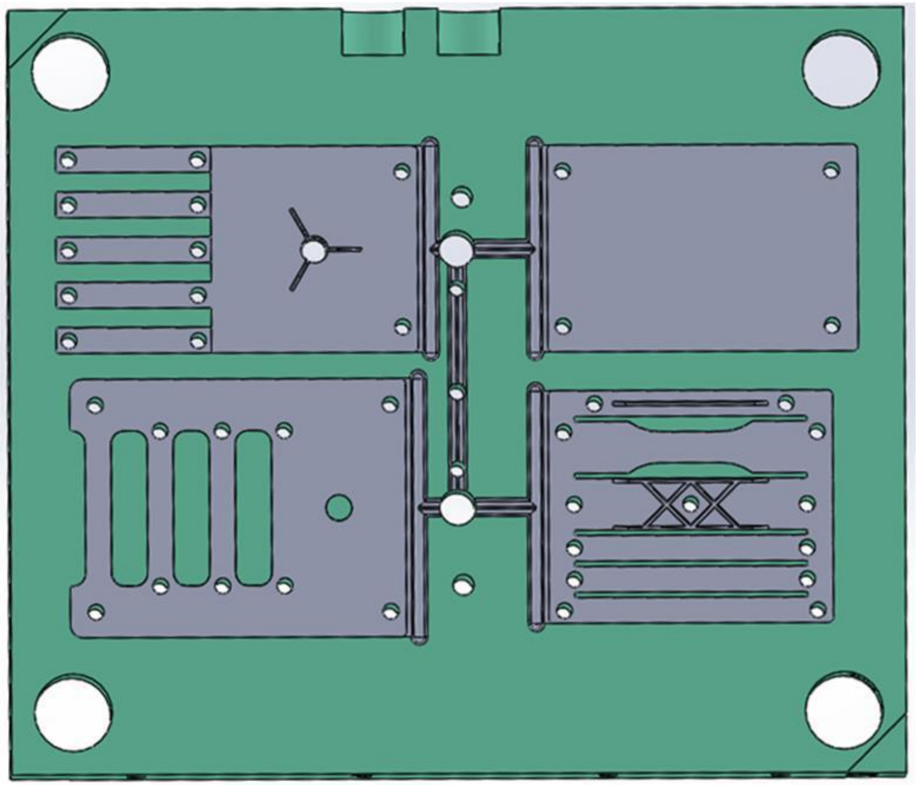
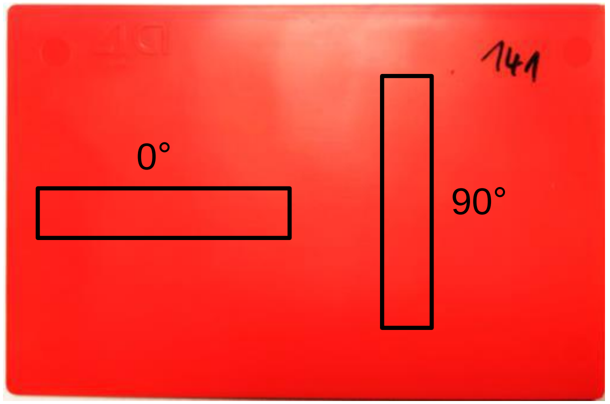
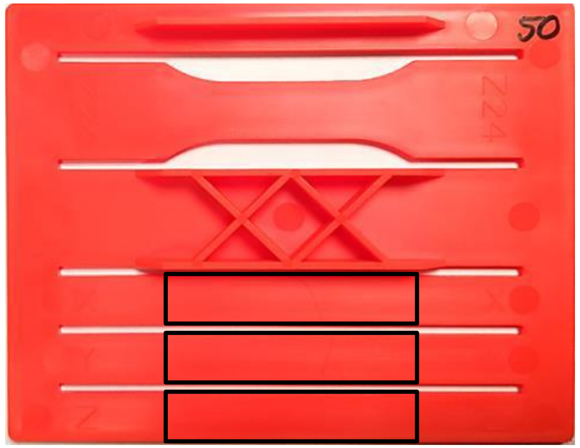


Plate 120x80x2 mm



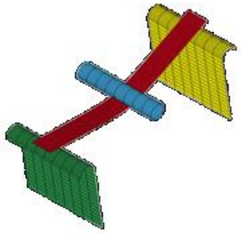


Multi specimen, rib & component

The test specimens were made from injection molded plates from the 4A mold

Material testing at -30°C

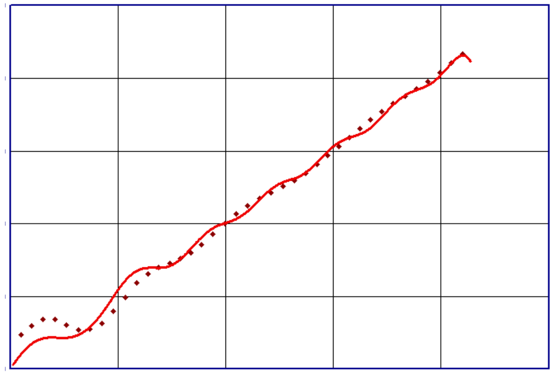
Reverse engineering of a MAT 24 material model with VALIMAT



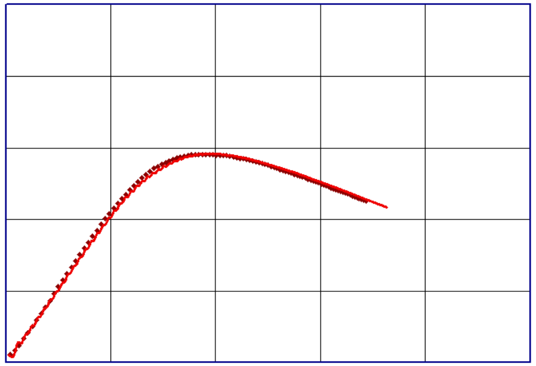
The tests are re-created with simulation models and the mean deviation of test and simulation is calculated.

With optimization techniques, the material properties of the simulation model are adjusted to minimize the mean deviation.

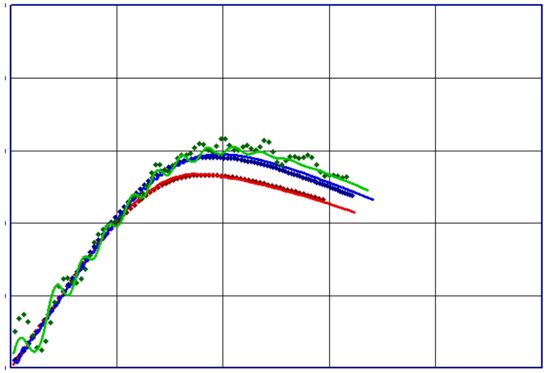
Step 1: Fit Youngs modulus to dynamic test



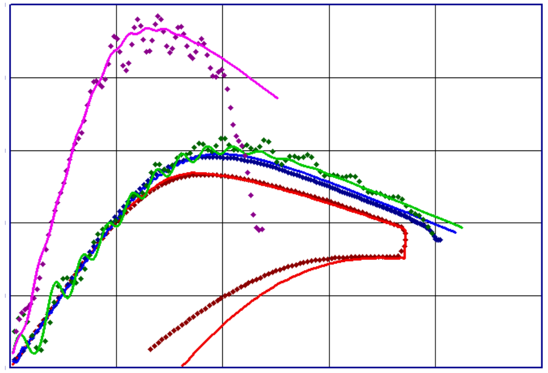
Step 2: Fit hardening curve to dynamic test



