Virtual Verification of the Hemming Process – VIVFAP

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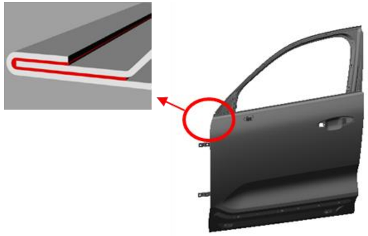
Motivation to project

- Problems with quality issues in products with hemmed edges cost much in time and cost
- Tuning and adjustments demand large efforts in time and money (complex cases can demand 700h)
- Simulation tools are used to a very limited extent
- Current simulation tools do not take glue/curing into account

Virtual Verification of the Hemming Process – VIVFAP

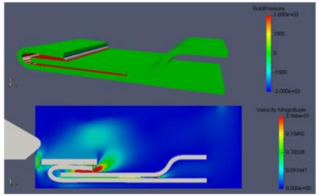
Project goals

- Implementation of methods and tools in industry for hemming simulation without adhesive
- Research and development of methods and tools that include the effect of adhesive in the hemming simulation



Benefits

- Shorter lead time for industrialization
- Less adjustment time for hemming process
- Improved quality for HOP parts



Project funding

- Total project budget: 16.65 MSEK
- Vinnova funding: 7.5 MSEK
- Industrial contribution: 9.15 MSEK

Project time

- April 2020 – November 2023

Project content

Workpackages:

WP 1 – Mapping of Hemming Process (State Of The Art)

WP 2 – Simulation of Hemming Process Without Glue

WP 3 – Simulation of Hemming Process With Glue

WP 4 – Curing Process and its Effect on The Hemming System

WP 5 – Measurement Processes

WP 6 – Quality

WP 7 – Administration

Result from industrial case study

Front Fender V54X - VCC

- **Aim:**
  - Verification model for hemming simulation without adhesive

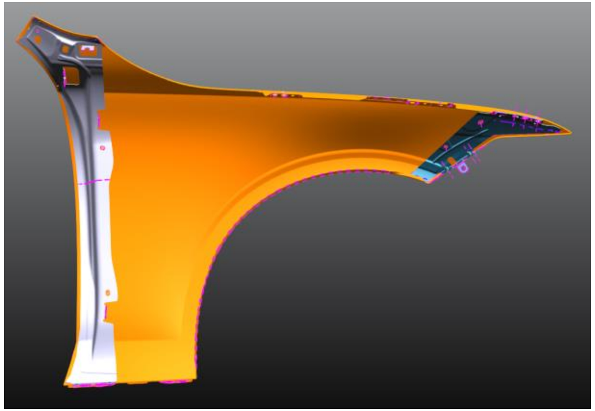
- **Model**
  - Simulation model based on nominal CAD
  - Initial simulations including assembly of reinforcements (riveting)

Overview Section

Source: Mats Sigvant, Autoform

  - Scanning of parts from ingoing processes in different steps
  - Analysis of spotting of hemming steel positions

- **Conclusion:**
  - Simulations and test shows good agreement
  - Non documented changes in the process where detected in simulations



Source: Philip Carlström, VCBC

Re

Front

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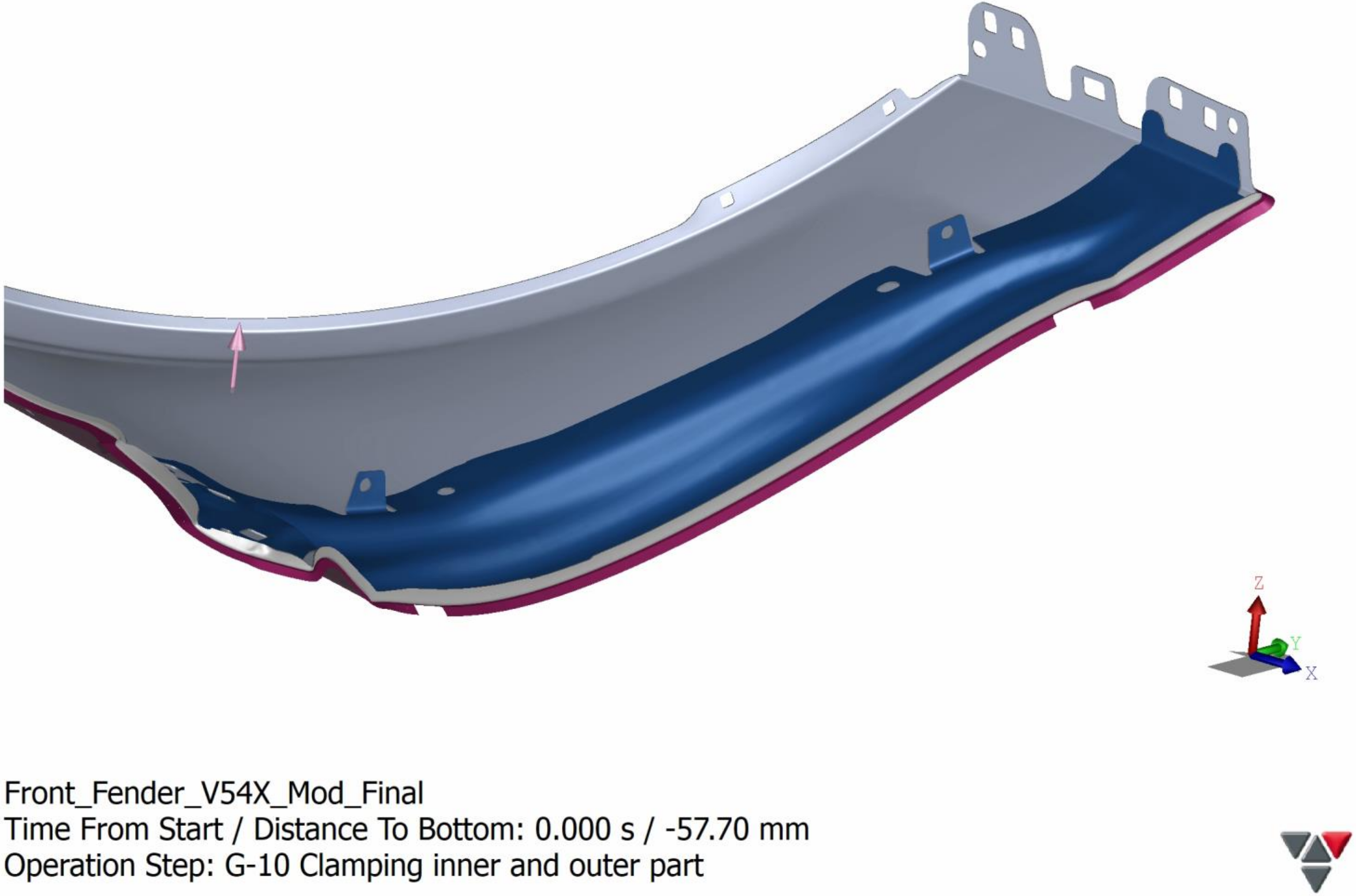

