Hot Stamping Experience and Tech Tour

Hot Stamping Die Development and Process Simulation
(Industrial B-pillar in 1.6 mm Usibor® 1500 AS)

November 29-30, 2022

Novi, MI

ArcelorMittal

DIVERSIFIED TOOLING GROUP

<u>ArcelorMittal:</u>

T. Lim, H. Yao, K. Compton, P. Patel, H. Song

<u>American Tooling Center:</u>

M. Austin

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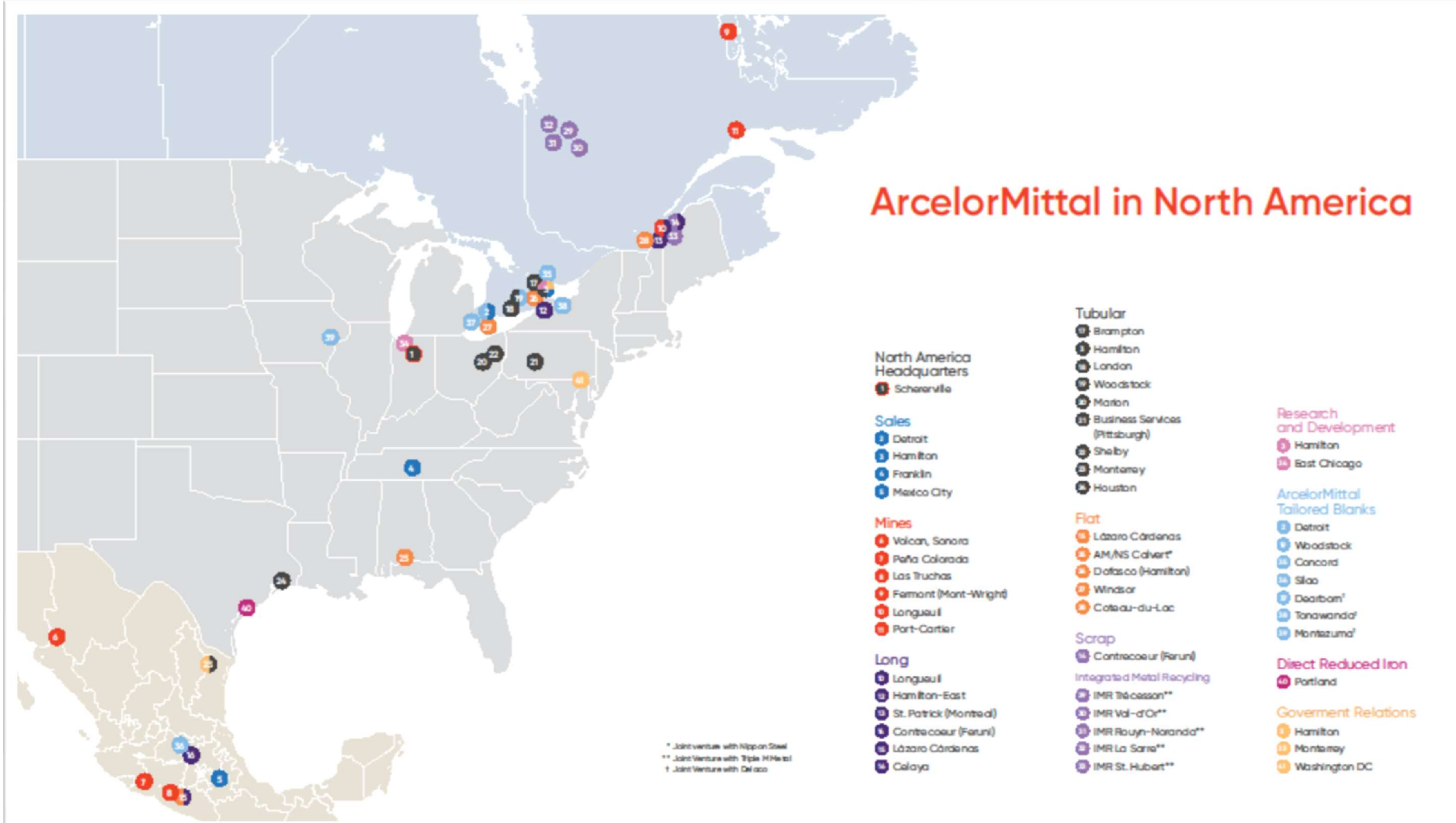
Introduction / Objective

- ArcelorMittal – leading global supplier of press hardened steel (PHS) products
- ArcelorMittal approached American Tooling Center (ATC) as an industrial press technology partner, and commissioned ATC to manufacture a production intent PHS B-pillar tool
- Part selected by ArcelorMittal and tool designed by ATC to represent a challenging part
- Objective is to study stamping conditions and process windows required for good, robust parts for various PHS grades under industrial production conditions
  - Usibor® 1500, Usibor® 2000, Ductibor® 1000, Ductibor® 500
  - Monolithic and same-gauge LWB combinations
- The tool was designed for 1.6 mm Usibor® 1500 AS
- Scope of this presentation – commissioning activities and FEA support

About ArcelorMittal

Scale	Sustainability	Innovation
Steel manufacturing in **16** countries	Group-wide target of **Net Zero** carbon emissions by 2050	More than **100** R&D programs in progress
Customers in **155** countries	Company's number 1 priority **H&S** since our formation in 2006	More than **724+** Active patent families
157,909 employees in 2021	**69.1** Million tones of crude steel production in 2021	**51** New products and solutions launched in 2021

ArcelorMittal North American Footprint



Global Research and Development Footprint

ArcelorMittal

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11 Geographical sites – 15 Research centres

Canada
Hamilton

USA
East Chicago
Southfield

Brazil
Tubarão

France
Le Creusot
Maizières
Montataire

Spain
Asturias
Basque Country

Belgium
Gent
*Liège (CRM)**

Luxembourg
Esch-sur-Alzette

Presence at customer location on 3 continents

Canada USA

Europe

China South Korea Japan

On-site product and process portfolio deployment:

- Product Development Engineers
- Resident Engineers
- Process Development and Deployment Specialists

* Strategic Partner

DIVERSIFIED TOOLING
G • R • O • U • P

ArcelorMittal

dtg
Full-Service

Superior Cam

Midland Design

Bespro Pattern

American Tooling Center

Full Service Tool & Die Operations

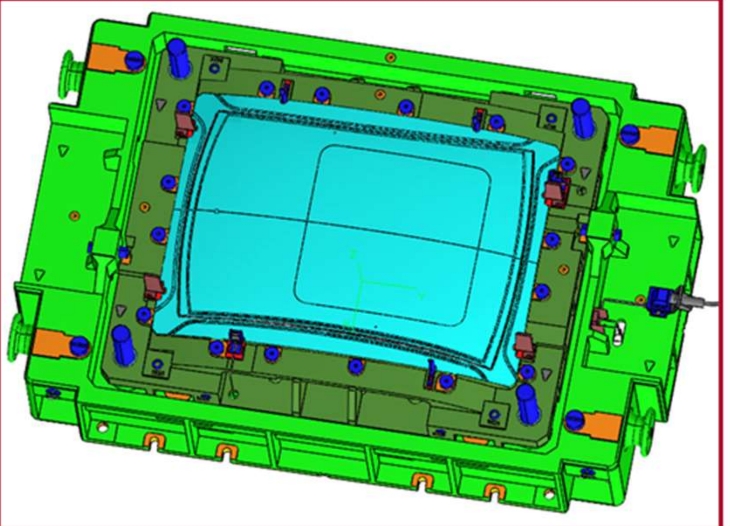
Superior Cam

Superior Cam has established itself as a technical leader in the Prototype Sheet Metal Industry during the past 46 years. Superior Cam specializes in low volume production parts and assemblies. We have built a reputation as an innovative, experienced and reliable full service operation which emphasizes production intent quality at every step of the tooling process.

Bespro Pattern

During the past 65 years Bespro Pattern has developed an excellent reputation for quality, timing and competitive prices. We are a respected leader in the CNC machining of poly patterns, wood patterns and urethane patterns off solid CAD die design.

425 Highly Skilled Workers
775,000 Sq. Ft. of Facilities



Midland Design

Midland Design has 50 years of experience designing all types of vehicle sheet metal stamping dies. Midland Design is regarded as a leader in the field of "Solid CAD Die Design." Midland Design has extensive experience servicing domestic and overseas customers with stamping engineering, die processing and die design.

American Tooling Center Grass Lake

American Tooling Center is a modern state-of-the-art Tool and Die facility. Our full service operation was designed and constructed in 1992 as a world class production die facility which emphasizes a CAD/CAM/CNC utilization. American Tooling Center is actively engaged in domestic build and outsourcing tooling on a global scale for the past 25 years.

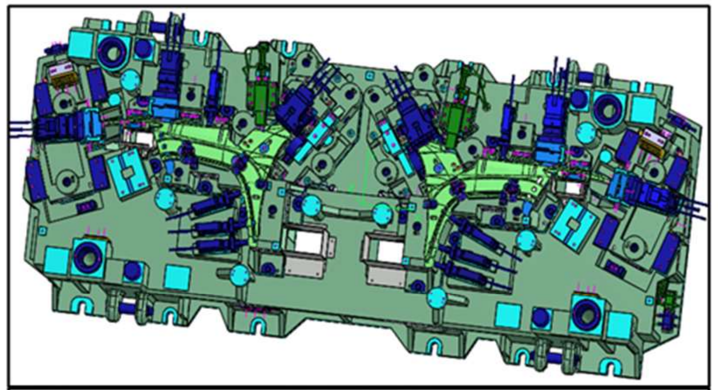
Full Service Tool & Die For Stamping

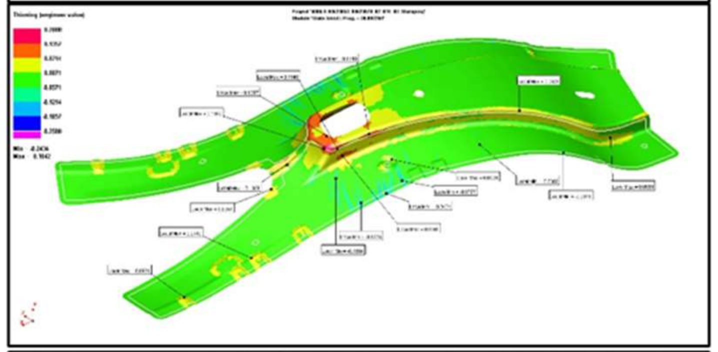
Midland Design Service

- Cad Draw Developments
- FEA Simulation
- Die Process
- Solid CAD Die Design – Cold & Hot Stampings. (Catia, Unigraphics)
- Hot Stamping Simulations

Bespro Pattern, Inc.

- Solid Modeling
- Solid Pattern Design
- CNC Machined Patterns
- Foundry – (Outside Sourcing)





Superior Cam | Midland Design | Bespro Pattern | American Tooling Center

Full Service Sheet Metal
Prototype & Low Volume Production

Superior Cam, Inc.