Step 3: Determine strain rate dependency



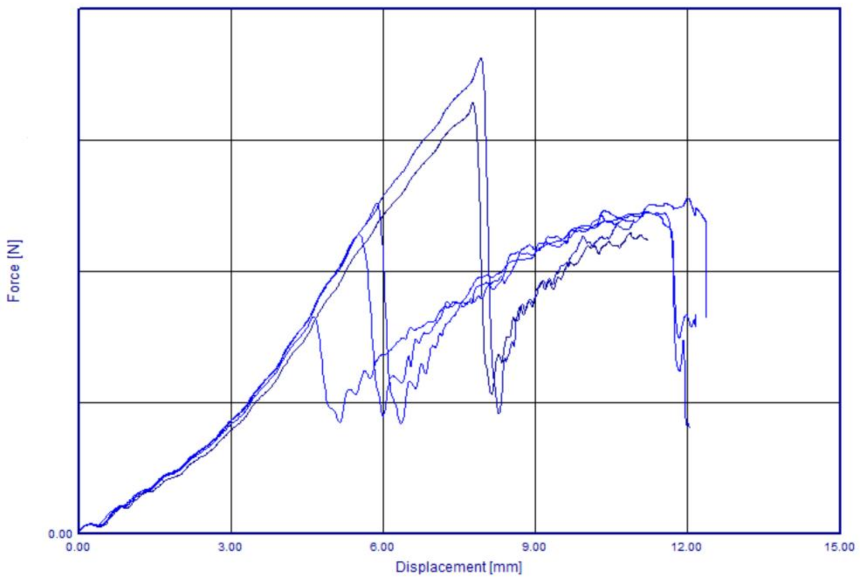
Step 4: Validate all bending tests without failure model

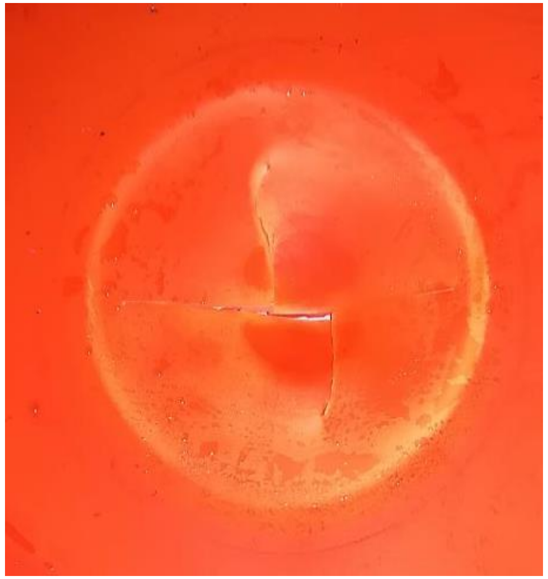


Force-Displacement
Mean value curves from testing (dotted)
Optimization curves simulation (solid)

Material testing at -30°C

Dynamic puncture test





All test specimens failed. First failure displacement has a large scatter.

Material testing at -30°C

Failure model

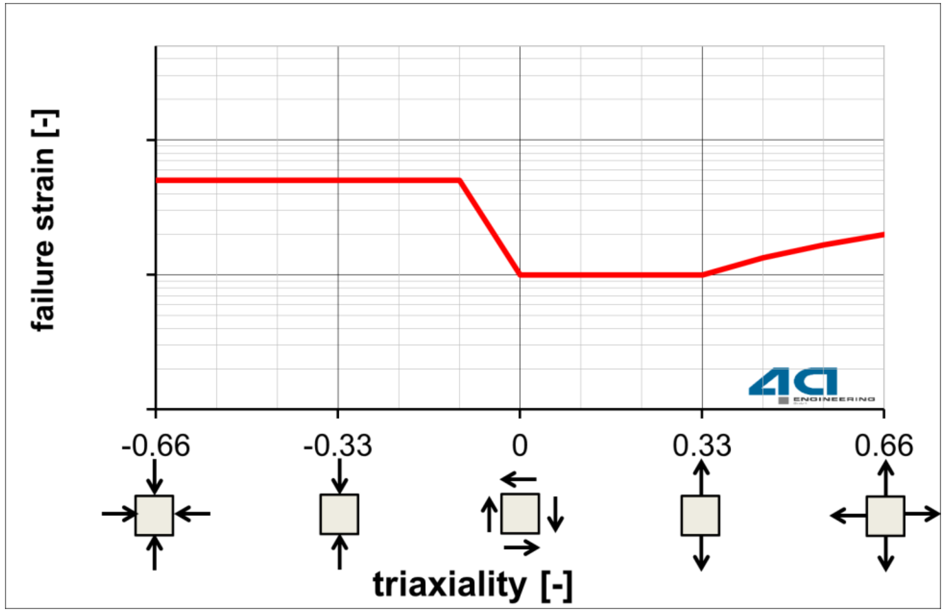
LS Dyna ***MAT_ADD_EROSION**
DIEM Model was used

Damage **I**nitiation **M**odel with 4A simple approach

Damage **E**volution **M**odel with constant plastic displacement

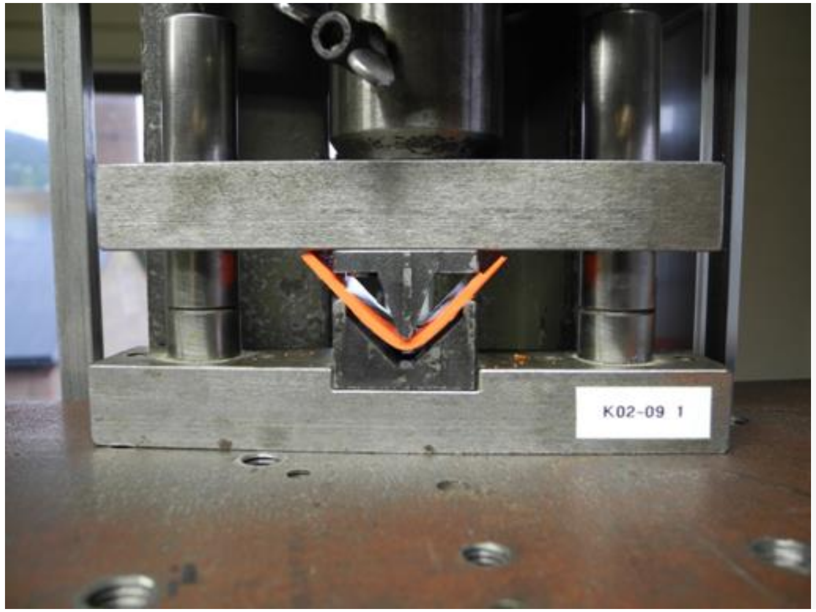
No detailed characterization was ordered

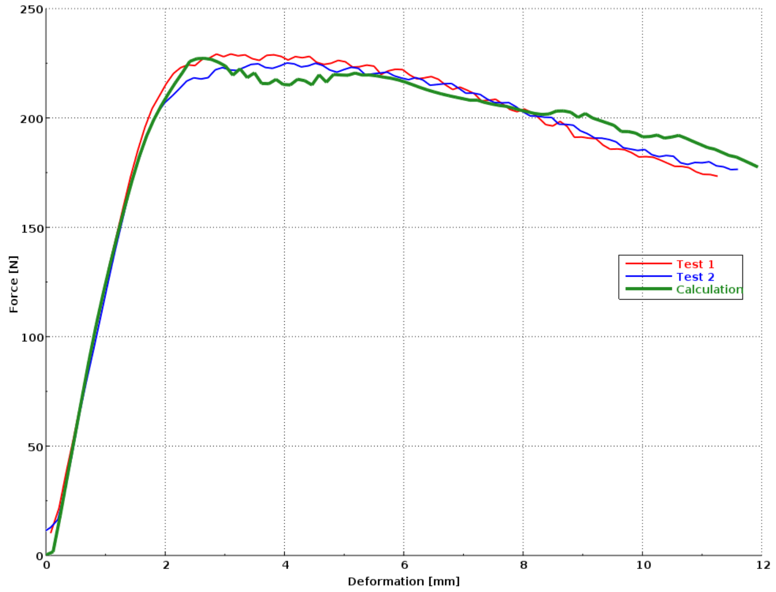
No strain-rate dependency of failure strain due to reduced test program



Material testing at +50°C

Material data for +50°C was obtained by quasi-static 3-point bending tests in combination with existing high speed tensile tests of a similar material. These tests were done at Husqvarna.