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ström, VCBC

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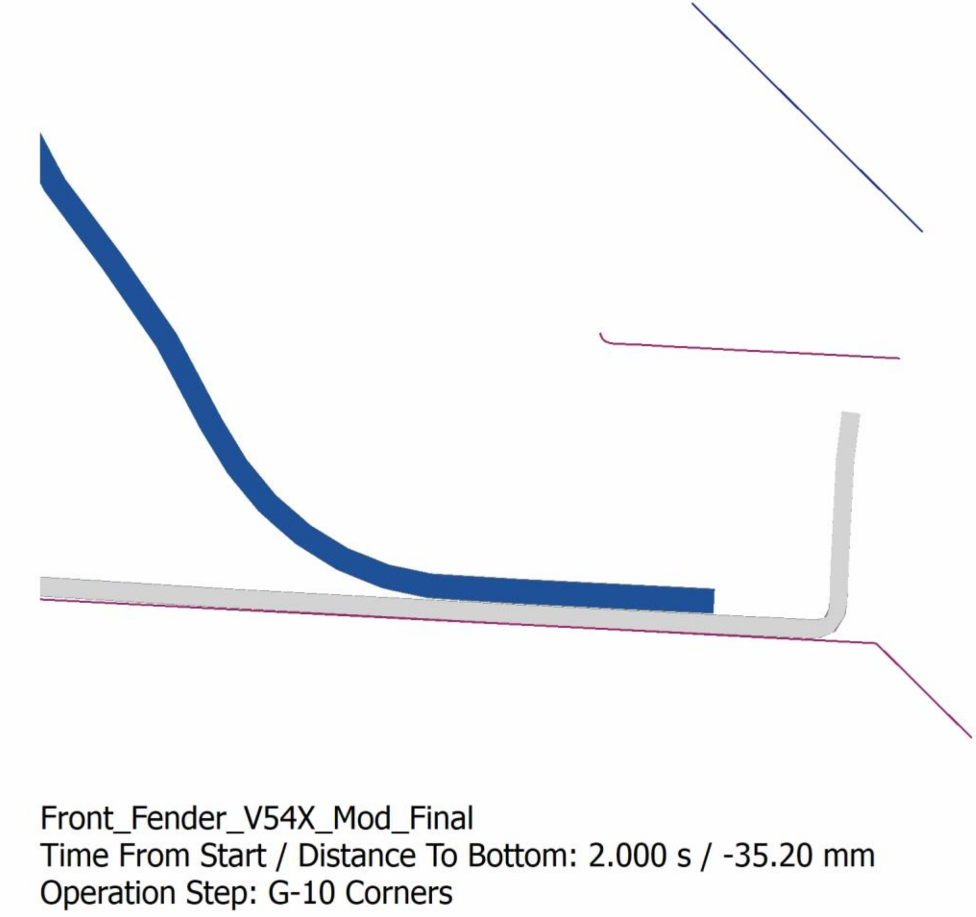
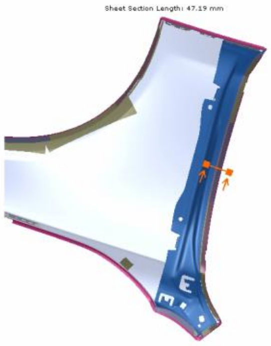
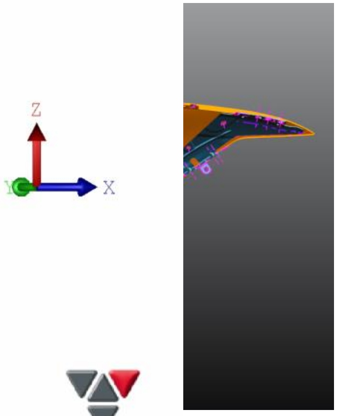






ström, VCBC

Modelling and optimization of adhesive joining process

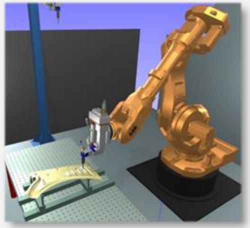
Hemming tool motions

Application path

Adhesive geometry

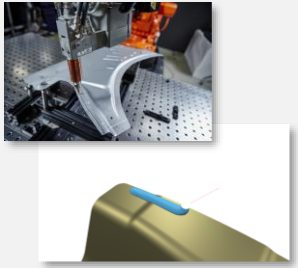
Joint geometry

Robot programming and optimization



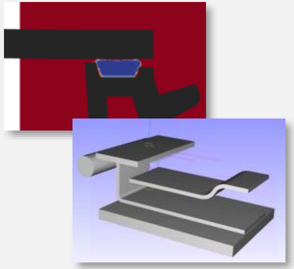
- Robot motions
- Cycle time

Adhesive extrusion



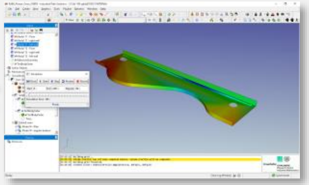
- Material consumption
- Adhesive geometry