- Prototype Parts
- Prototype Assemblies
- Low Volume Production
- Low Volume Assembly
- Low Volume Robotic Welding
- Low Volume Robotic Roller Hemming
- Low Volume Production Door Assembly


Superior Cam | Midland Design | Bespro Pattern | American Tooling Center

Full Service Tool & Die For Stamping

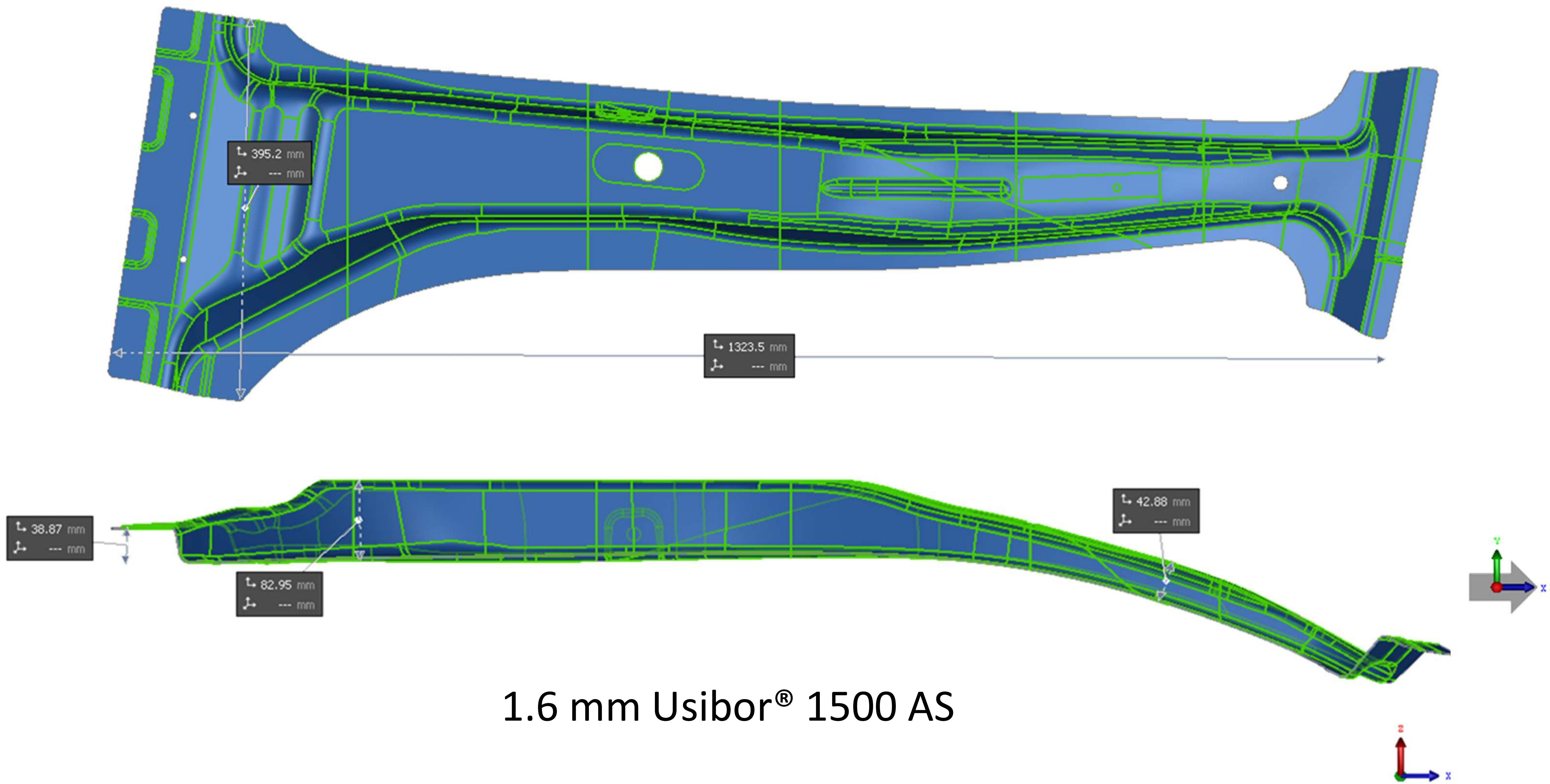
American Tooling Center

- CNC Programming
- CNC Machining
- Die Assembly
- Die Tryout
- Die Buyoff
- Quality / Inspection
- Home line Support
- Hot Stamping Dies & PHS Press Validation
- Certified PHS Laboratory

Superior Cam Midland Design Bespro Pattern American Tooling Center

B-pillar - Part / Press / tooling

B-pillar Part



1.6 mm Usibor® 1500 AS

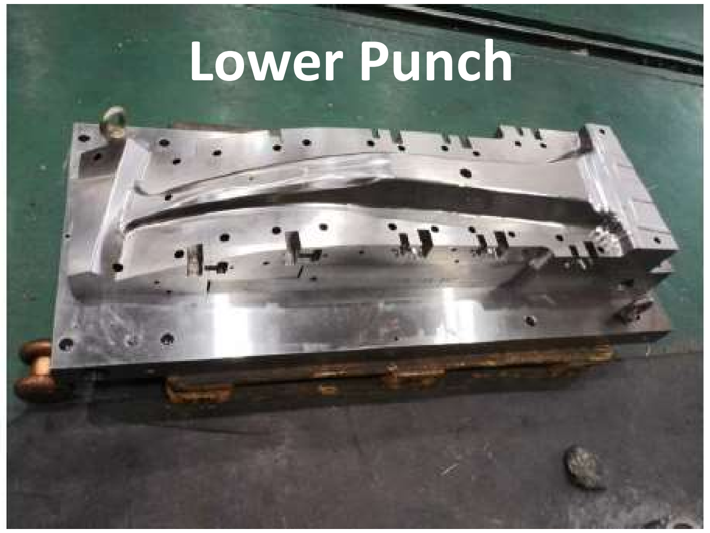
AP&T Press Cell

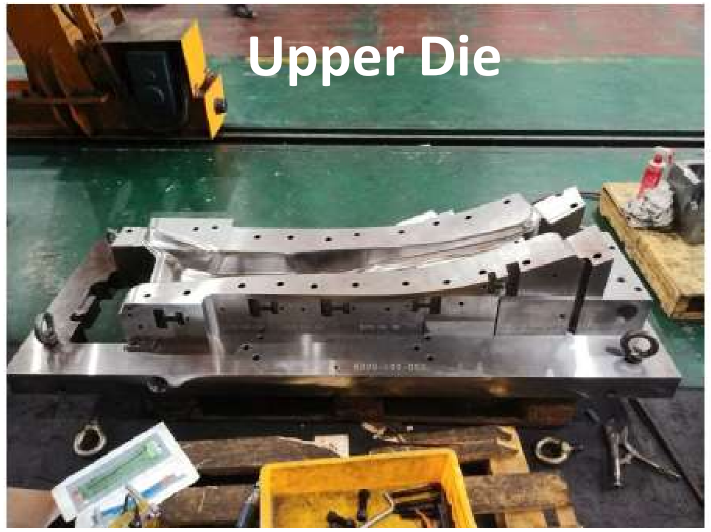
ArcelorMittal

DIVERSIFIED TOOLING GROUP

- 12,000 kN open loop hydraulic press
  - Servo controlled hydraulic pumps to provide press force
  - Servo controlled valves to control velocity, force, and other variables in the press process.
- Previously used for low volume supply of hot stamped parts
- Authorized production press to several automotive OEMs