Material testing on helmet samples

Validation of the material model on samples taken from helmet in Impetus pendulum rig.

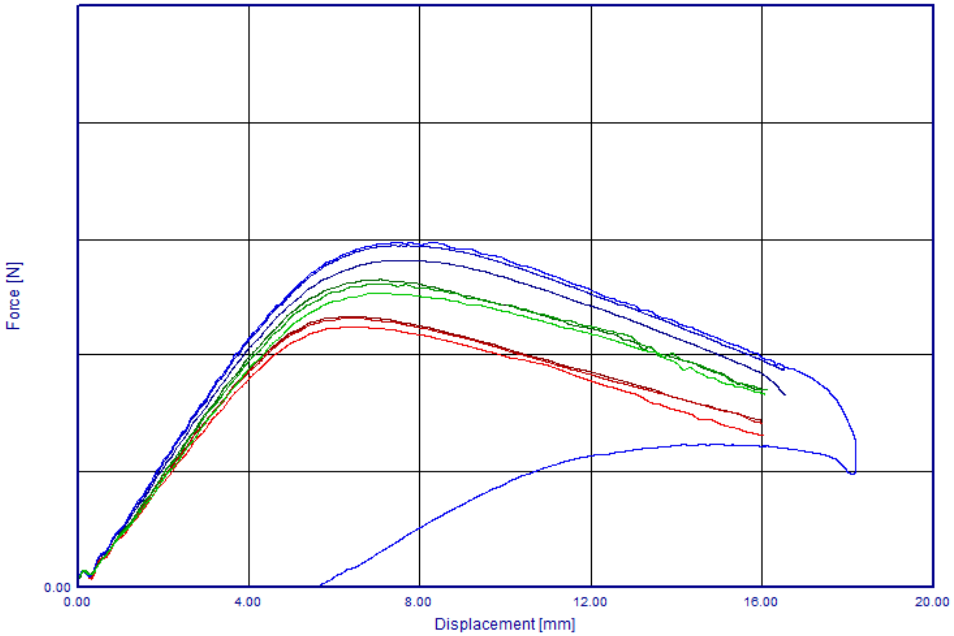
Injection point

During this testing it was discovered that the top part of the helmet was slightly thicker than the CAD-modell (3.8 mm instead of 3.6).

Material testing on helmet samples

Validation of material model on samples taken from helmet

Dynamic 3-point bending test results



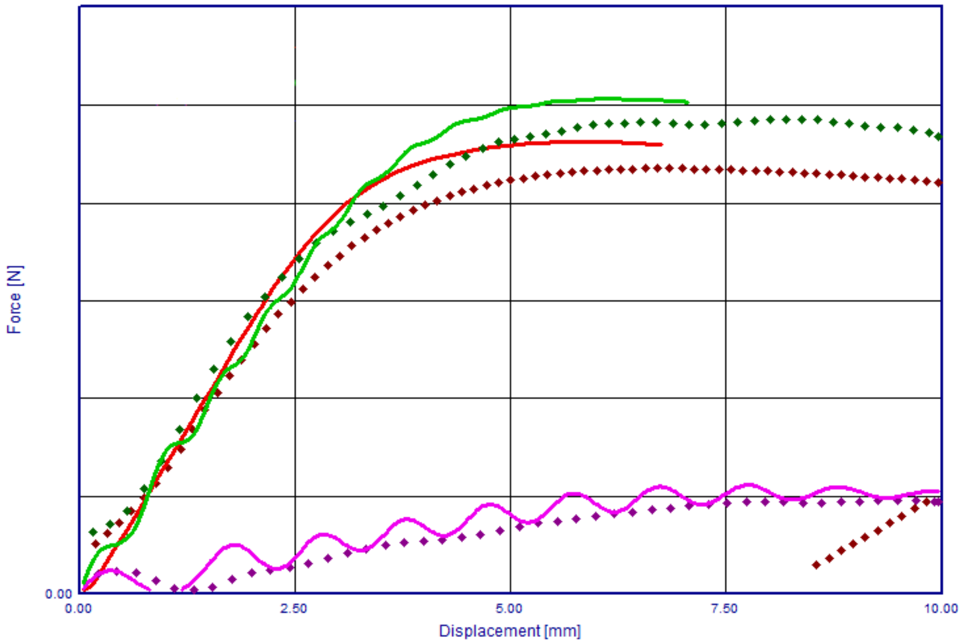
Blue -30 °C

Green +23 °C

Red +50 °C

Dashed = mean value curves from testing

Solid = Simulation



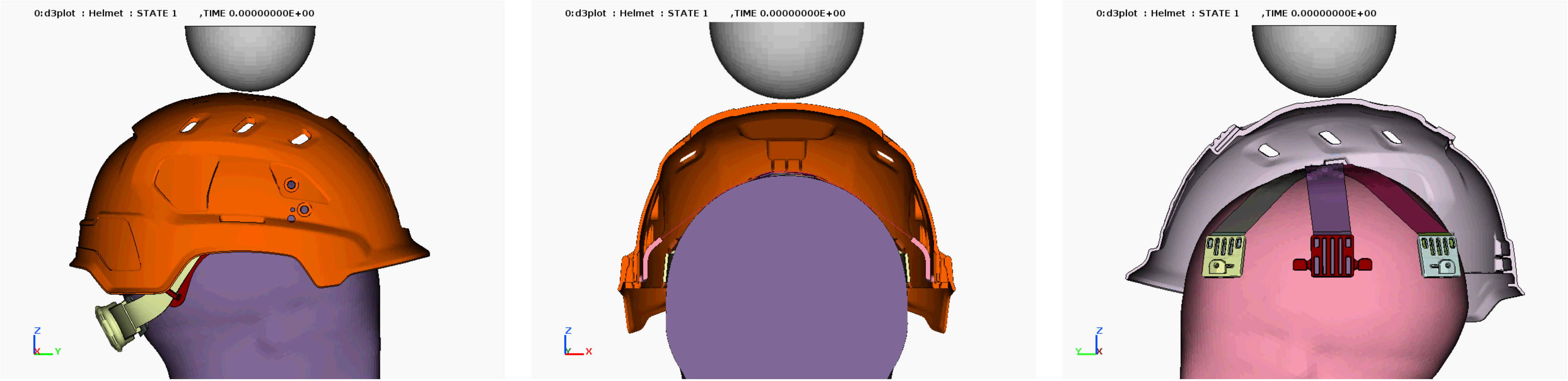
Deformation behavior suits in principal good

Too brittle failure criteria due to simplified approach with no strain rate dependency and limited testing

Helmet drop testing

Complete helmet simulation

A forest helmet must comply with the shock absorption demands stated in the standard SS-EN 397:2012. A hemispherical striker that weighs 5 kg will fall on to the centre of the helmet shell from a height of 1000 mm in the test. Shock absorption will be measured by the maximum force transmitted to a rigidly mounted head-form on which the helmet is fitted. The force on the head-form shall not exceed 5.0 kN in either -30°C and +50°C according to the demands.

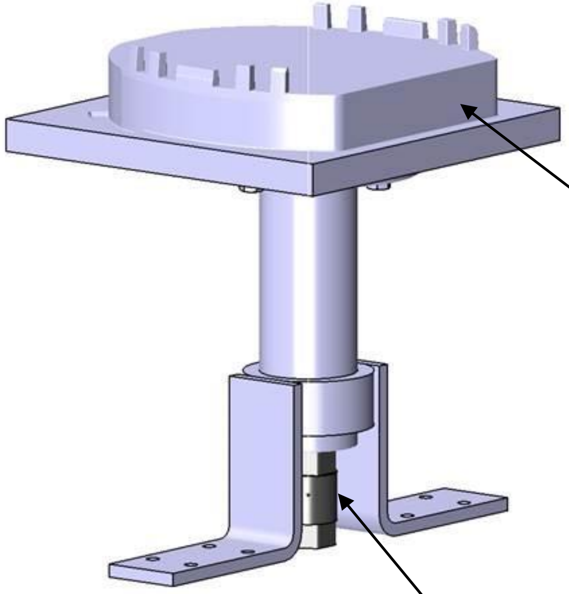


The performance of the complete helmet depends not only on the properties of the outer shell, but also on the head-band stiffness and the interaction between other parts.