Adhesive joining



- Joint geometry
- Reaction forces

Oven curing



- Temperature history
- Cured adhesive
- Structural stresses

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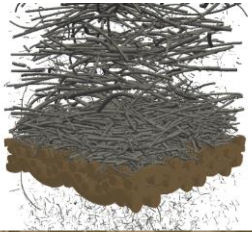
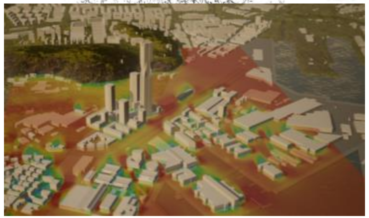
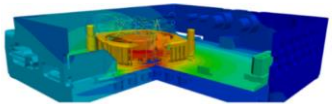
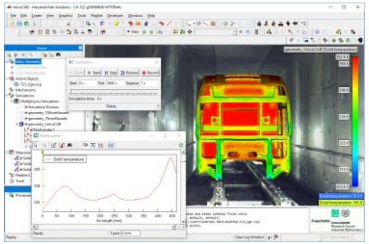
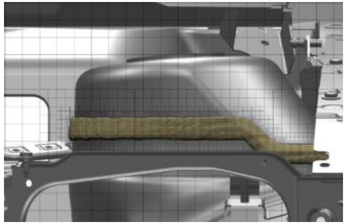
Immersed Boundary Octree Flow Solver

- State-of-the-art solver for complex flow applications
  - In-compressible finite volume solver
  - Coupling using SIMPLE-C method
  - Unique immersed boundary techniques
    - Greatly simplified pre-processing – no “bodyfitted” meshing
    - Dynamic and adaptive octree grid
  - GPU acceleration
  - Spalart-Allmaras and k-omega SST turbulence models with stress-based wall model treatment
  - Complex rheology
- Interfaces to other tools
  - LaStFEM™ for fluid-structure interaction
  - Demify® for DEM-CFD applications
  - CST MICROWAVE STUDIO for electronics cooling

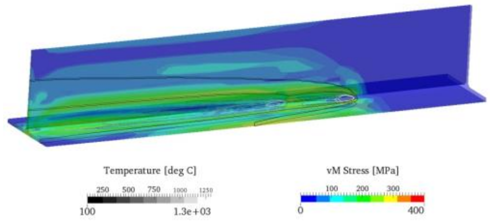


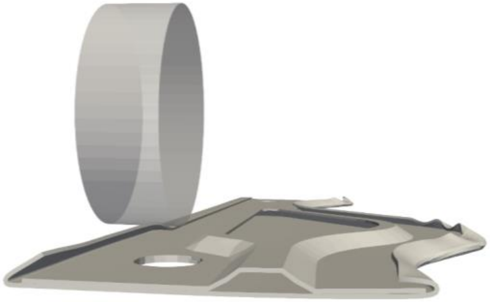





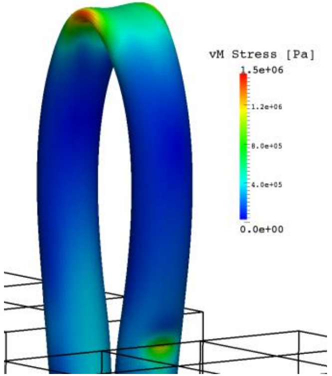
IPS IBOFLOW ®

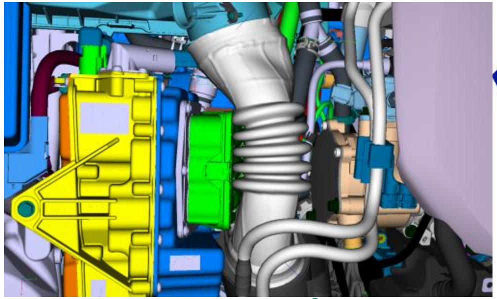
LaStFEM

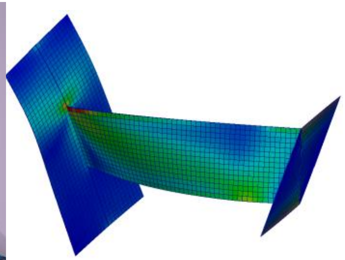
- Accurate simulations of structural deformations using the Finite Element Method (FEM)
- Models for slim and bulky structures undergoing large deflections and frictional contact
  - Steel, aluminium, rubber, composites
- Welding
  - Thermo-mechanical coupling
- FEM engine in several software tools
  - RD&T (Geometry assurance)
  - IPS Bellows & Grommets
  - IPS Flat Cables











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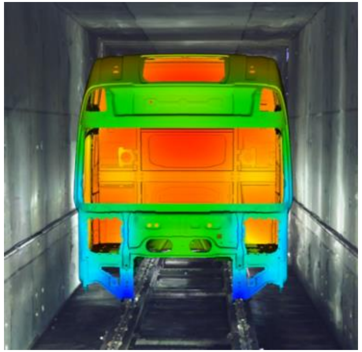
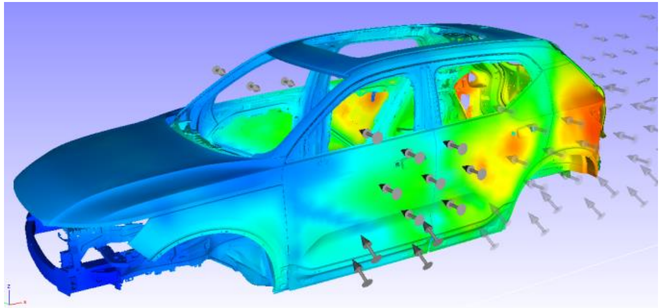
IPS Oven Simulation