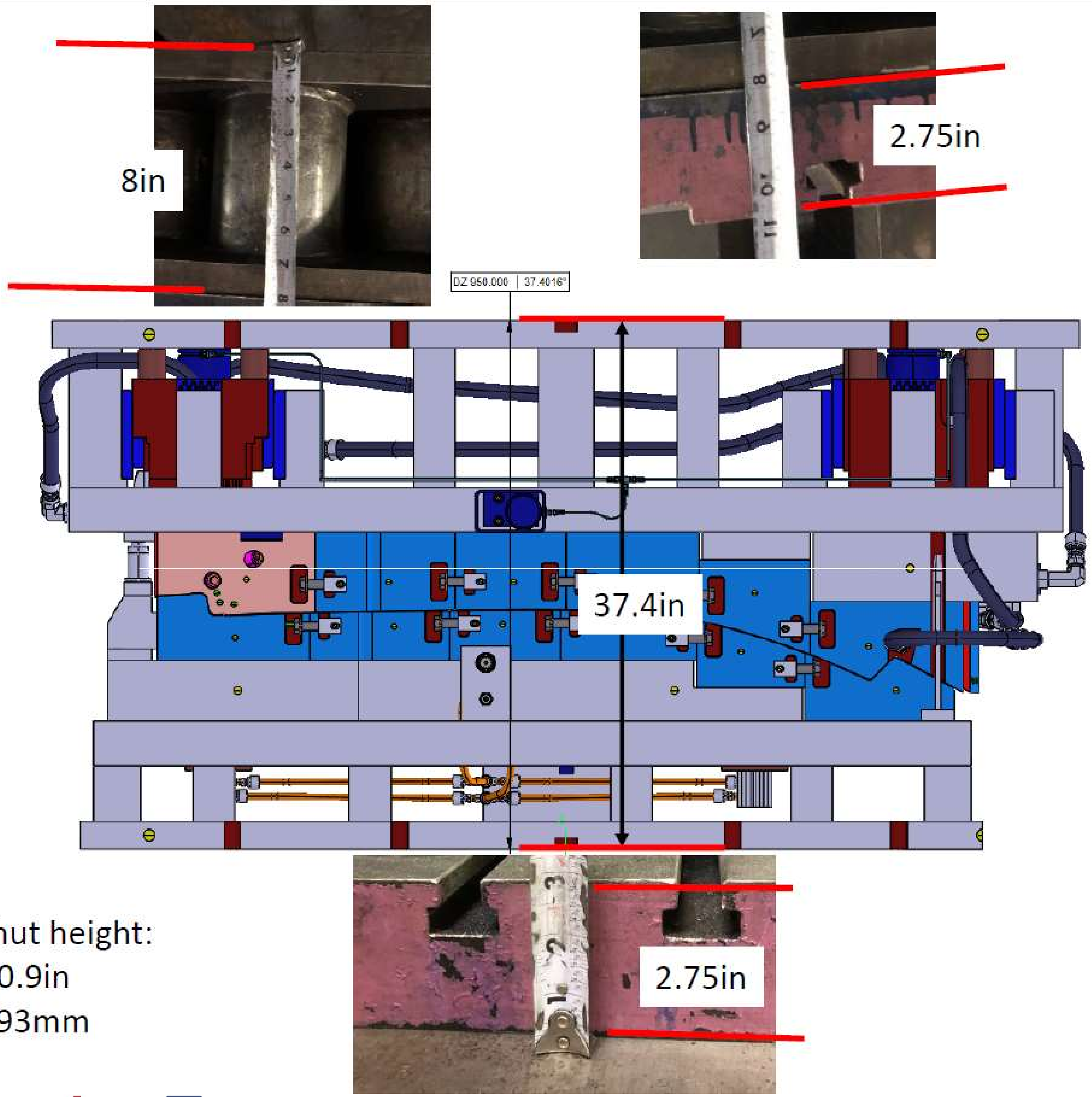
Tooling Components and Assembly





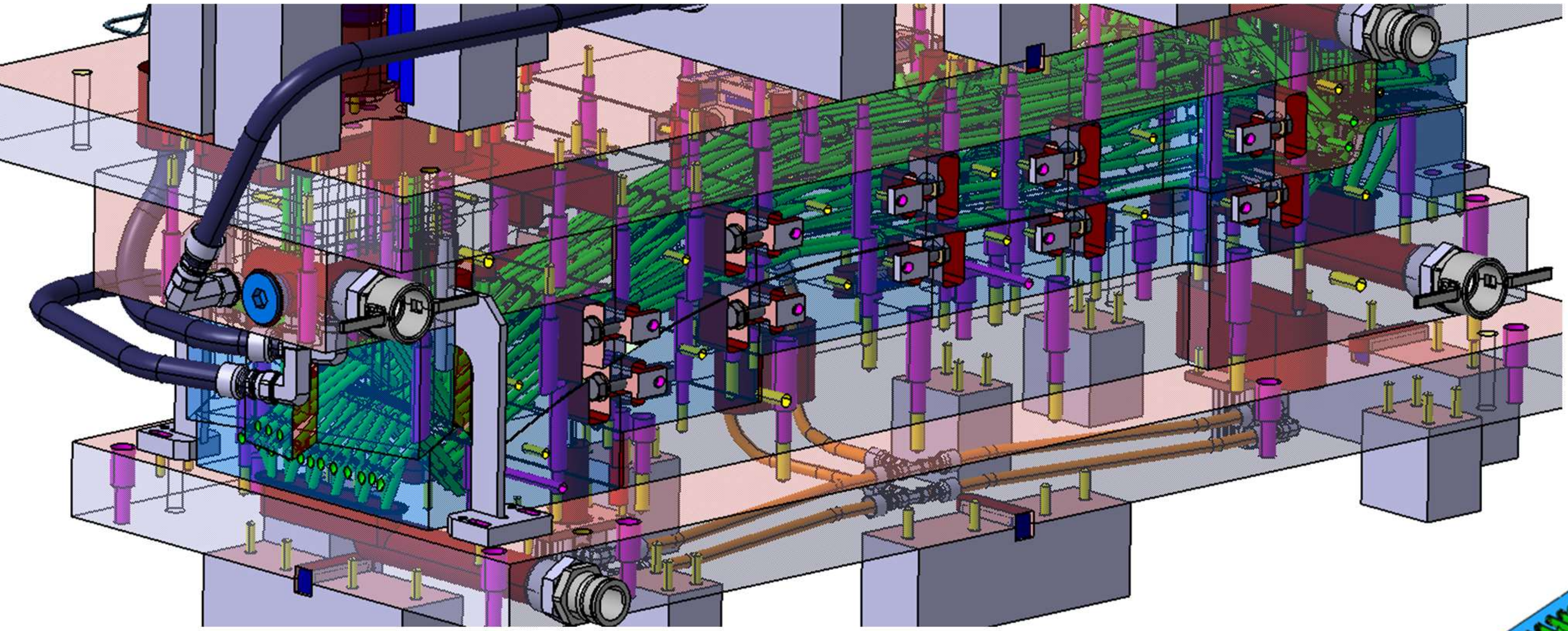
Not intended for large volume production