Helmet component test

Testing of a complete helmet mounted on a head-form would be too complex to evaluate the material model.

Fixture



All other helmet parts were omitted to simplify comparison with simulation.

The position of the striker was measured by a series of laser beams stacked vertically and directed towards the drop-weight path. The number of blocked beams was translated into a position.

A high speed camera was also used to record the impact.

Helmet component test

High speed footage, tests in +50°C

Energy absorption (5.0 kg from 1.0 m, 49 J)

Penetration (3.0 kg from 1.0 m, 29 J)

Helmet component test

High speed footage, tests in -30°C

Energy absorption (5.0 kg from 1.0 m, 49 J)

Penetration (3.0 kg from 1.0 m, 29 J)

Simulation

Model resolution

Thickness in upper part of helmet ~3.6 mm

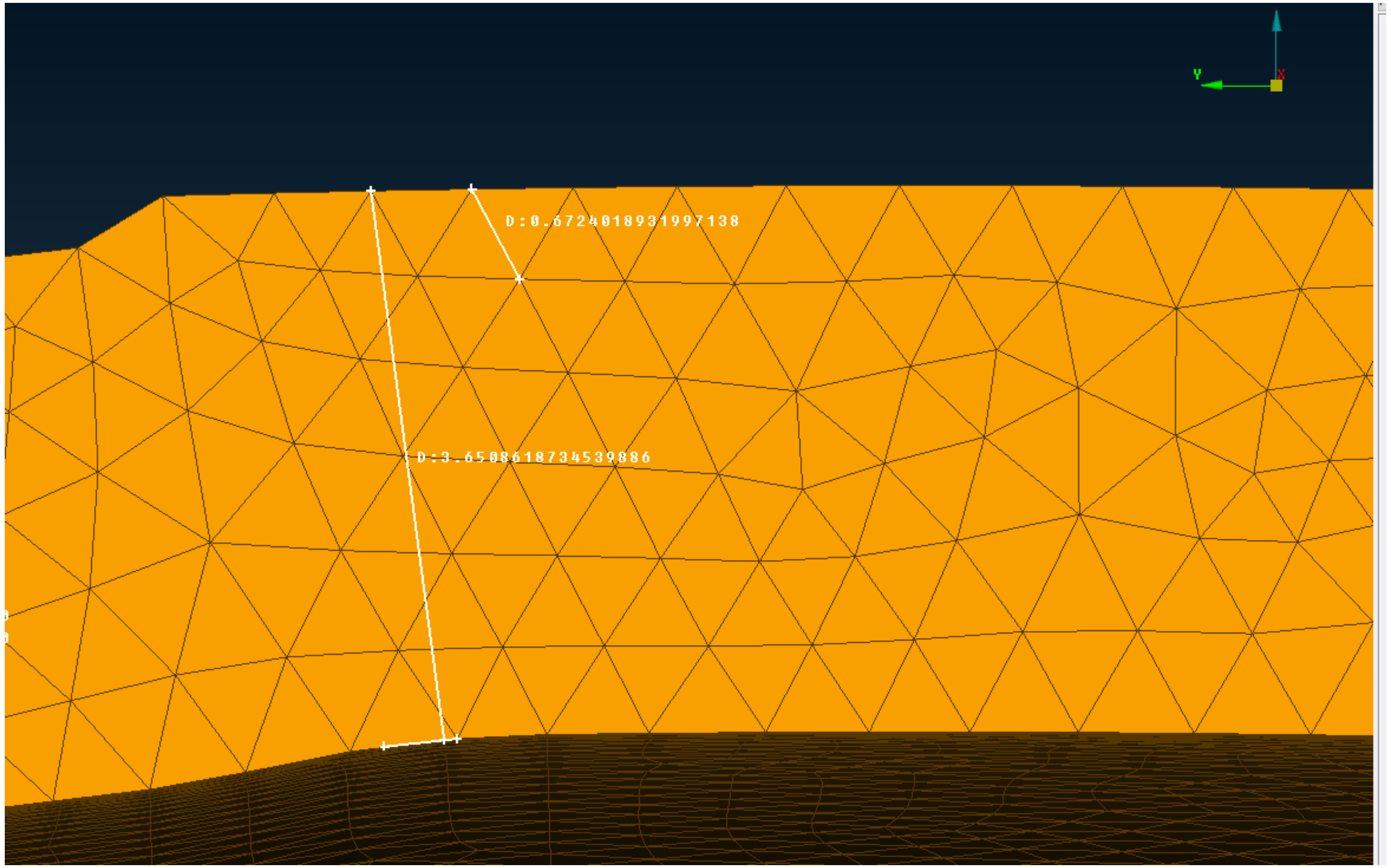
Number of elements through the thickness, 6-7

Element size ~0.7 mm

Choice of tetrahedral solid element type:

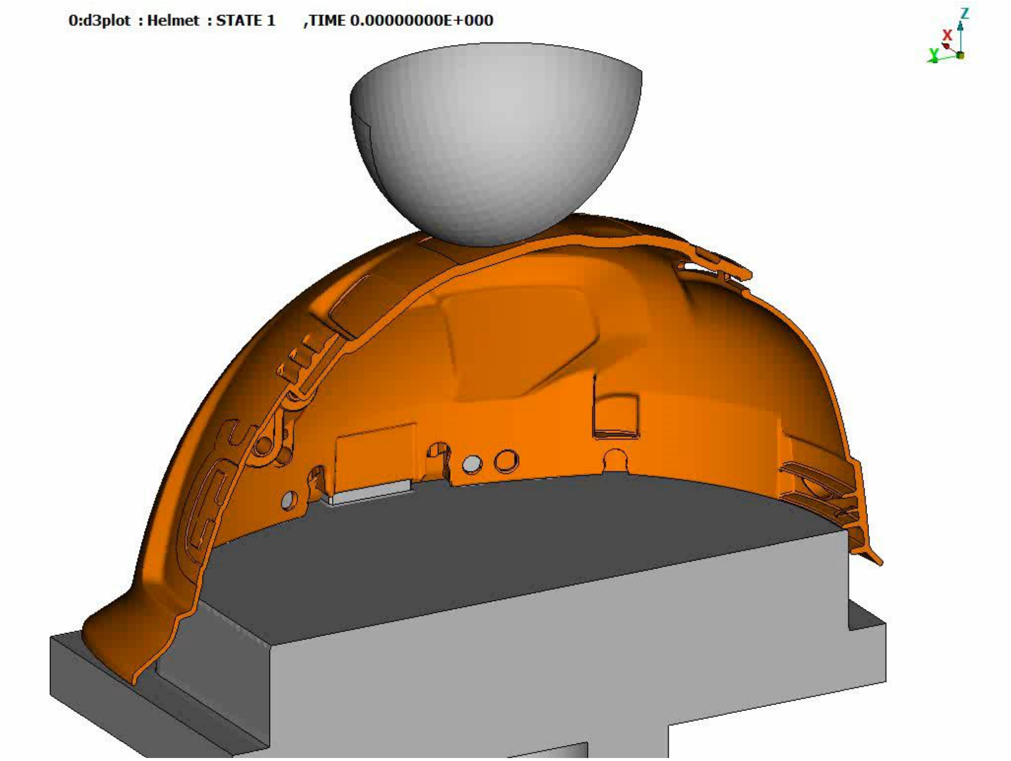
- Type 4: Tendency to volumetric locking
- Type 13: Poor performance in bending load-cases
- Type 16/17: Not suited for large strains. Can be unstable with element erosion.