Design your oven to optimize heat transfer and curing using unique simulation technology





- Unique algorithms for accurate and close to real time simulation of oven curing
- Powerful design tools and automatic meshing to setup your oven simulation in just a few hours
- Proven accuracy in industrial benchmarks
- Support for convective ovens
- Curing window analysis
- Export of temperature curves for thermomechanical analyses

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R&D contributions to simulation of adhesive joining

Flow solver

- Phase-dependent adaptive time-stepping and SIMPLE iterations have been introduced to optimize the adhesive's time step and thus reduce the total number of time steps.
- Adaptive volume mesh refinement to handle narrow gaps

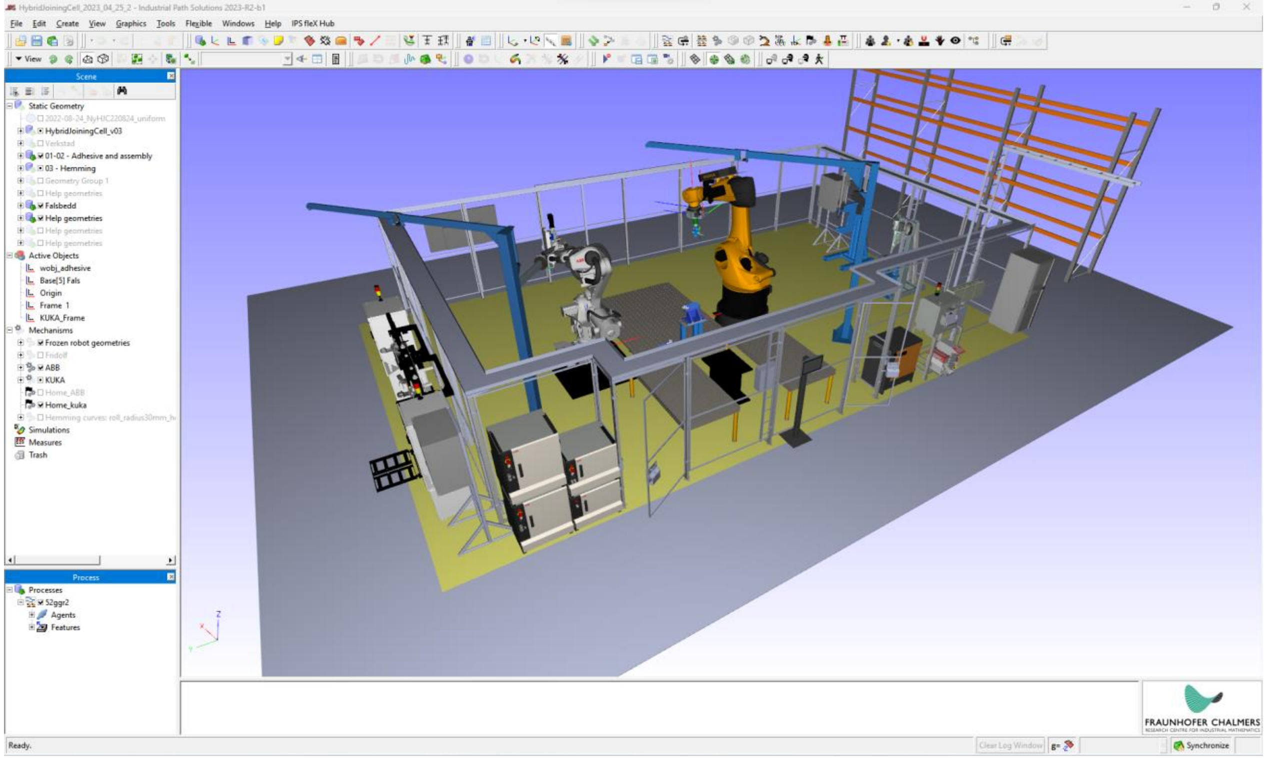
Adhesive

- A new backwards-tracking Lagrangian-Eulerian method has been developed to enable simulation of two-phase with a viscoelastic adhesive and the surrounding air
  - A Lagrangian-Eulerian Simulation Method for Viscoelastic Flows Applied to Adhesive Joining, S. Ingelsten, PhD thesis, Chalmers University of Technology, May 2022

Structural solver

- To improve prediction of sheet metal deformation an anisotropic plasticity model (YLD2000) for shell elements has been developed
- Improved matrix assembly. Allow for computation on active zone close to hemming tools

Hybrid joining cell @ RISE



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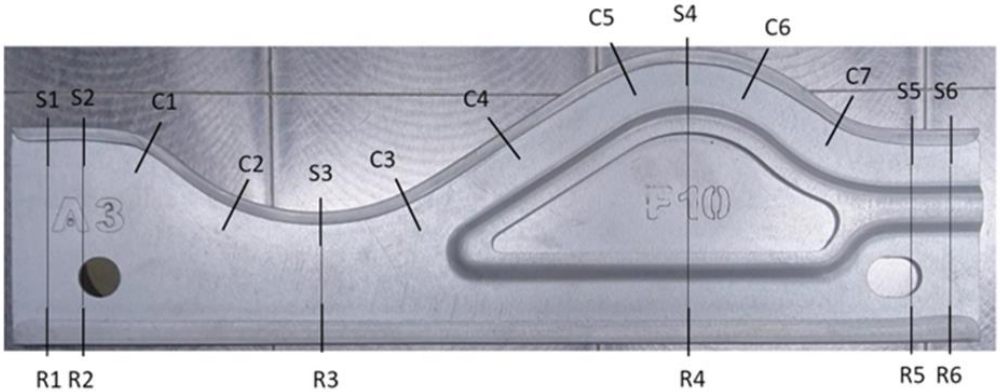
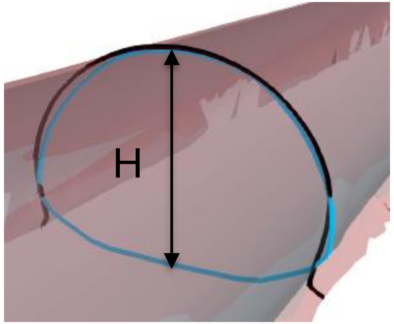
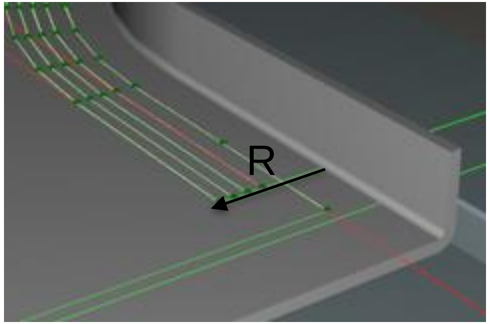
Experimental data from RISE