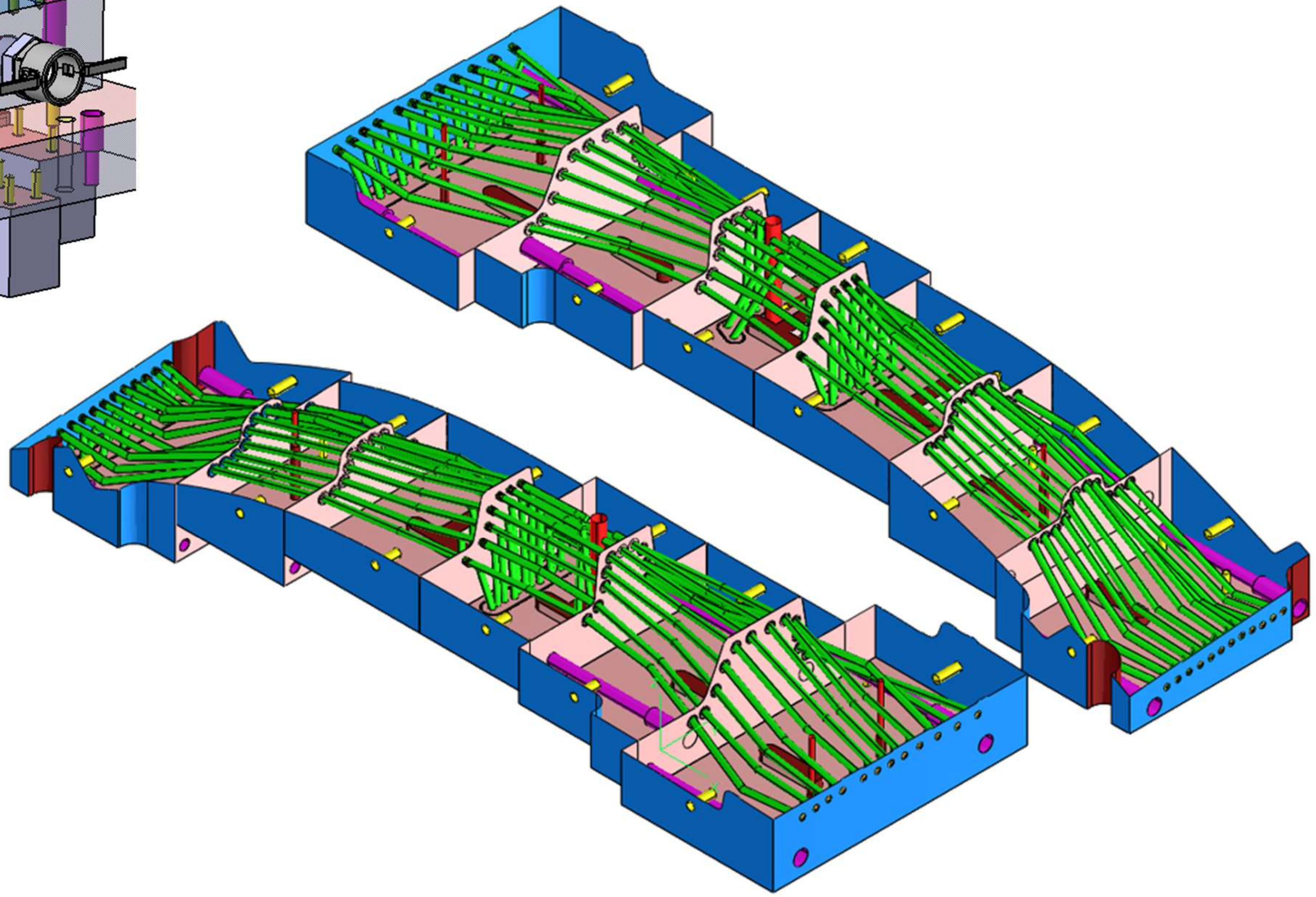
Press Build Up



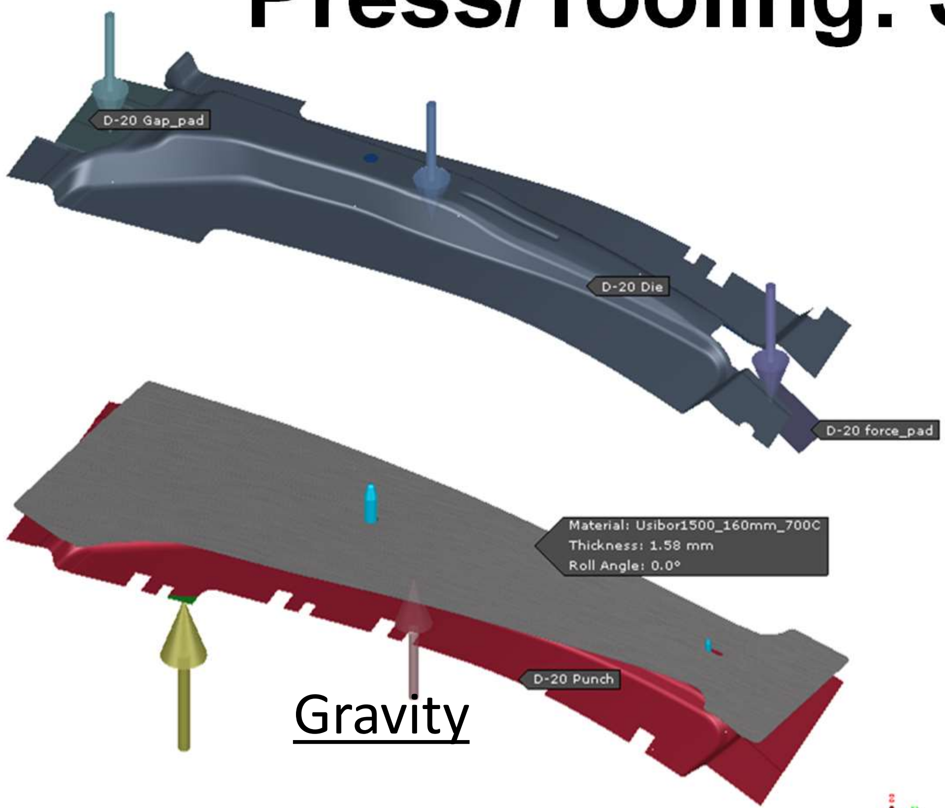
Total shut height:
50.9in
1293mm

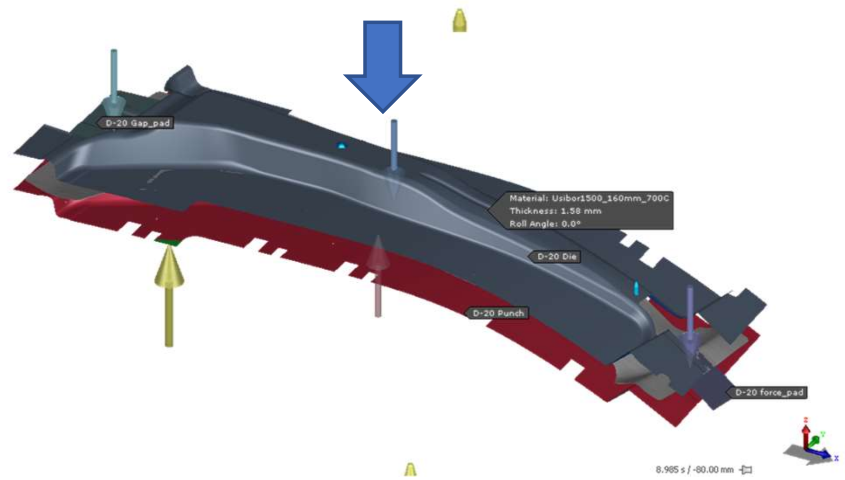
Cooling Water Channels





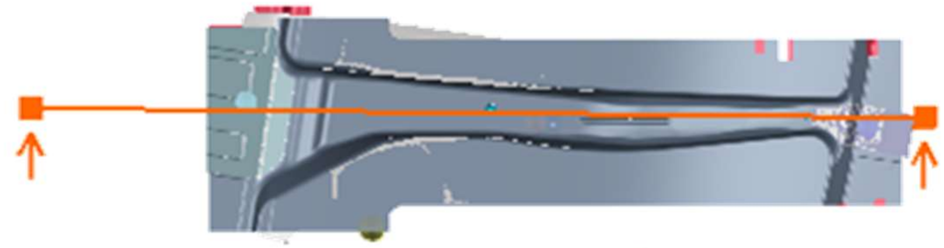
Press/Tooling: Slide/Ram Operation

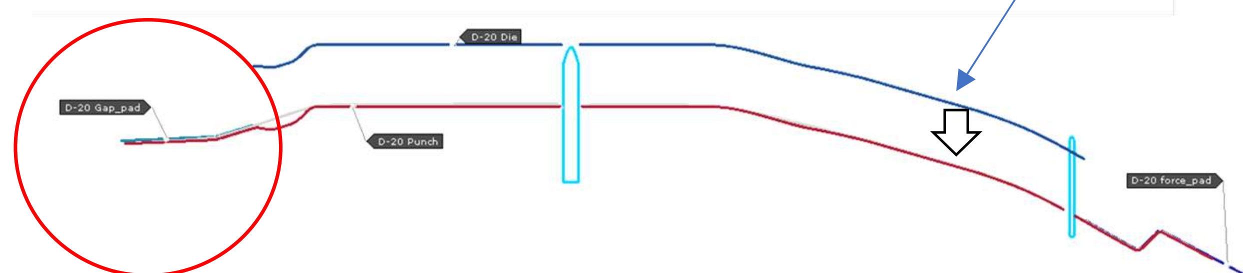




Pads are set, 85 mm to home

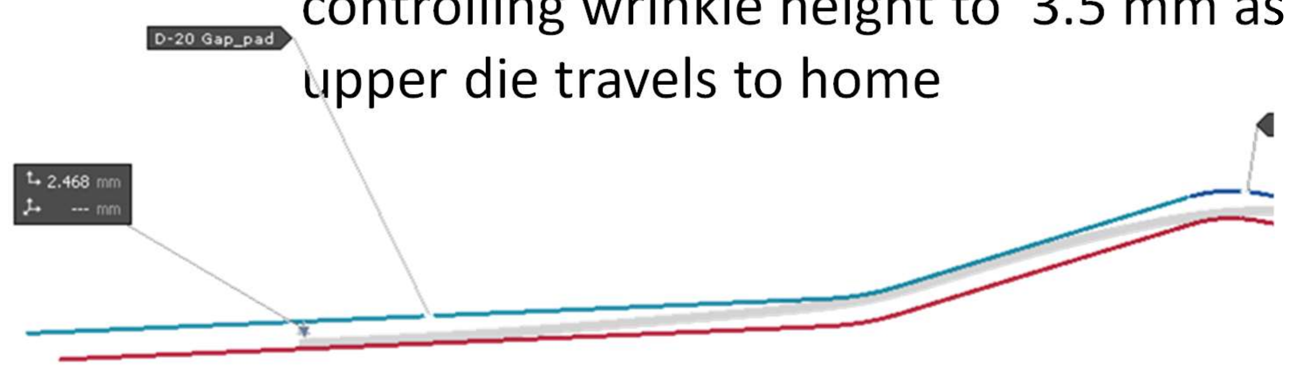
Cross Section 85 mm to home





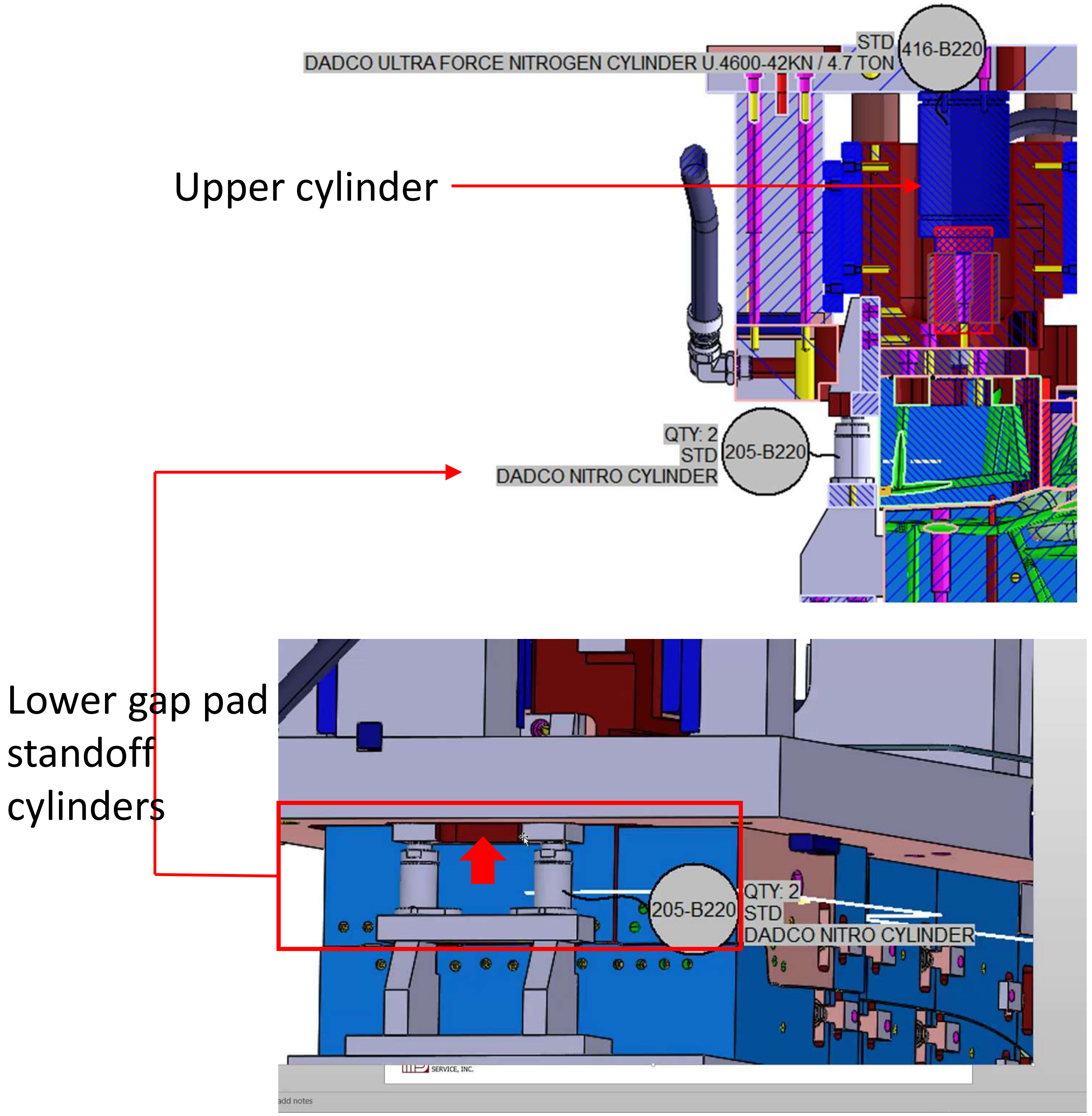
Upper die
85 mm
from home

Gap pad, total gap =t +3.5 mm, controlling wrinkle height to 3.5 mm as upper die travels to home

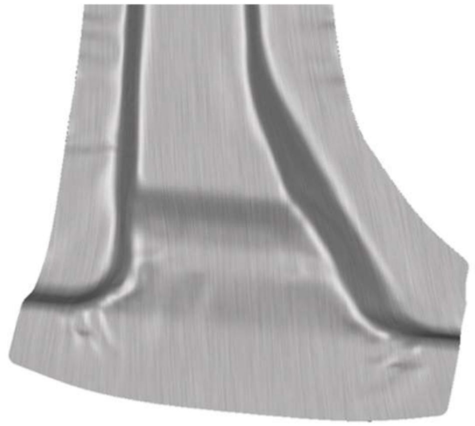


- Pads are set 85 mm from home
- Slide velocity 94 mm/s 85 mm from home
- Slide velocity 50 mm/s from 3.5 mm to home

Gap Pad/Force Pad Functioning

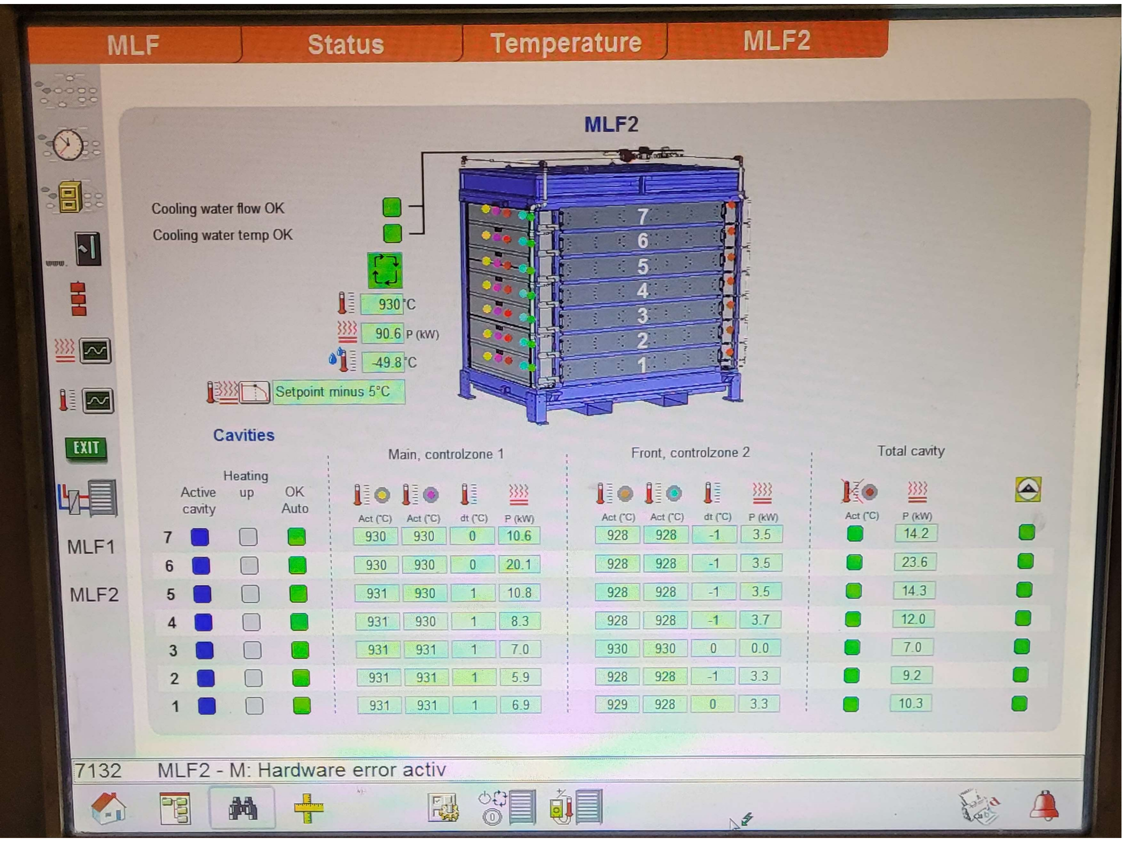


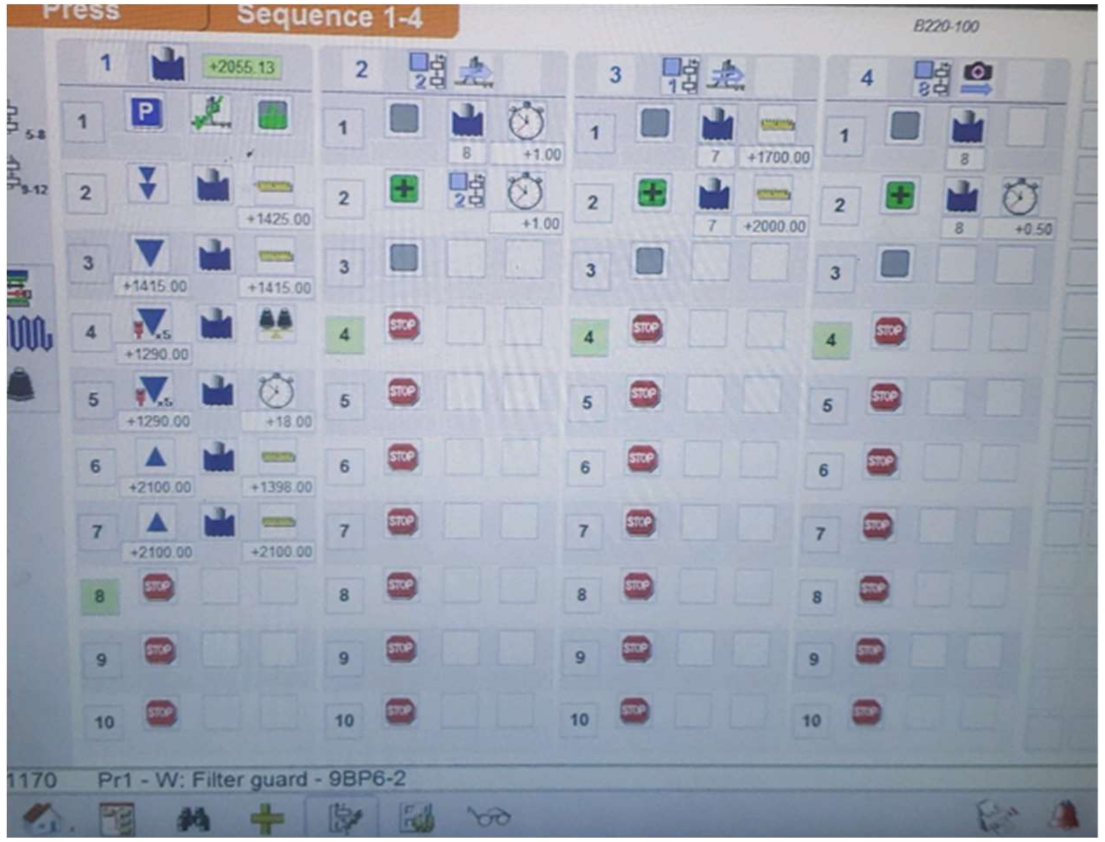
- Lower gap pad standoff cylinders maintain a t+3.5 mm gap, 85 mm from home, compressing upper cylinder.
  - Wrinkles heights are limited to 3.5 mm
  - Embossments are prevented from forming