The type 4 element was chosen for this application



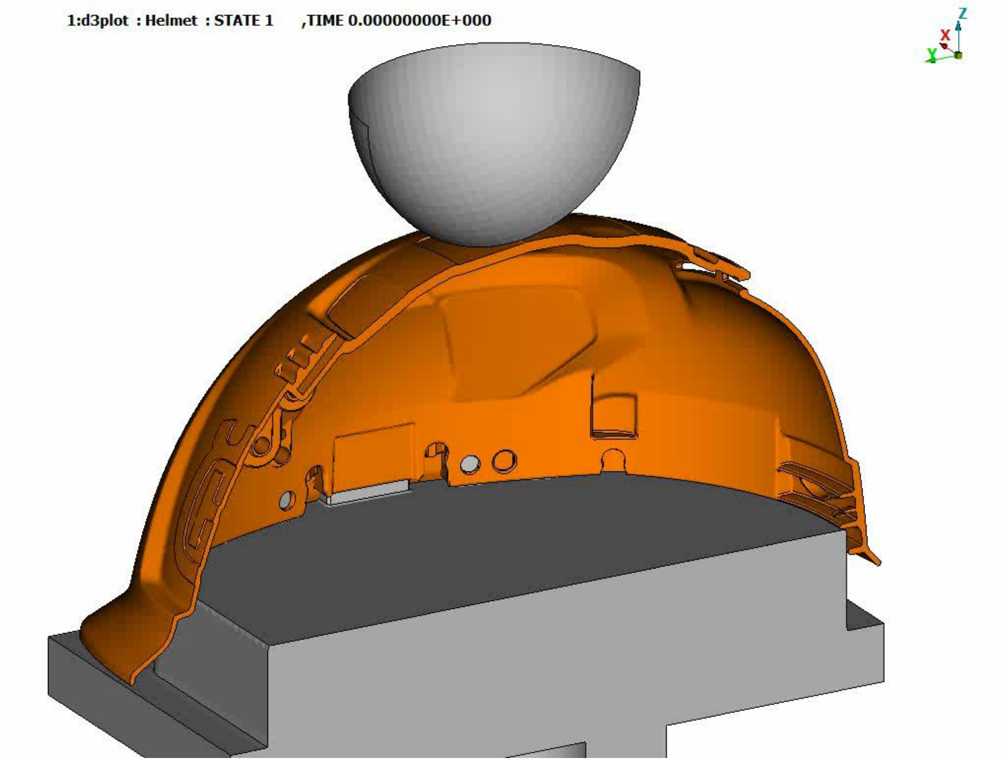
Helmet simulation

Simulations in +50°C



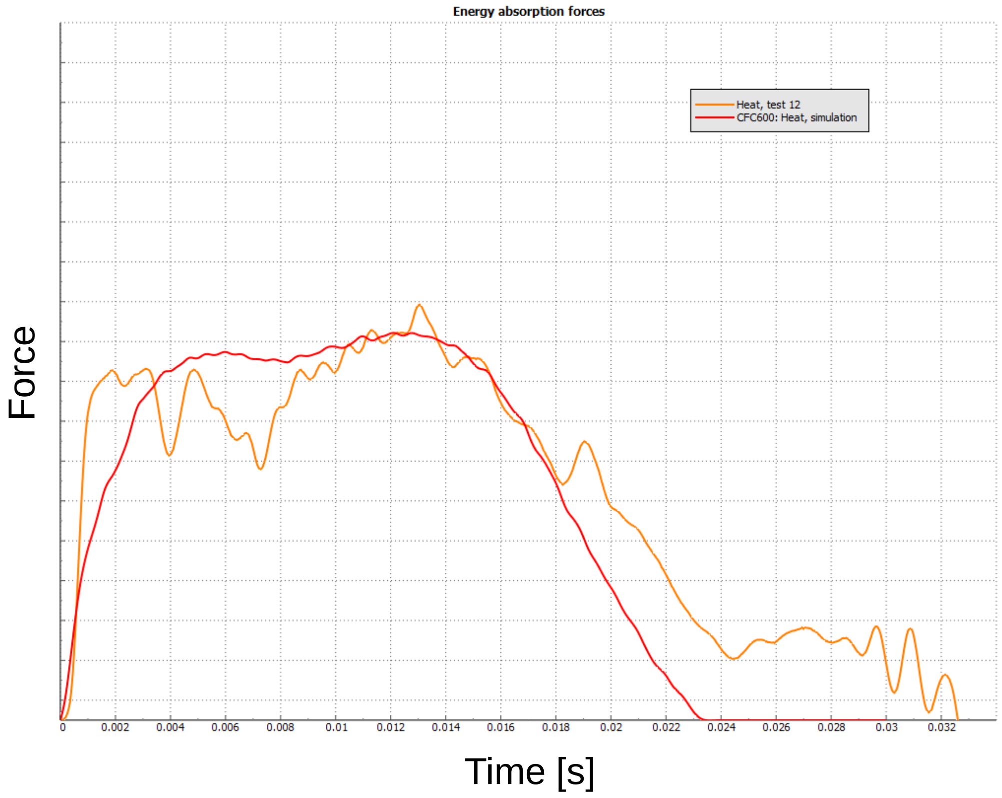
Helmet simulation

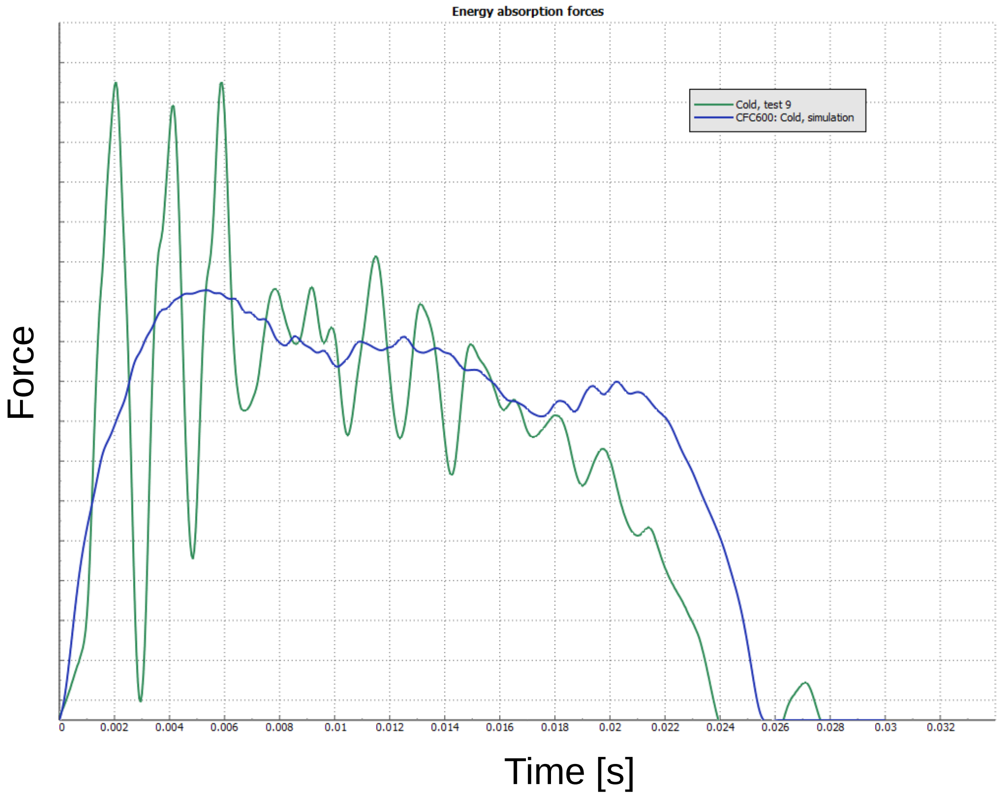