- Roll hemming of the test coupon performed at RISE
- Several test sections are studied and measured
- Adhesive bead height (H) and distance from flange varied (R)
  - H = 2.5, 3.0 and 3.5 mm
  - R = 5.5 and 8.5 mm
- After the hemming the coupon with adhesive is scanned







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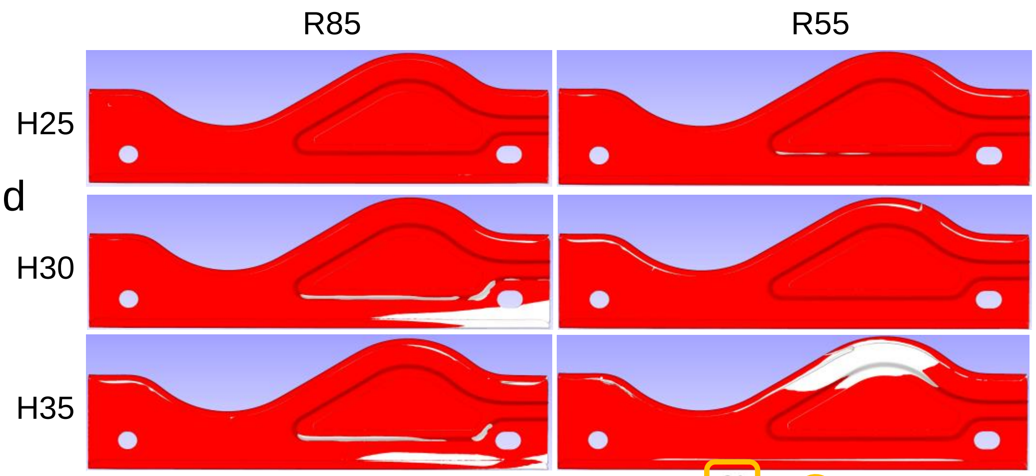
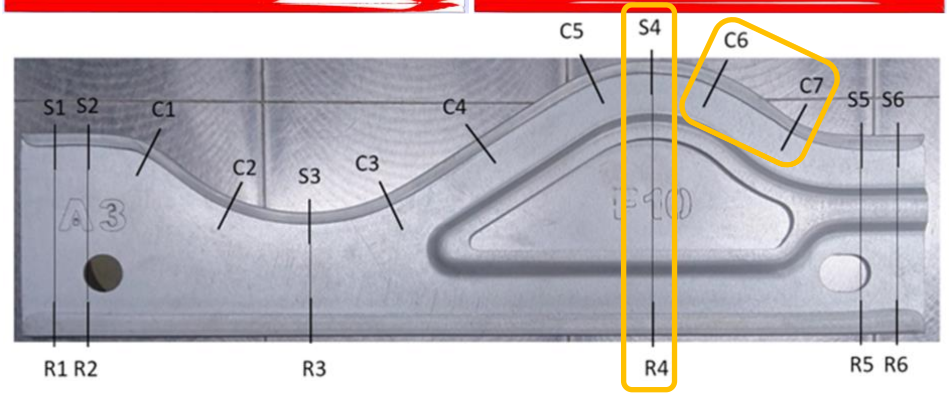
Define validation areas

- Identify areas with squeeze-out and not too close to start of bead
- S4 and R4 base case with squeeze-out for both adhesive beads
- Area between C6 and C7 has curved hemming combined with squeeze-out
- These three areas are chosen for experimental validation of the adhesive hemming simulations