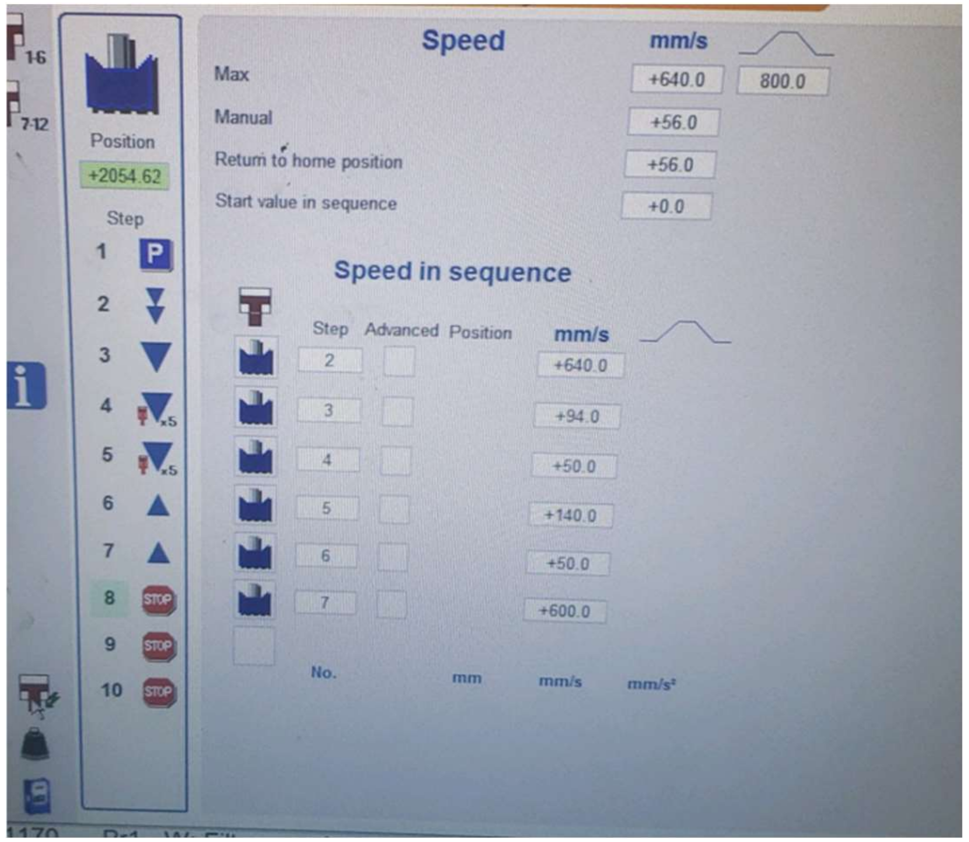


- At 3.5 mm to home, upper cylinder is "stroked out" overcoming the lower cylinders, and the gap closes to home with the slide
- Force pad, no opposing cylinders, pad set with 481 kN force (no extra gap) when the slide is 85 mm from home

Process



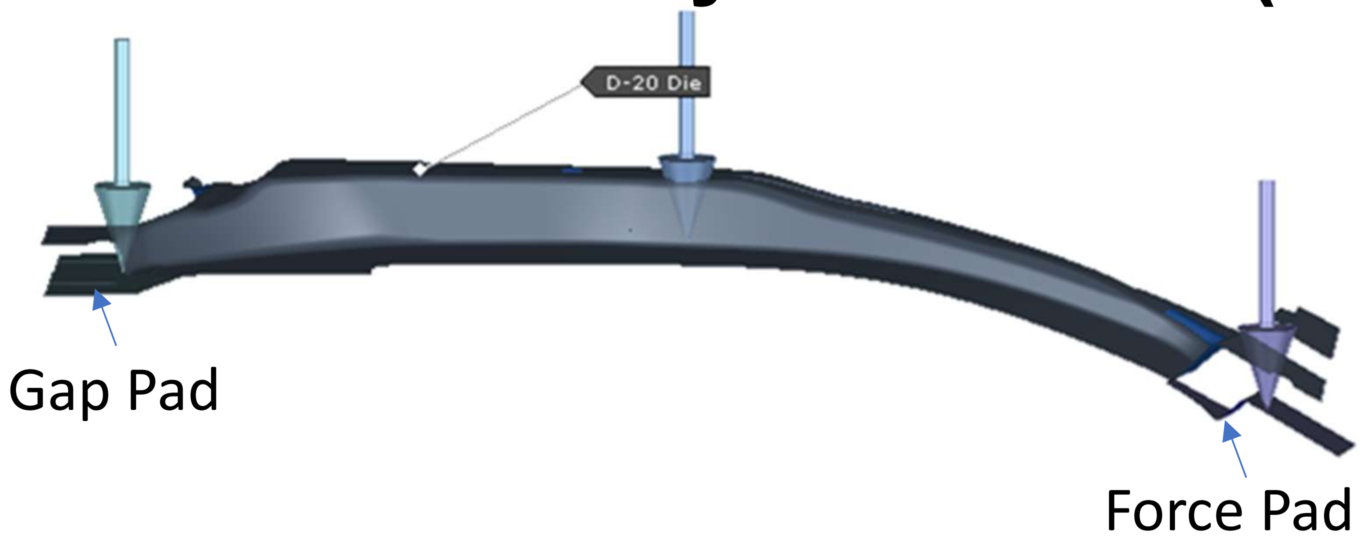




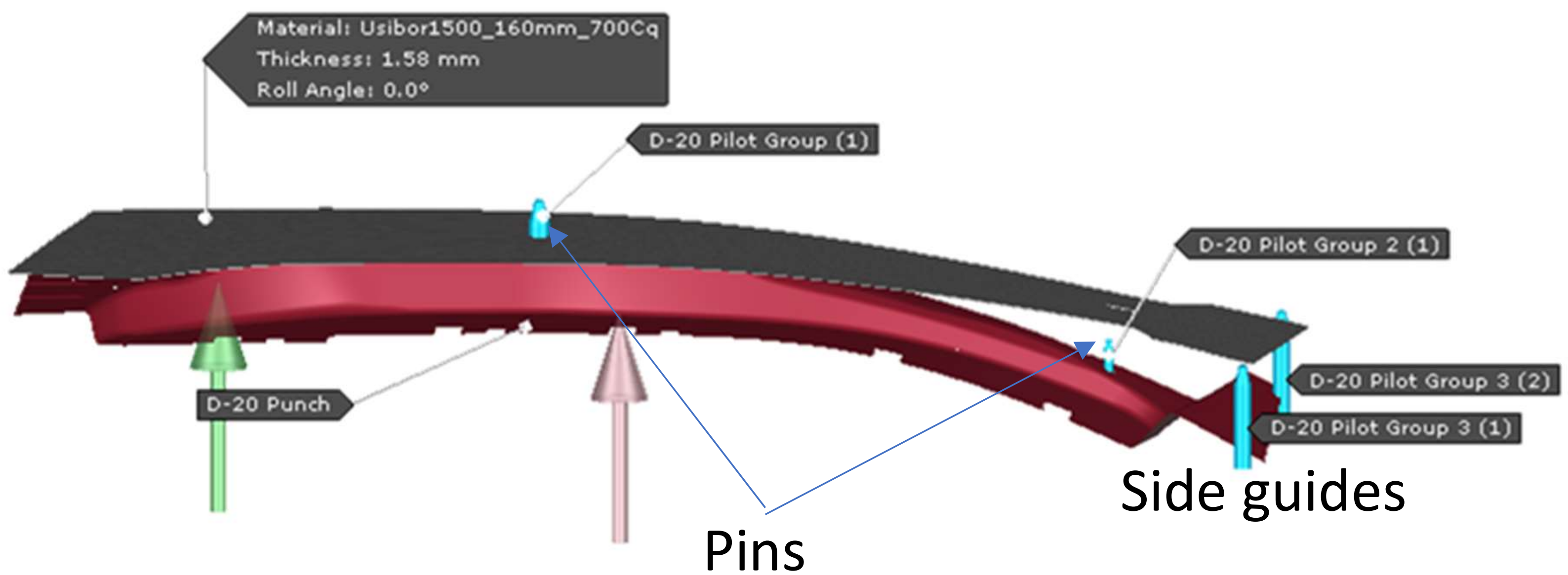
- “Pizza” oven type furnace, 300 s soak time , 930°C
- 12 s for blank transfer
- 7 stage press program