Simulations in -30°C



Helmet simulation

Drop weight displacement

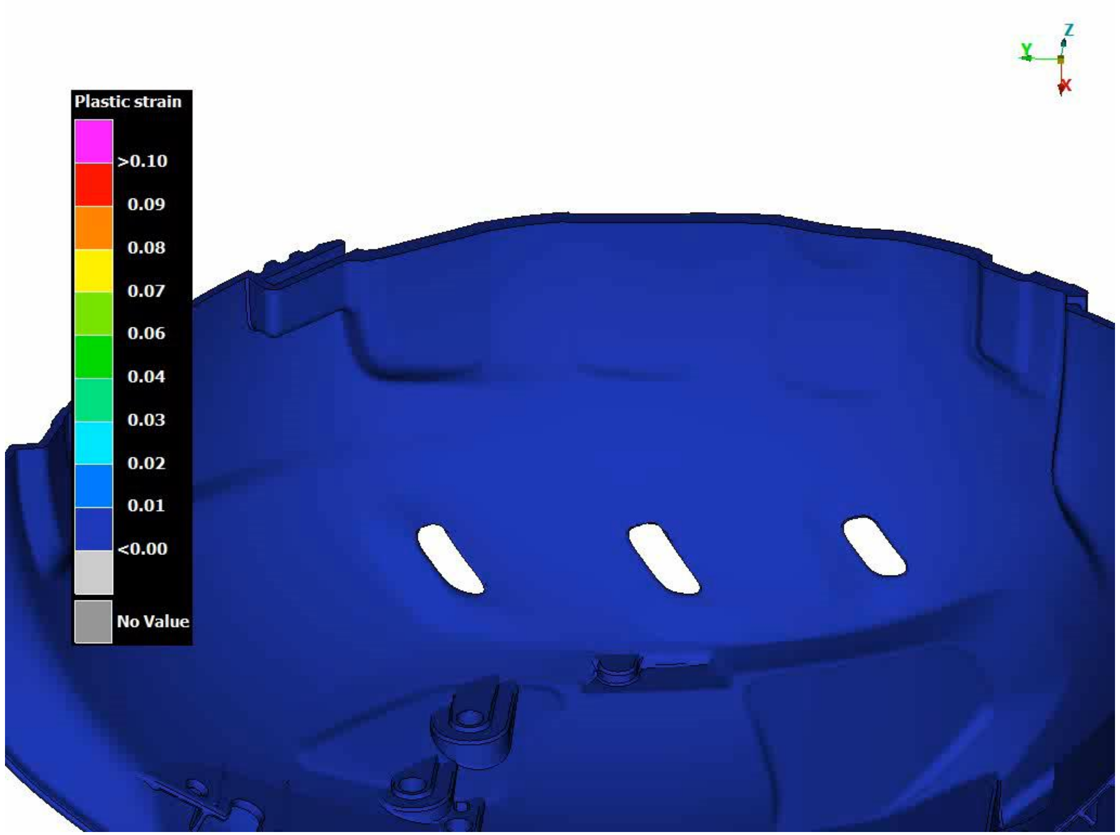




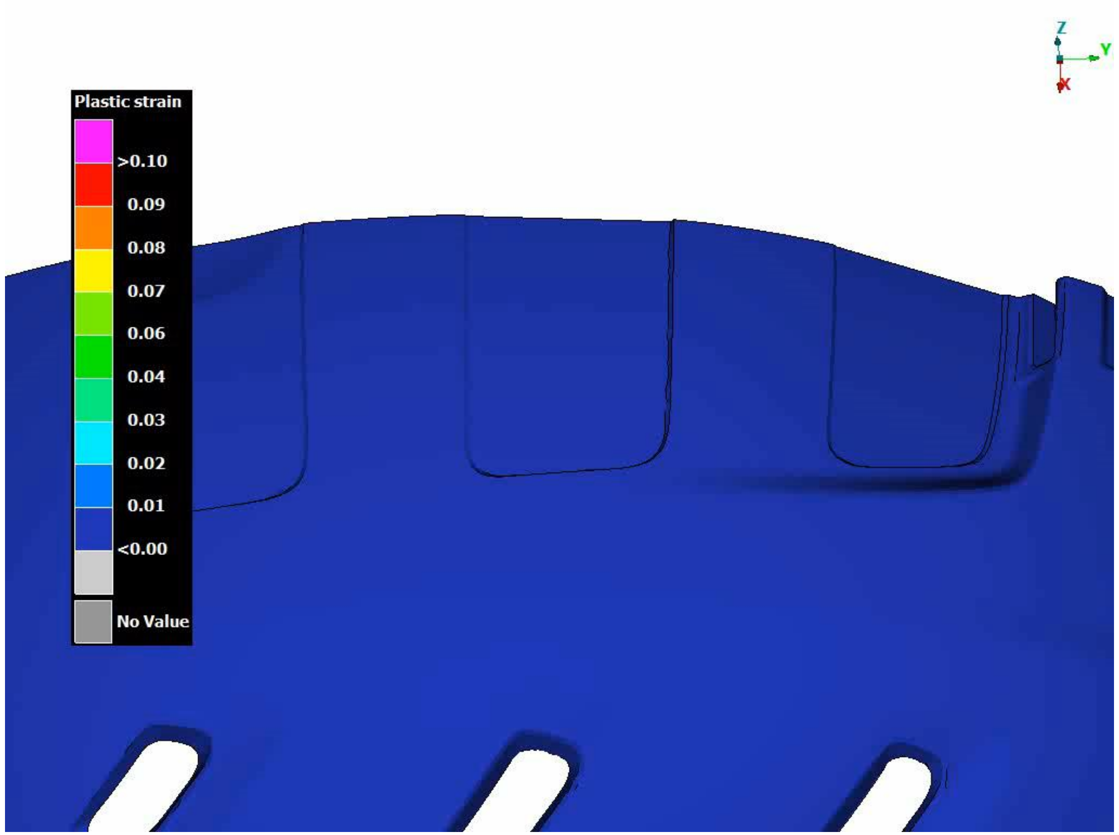
A lot of oscillations in the cold force curve. Freq ≈ 500 Hz