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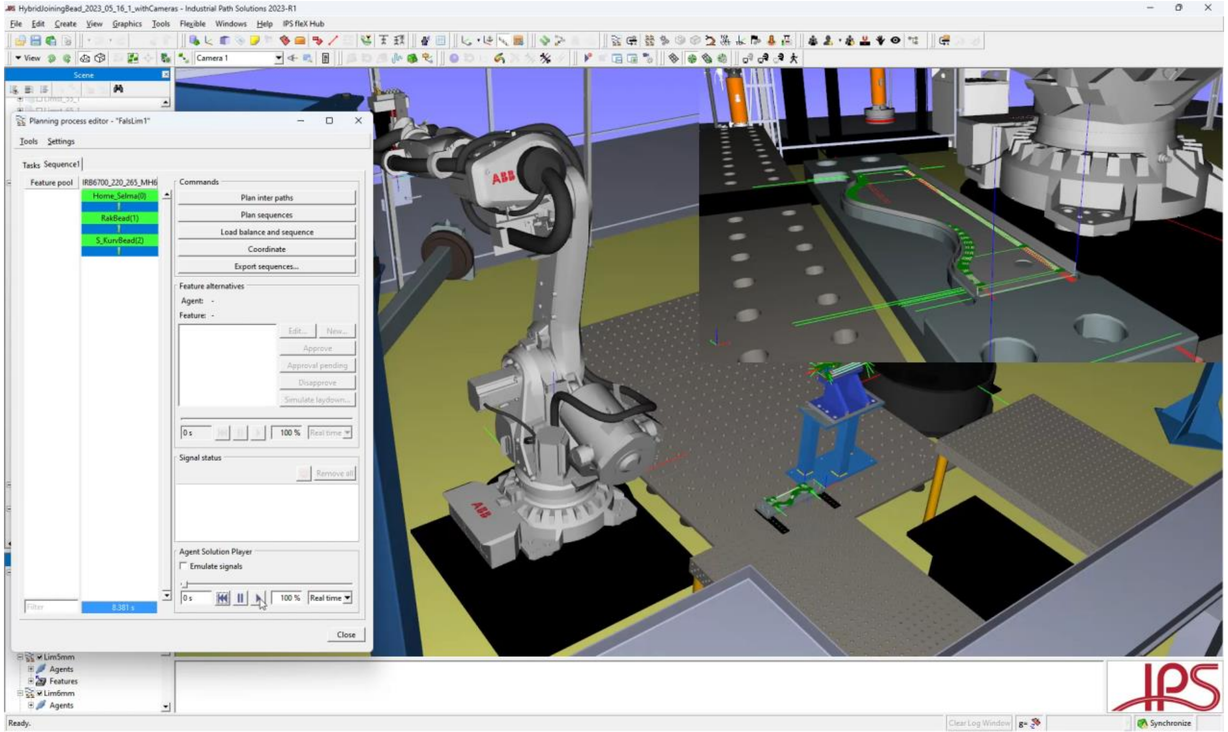
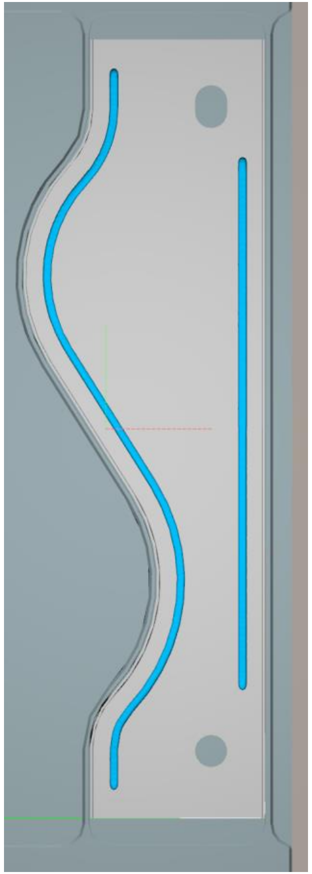
Adhesive extrusion





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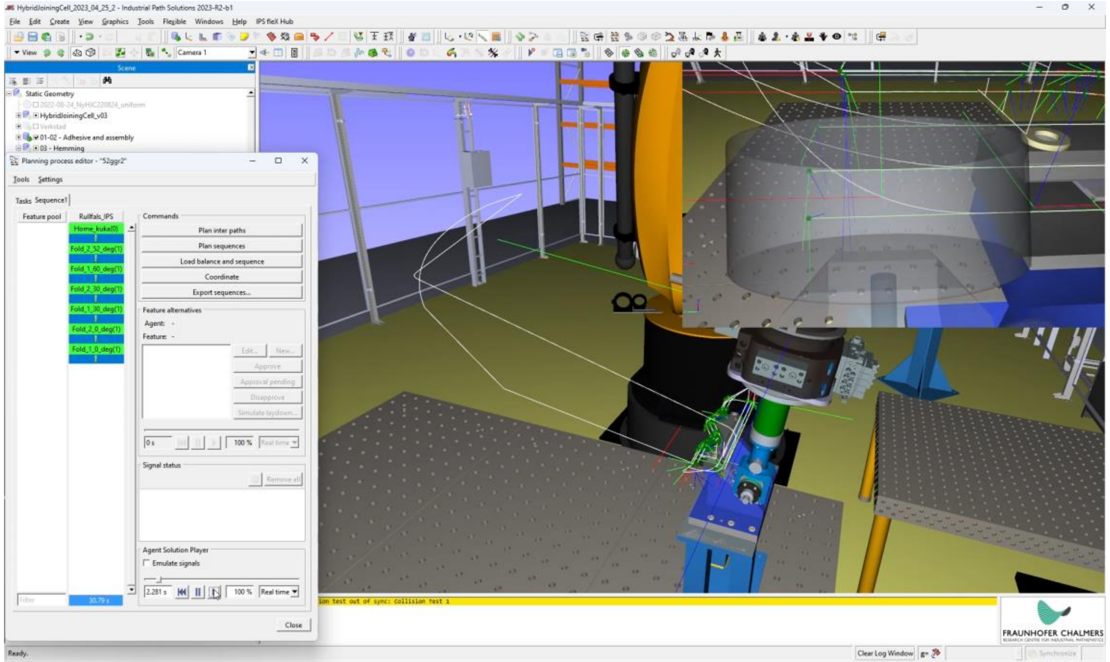
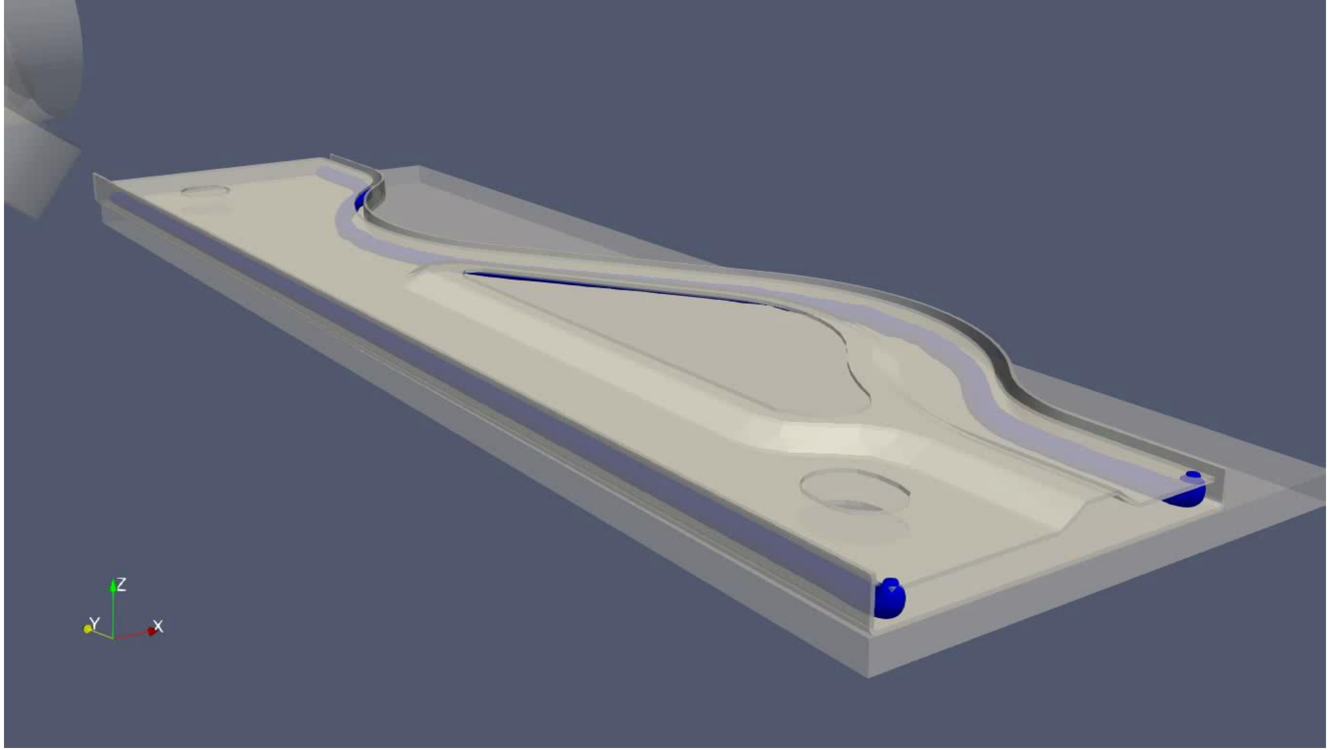
Creation of hemming paths