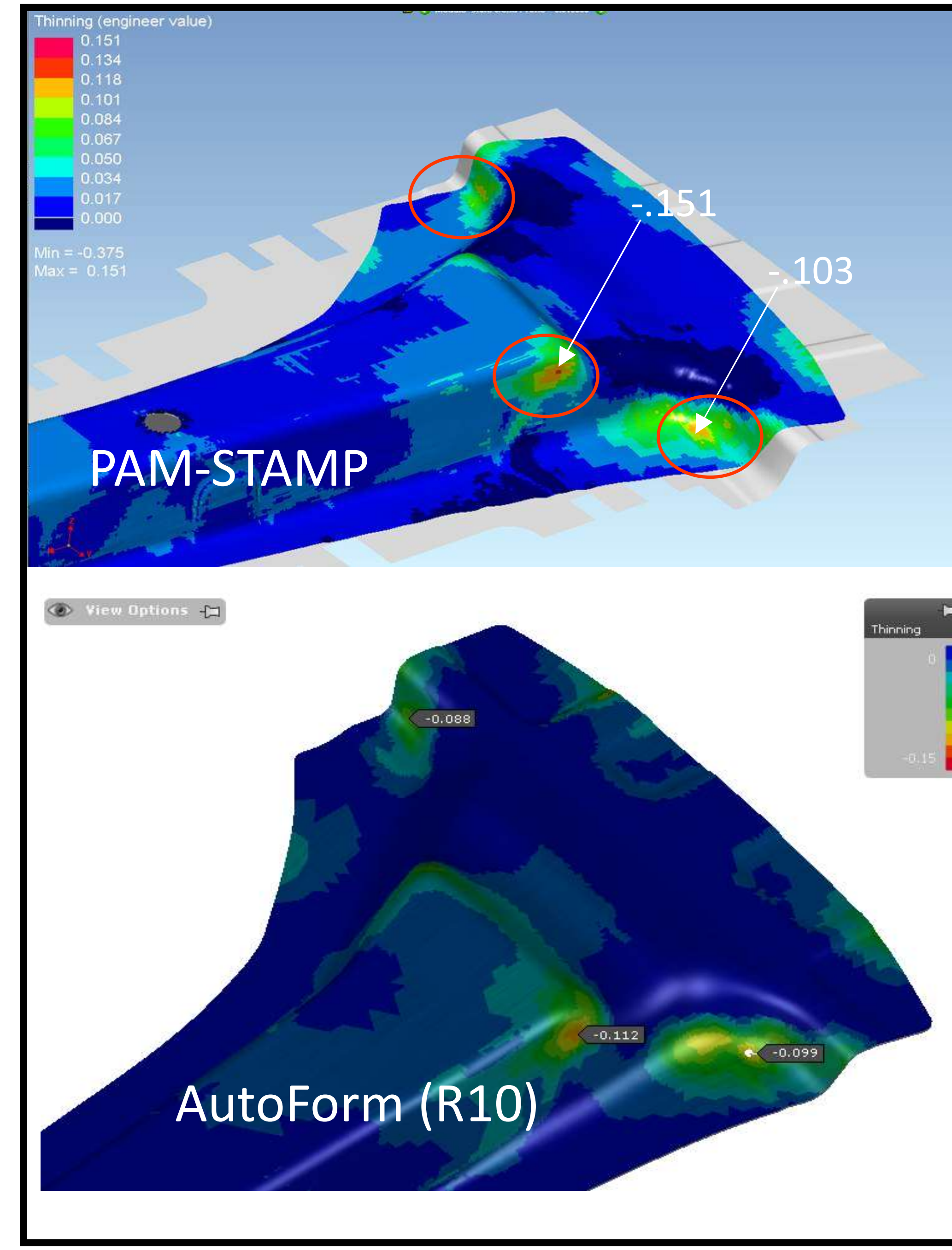
Initial FEA for 1.6 mm Usibor® 1500 AS

Preliminary AutoForm (R10) and PAM-STAMP FEA



ArcelorMittal material cards used



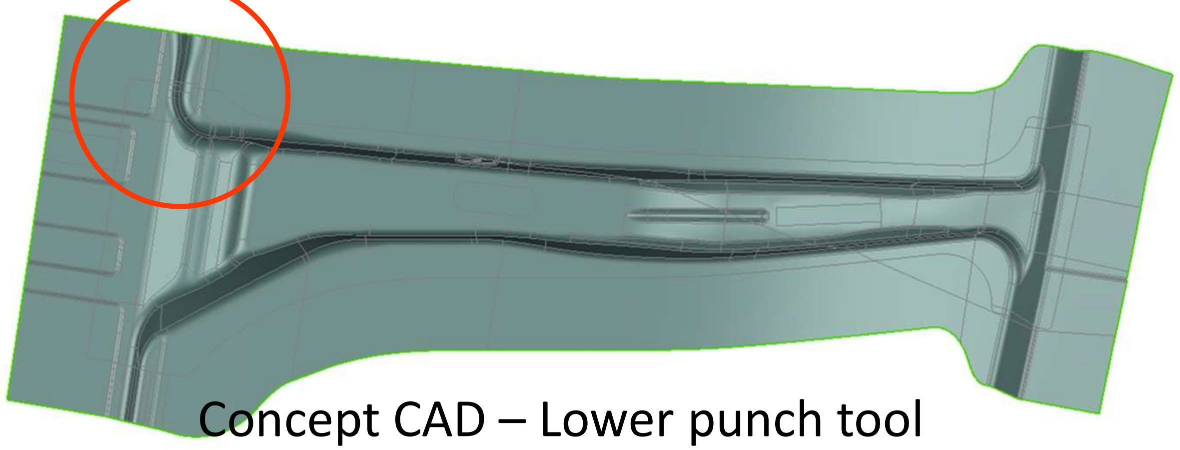


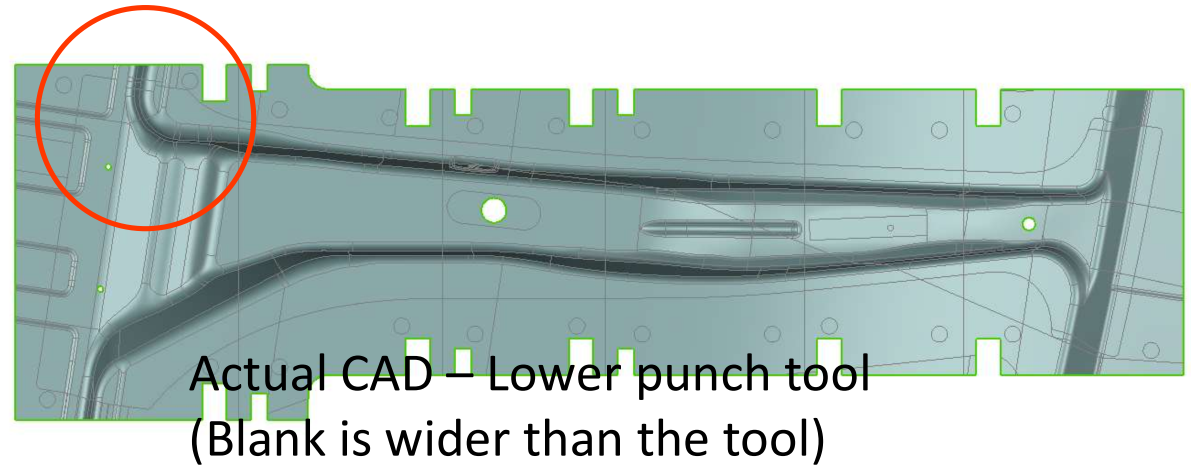
- PAM-STAMP – slightly more thinning vs. AutoForm
- AutoForm – quicker turnaround

Tooling Commissioning and ArcelorMittal supporting FEA – AutoForm and PAM-STAMP

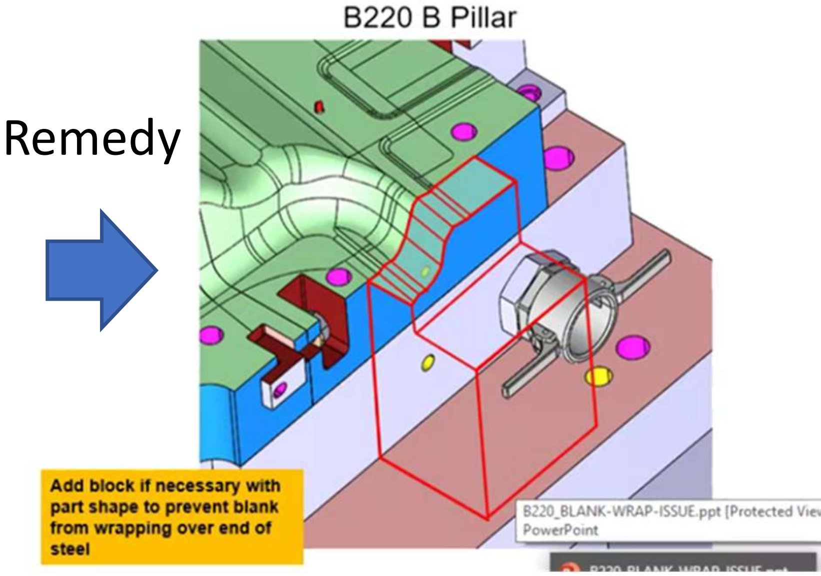
- PAM-STAMP FEA also performed by ATC and ESI to support activities
- ArcelorMittal results are shown in this presentation

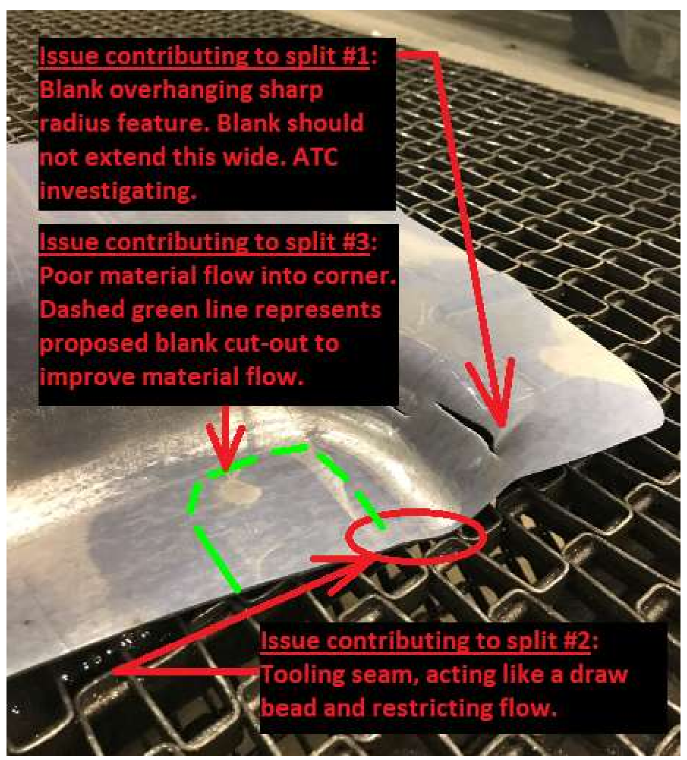
Initial Trial on New Tools:
FEA Using Concept CAD vs. Actual CAD