Helmet simulation

Animations, -30°C



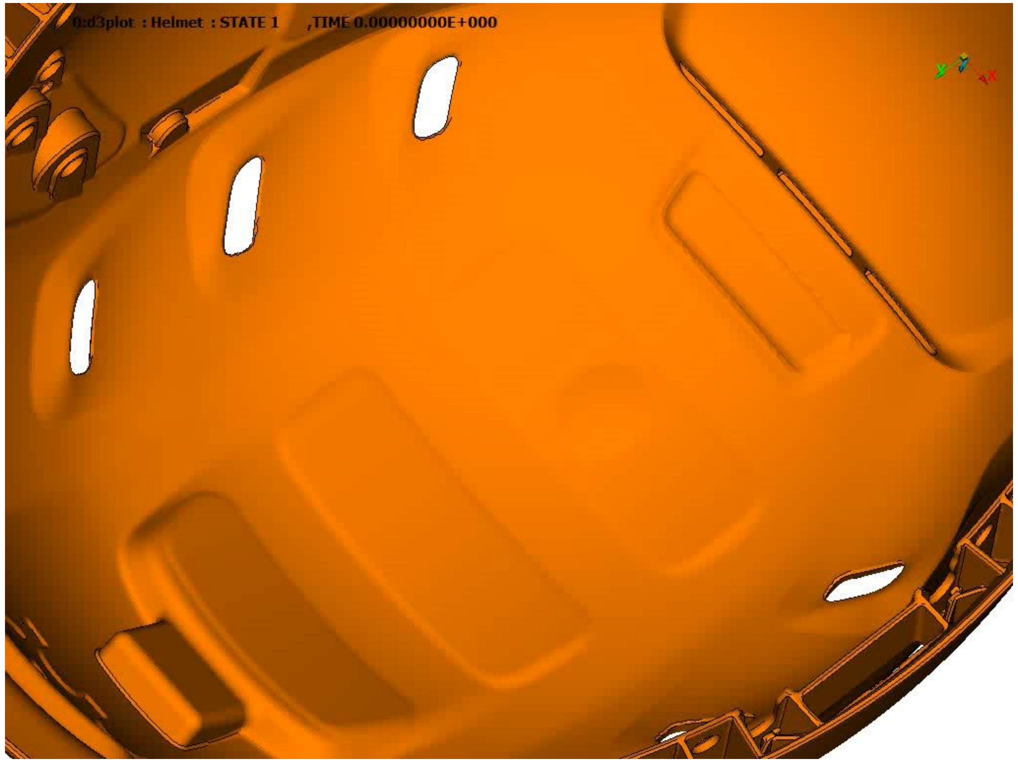
Plastic strain distribution, inside

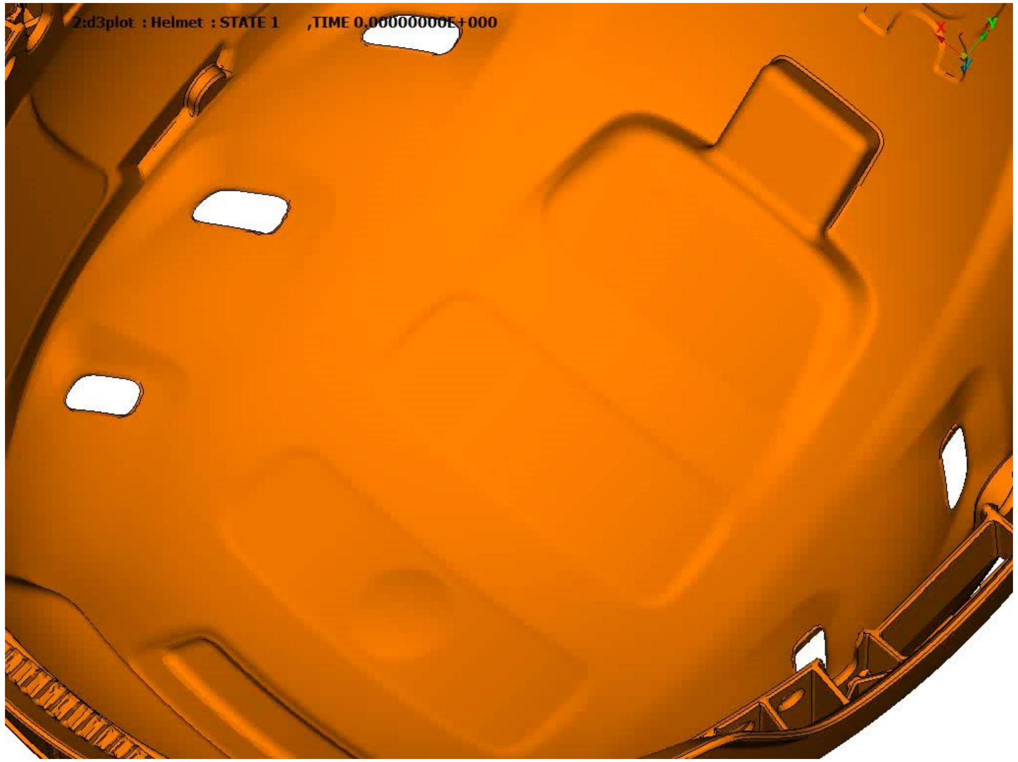


Plastic strain distribution, outside

Helmet simulation

Simulation of the penetration test (inside view)



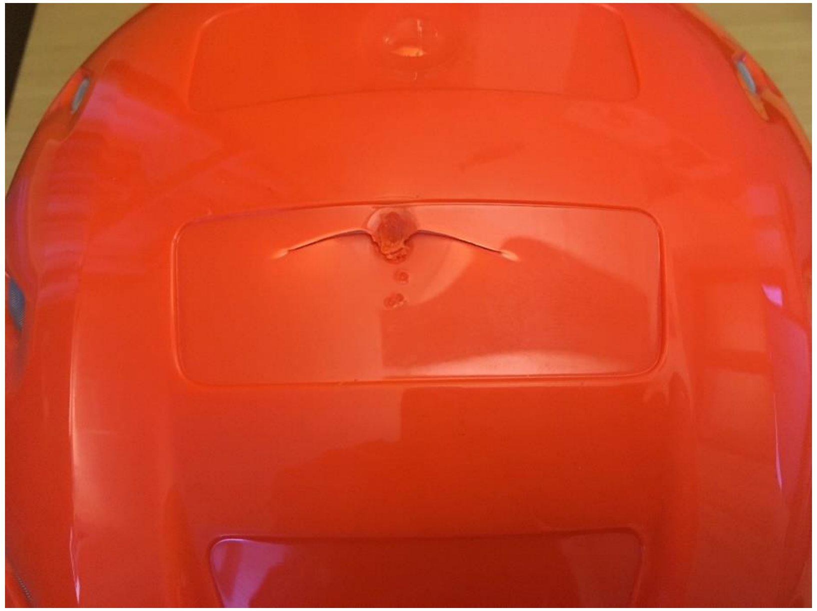


+50°C (no failure/damage model)