- Nominal paths are created from recipe and base curve
- Used for planning of robot motion



Full coupon simulation with adhesive



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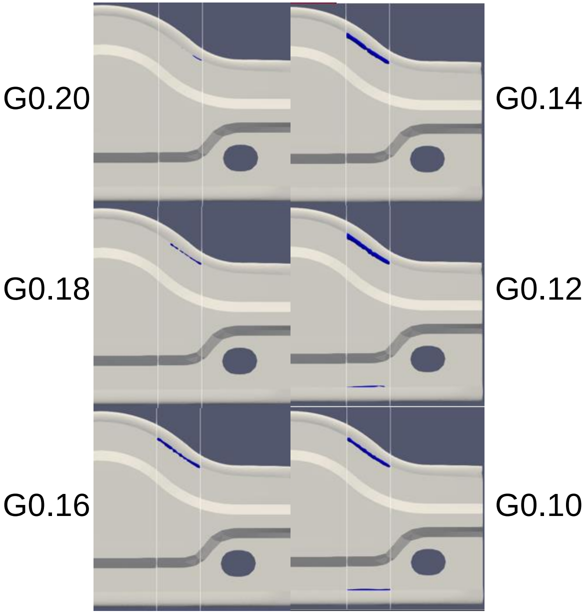
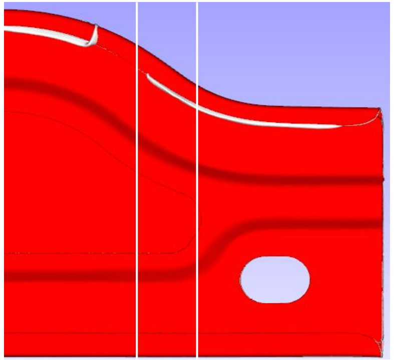
Nominal gap calibration for C6-C7

- The H = 3mm and R = 8.5 mm experimental setup is used in the calibration
- The area between C6 and C7 is simulated to determine the nominal gaps between the parts
- The simulated squeezed-out adhesive is colored blue
- Several simulations of the area are performed with the gap varying from G = 0.2 to 0.1 mm
- Gap 0.16 mm gives best comparison and is considered as the calibrated value



Hemming simulations



Hemming experiments

Comparison between simulation and experiments R55

- Distance from bead to flange 5.5 mm
- Gap set to 0.16 mm

- Signs of squeeze-out for R55H25
- Some squeeze-out R55H30
- Large squeeze-out for R55H35

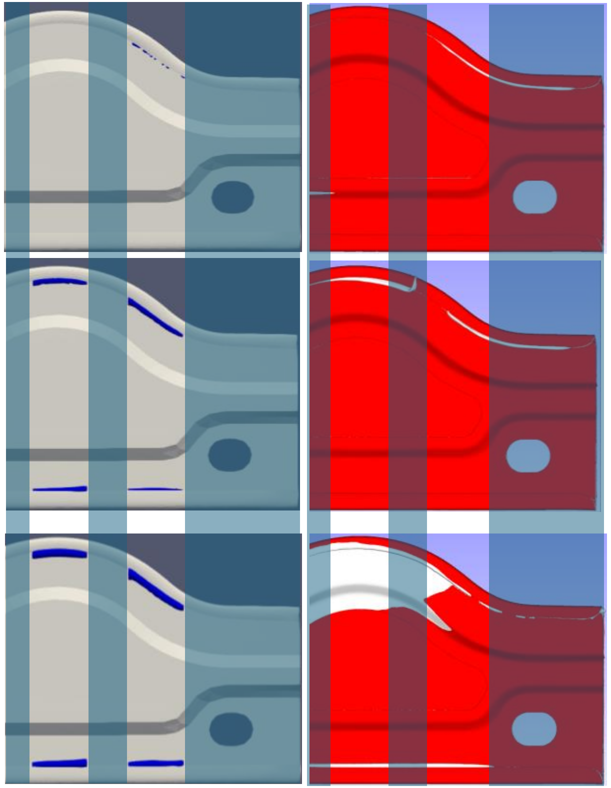
- Trend captured
- Slightly overpredicts amount of squeeze-out, especially for straight side