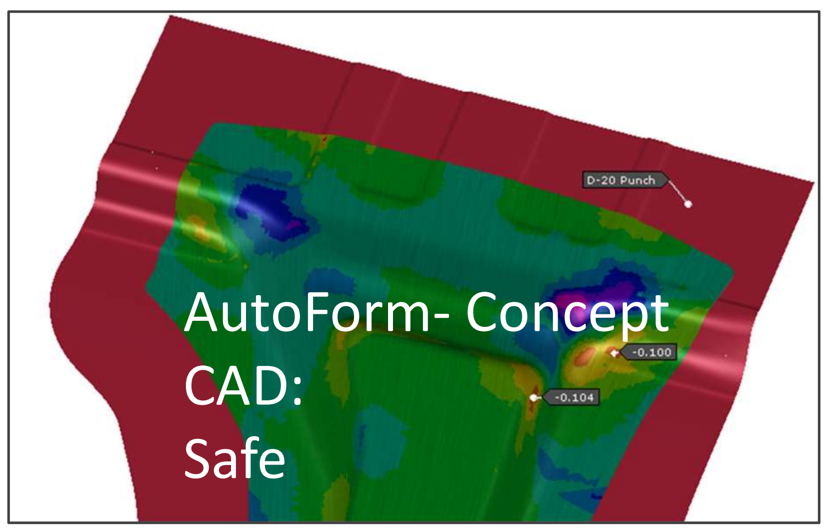


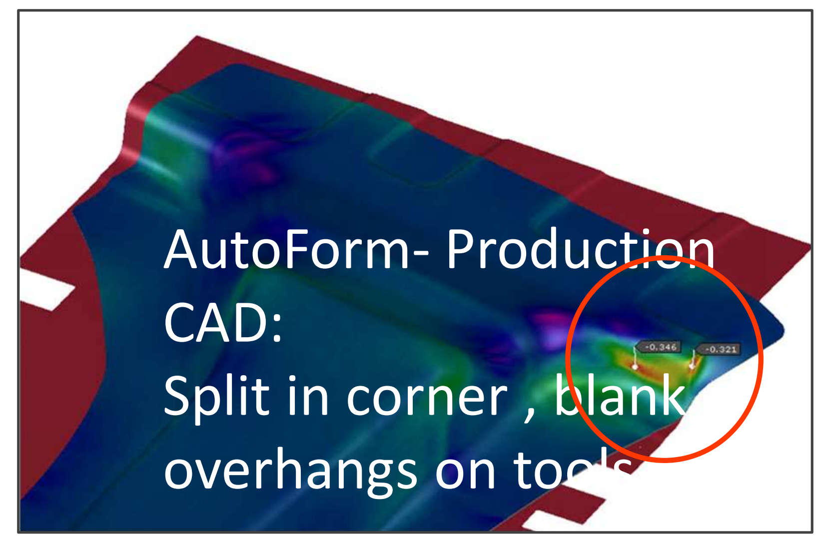


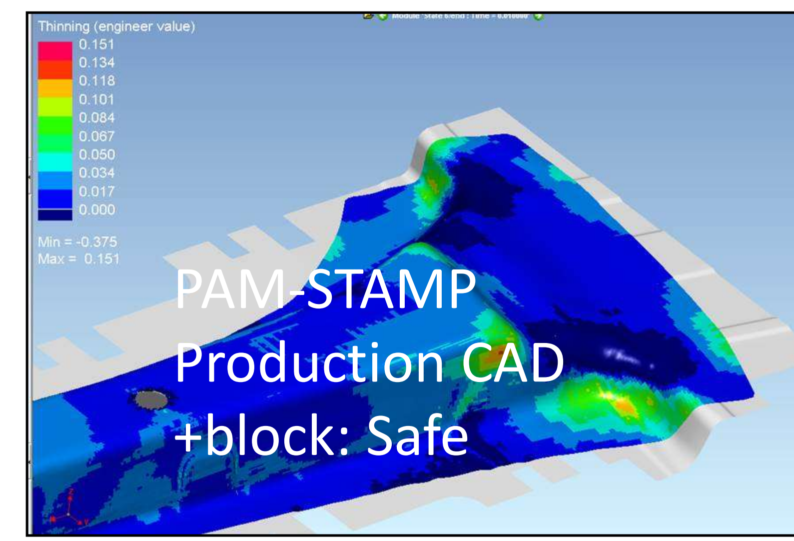
Remedy





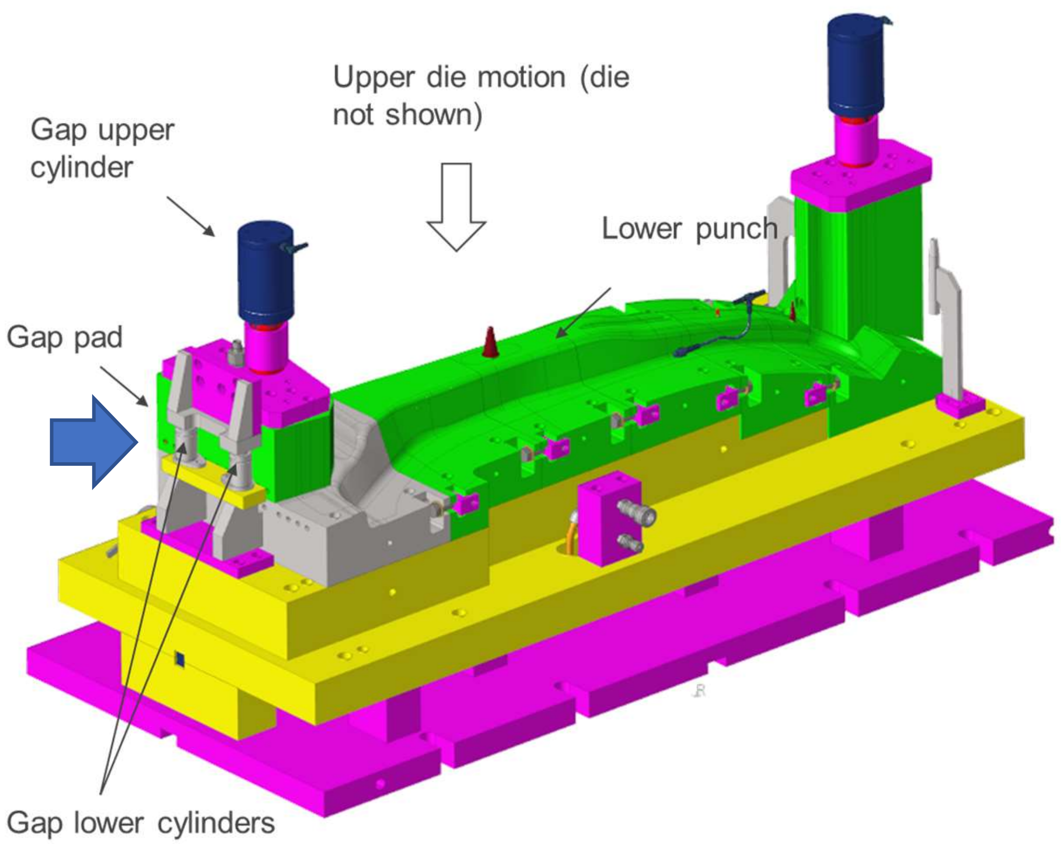


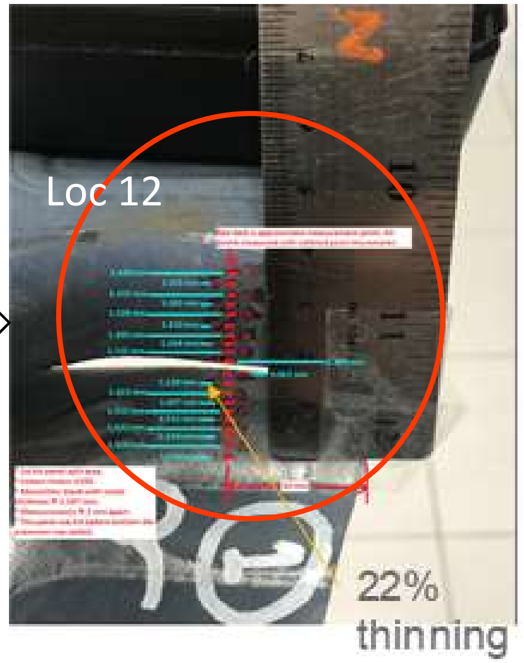




- Interpretations from FEA based on concept CAD can be a risk
- FEA should be used to check production tools

Gap Pad Operation Failure

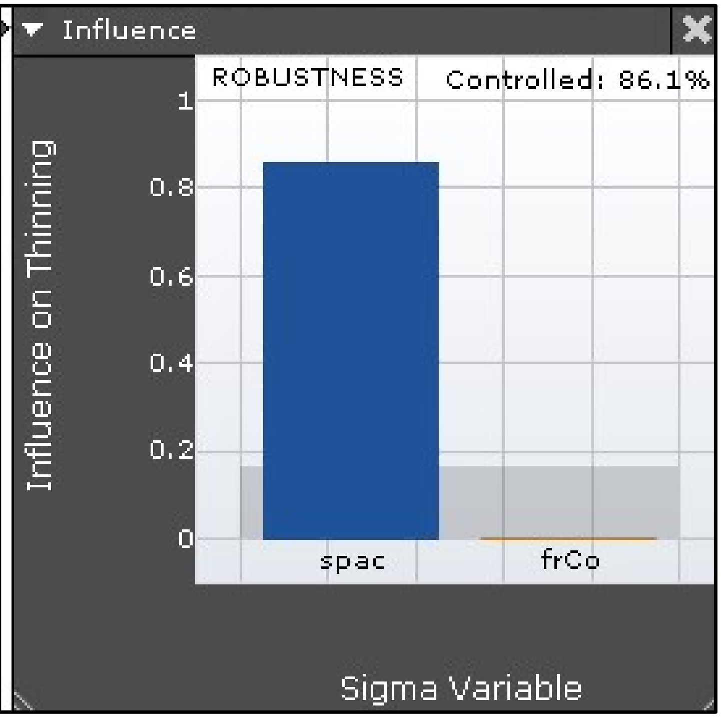


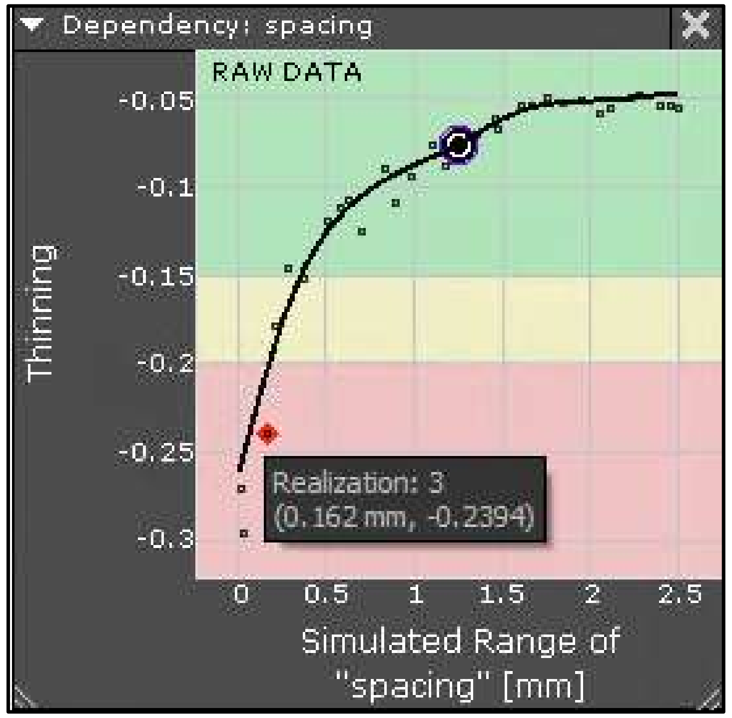


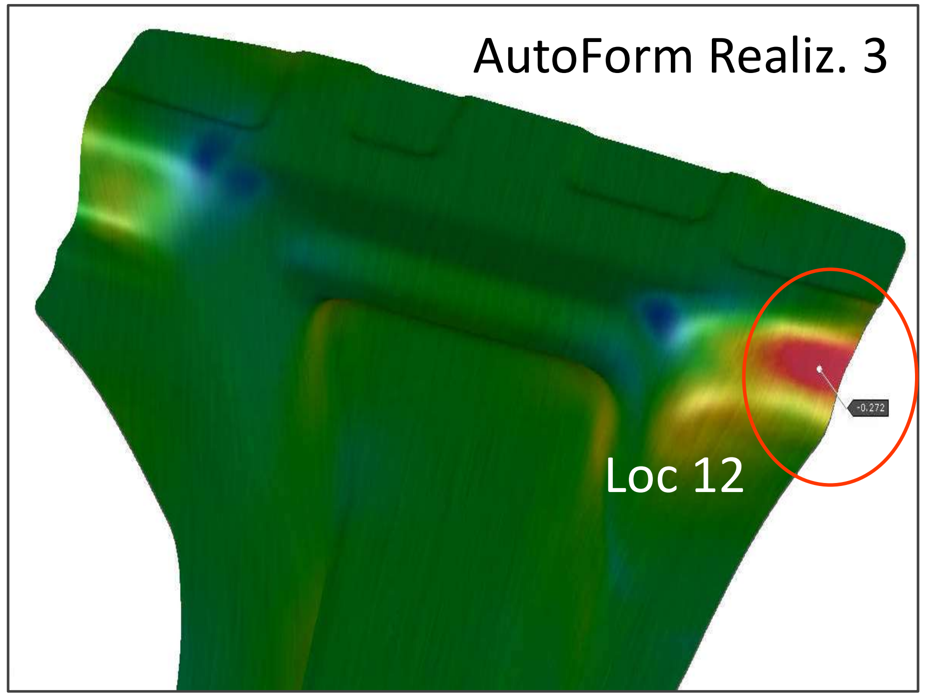
- Unknown at the time – upper cylinders were overcoming the lower cylinders (gap was closed)
- The result was excessive thinning in the wall of the part (Loc 12)
- Remedy – The cylinder configuration was changed (new cylinders added, the old configuration is shown for illustration). Lower cylinders are not overcome by the upper