-30°C

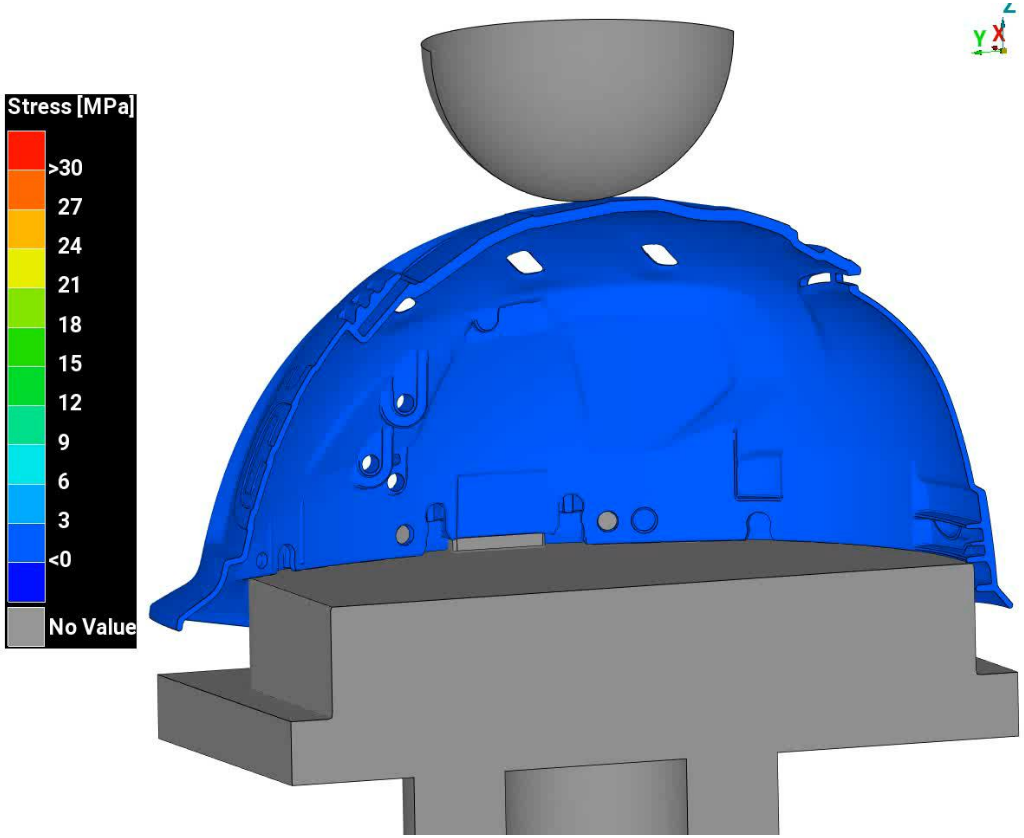
Helmet simulation

Comparison of crack pattern in -30°C



Helmet simulation

Simulation of cooling the helmet while it is mounted on the fixture

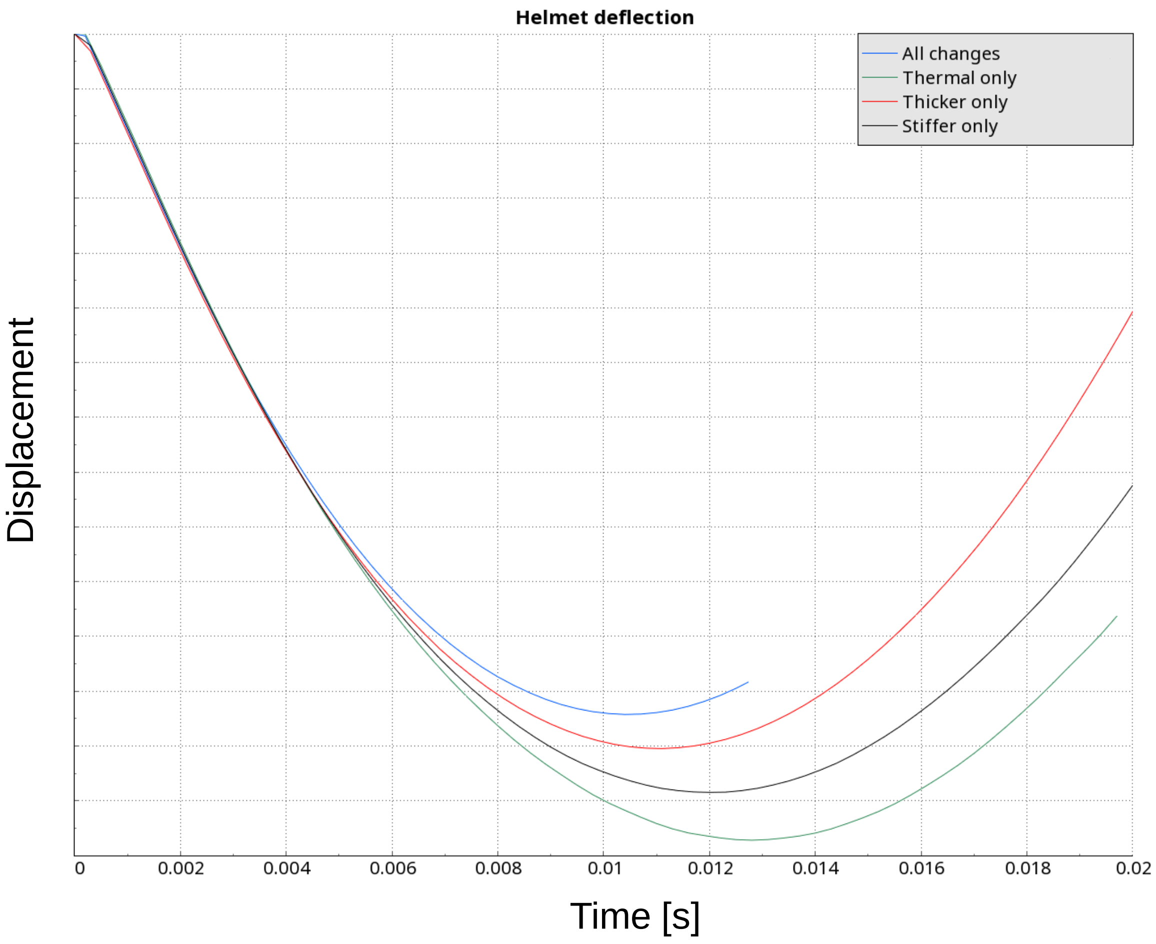


The resulting pre-tension and remaining stresses will make the helmet shell stiffer.

Other changes that was done to improve the correlation was: increased helmet thickness from 3.6 to 3.8 mm and usage of the highest measured E-modulus for the cold material data.

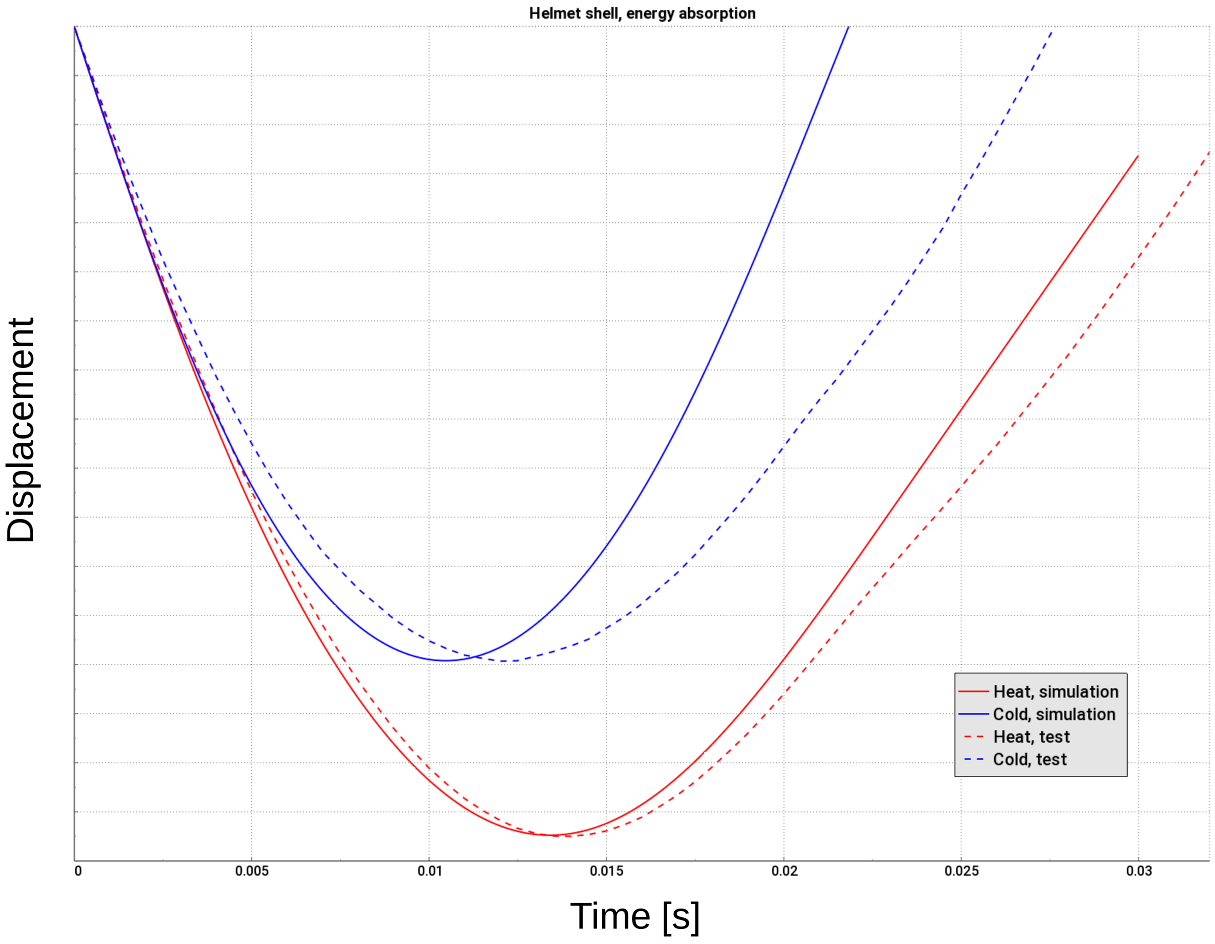
Helmet simulation

Influence of correlation parameters



Helmet simulation

Final comparison of deflection for both testing and simulation



Summary
• The fit of the helmet against the fixture in cold condition should be improved. • The provided material data for -30°C correlated with the test result after adjustments to the material thickness and elastic stiffness. A cooling simulation was also done before the impact. • The failure and damage criteria performs well considering the limitations in the scope of the testing. • Since the structural properties of plastic parts depends highly on the manufacturing process it is often not possible to do representative prototypes and it is crucial that simulations can predict the outcome of impact tests. The presented simulations give an opportunity to optimize the performance and minimize weight.

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