- Note that the hemming roll has taken a large amount of adhesive from R55H35

R55H25

R55H30

R55H35



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Comparison between simulation and experiments R85

- Distance from bead to flange 8.5 mm
- Gap set to 0.16 mm

- No squeeze-out for R85H25
- Signs of squeeze-out for R85H30
- Squeeze-out for R85H35

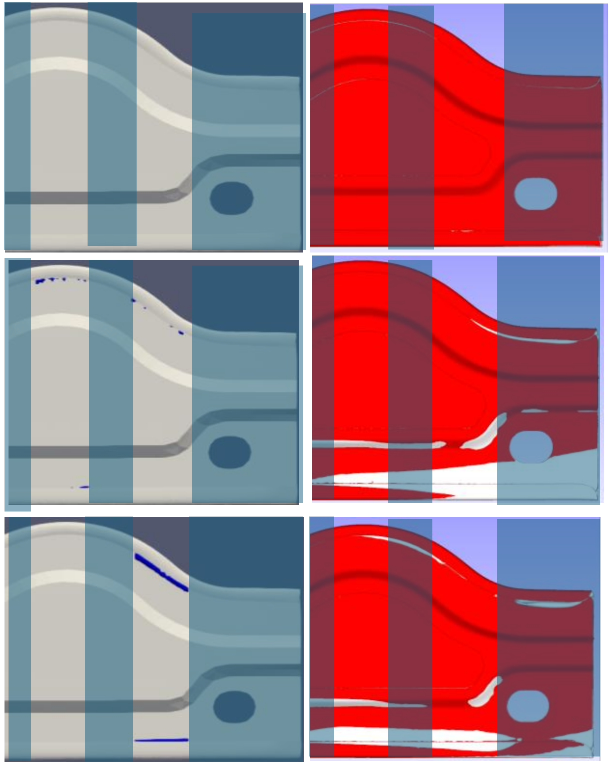
- Trend captured
- Slightly overpredicts amount of squeeze-out, especially for straight side

- Note that the hemming roll has taken some amount of adhesive from R85H35

R85H25

R85H30

R85H35



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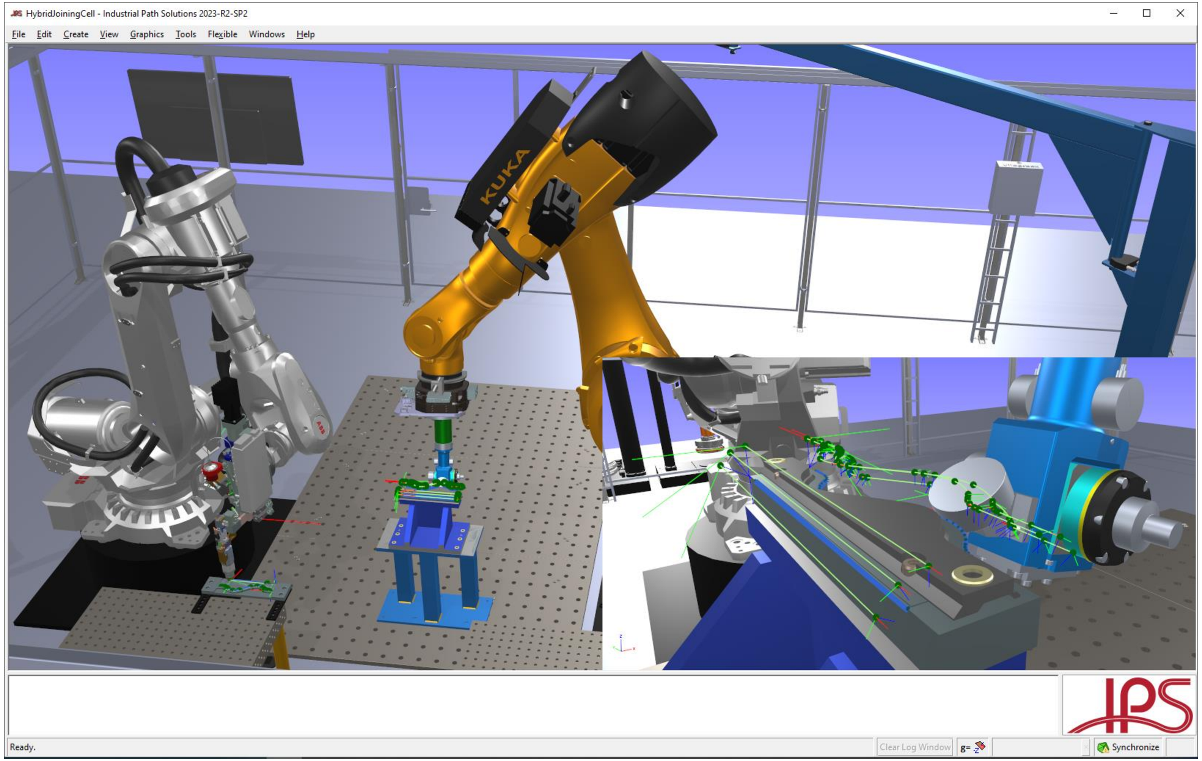
Software demonstrator



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Summary and future work

- Validation of simulation results against SAM-scanned test bodies from roller hemming with and without adhesive
  - Without adhesive, good prediction of roll-in and hem thickness have been obtained
  - With adhesive, several sections of the coupon have been measured in detail for three different adhesive bead heights and two distances from the hem edge. General trends in adhesive squeeze-out are captured
- Three journal articles, one doctoral thesis and presentations at five conferences
- Ongoing discussions with several companies on adhesive joining simulations including applications in body and battery assembly