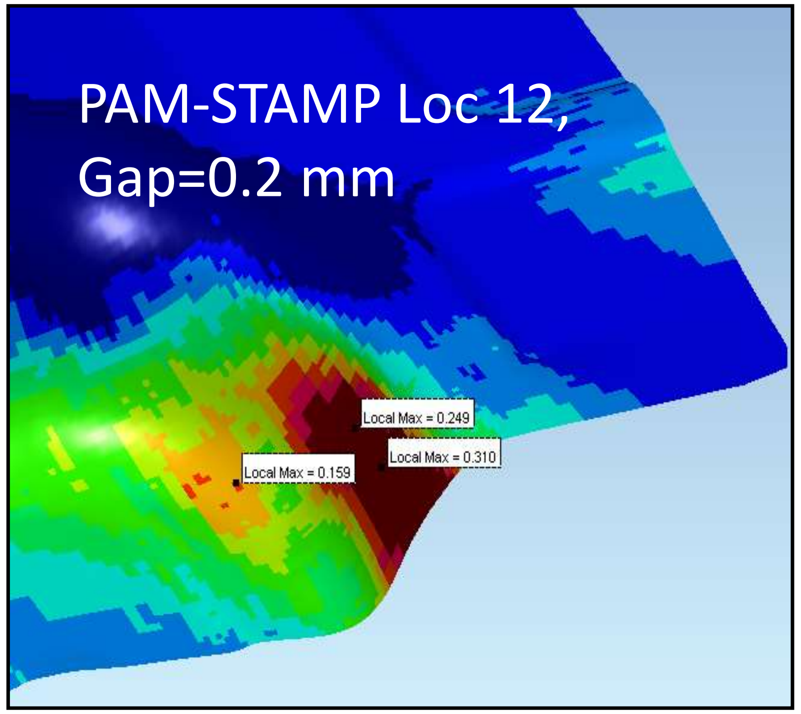
Gap Pad Operation Failure Diagnosed with FEA

AutoForm Sigma – 32 Runs



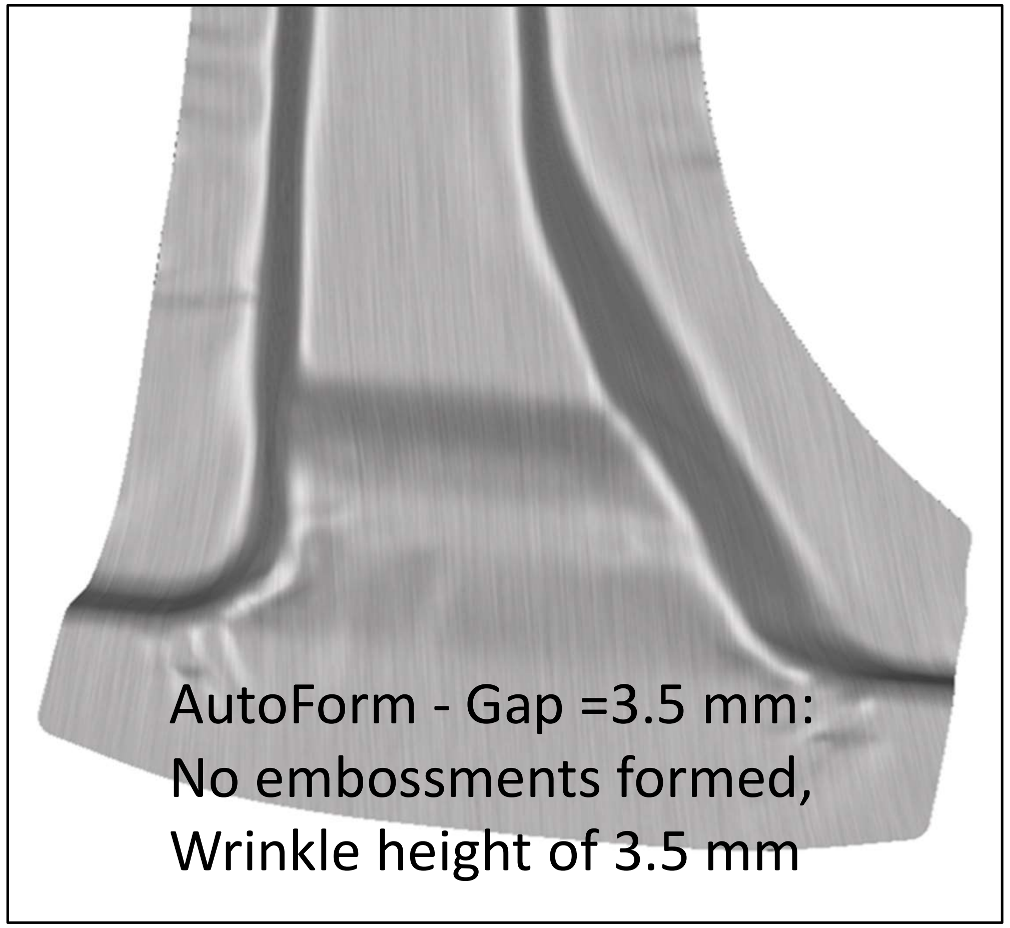


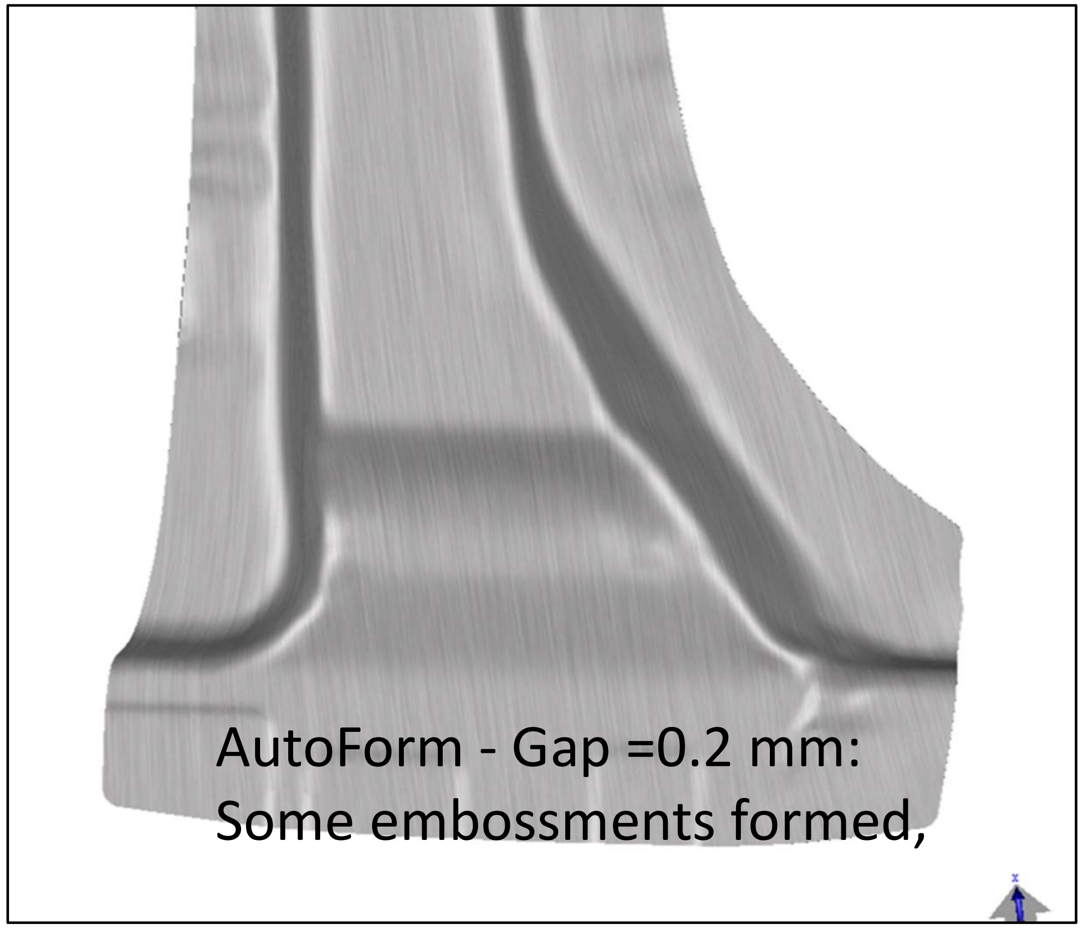


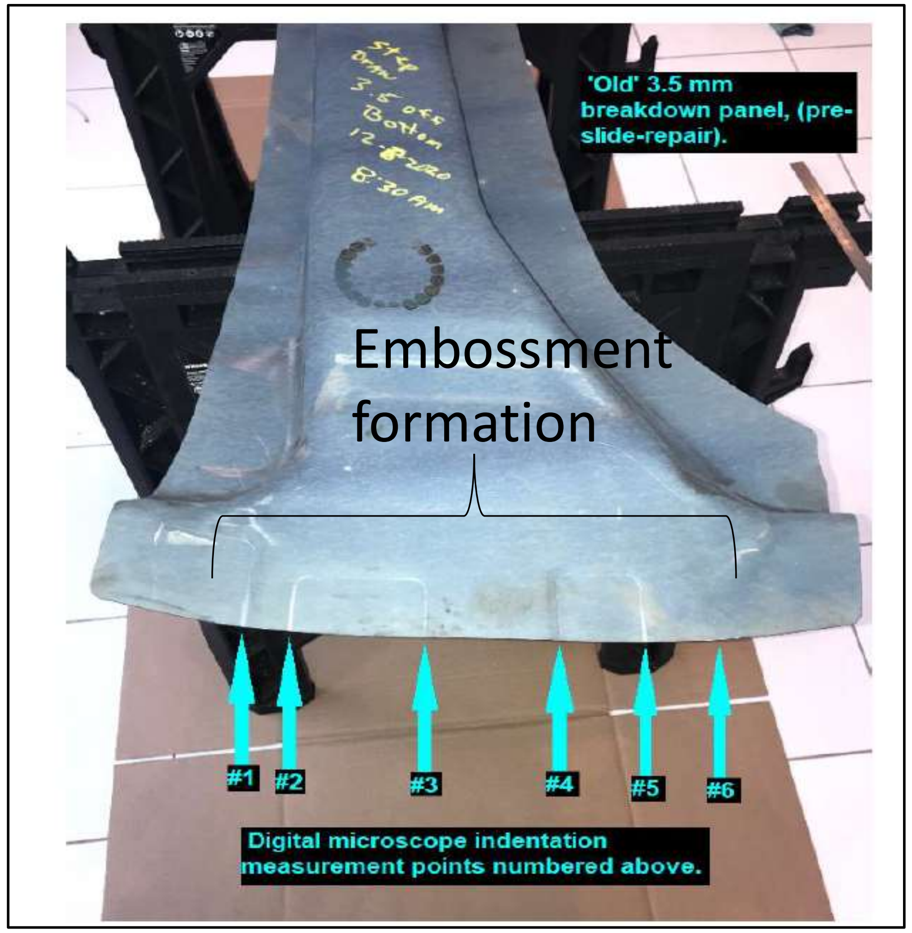


- AutoForm Sigma:
  - Influence: Gap (spacing) has a greater effect on thinning than friction in Loc 12
  - Dependency: thinning as a function of die gap
  - At a die gap of ≈ 0.2 mm, thinning in AutoForm is more than -0.20
- AutoForm and PAM-STAMP FEA predicted thinning to be more than -0.20 at small gap.
- Proposed cause for splitting – smaller than expected die gap

Gap Pad Operation Failure Diagnosed with FEA

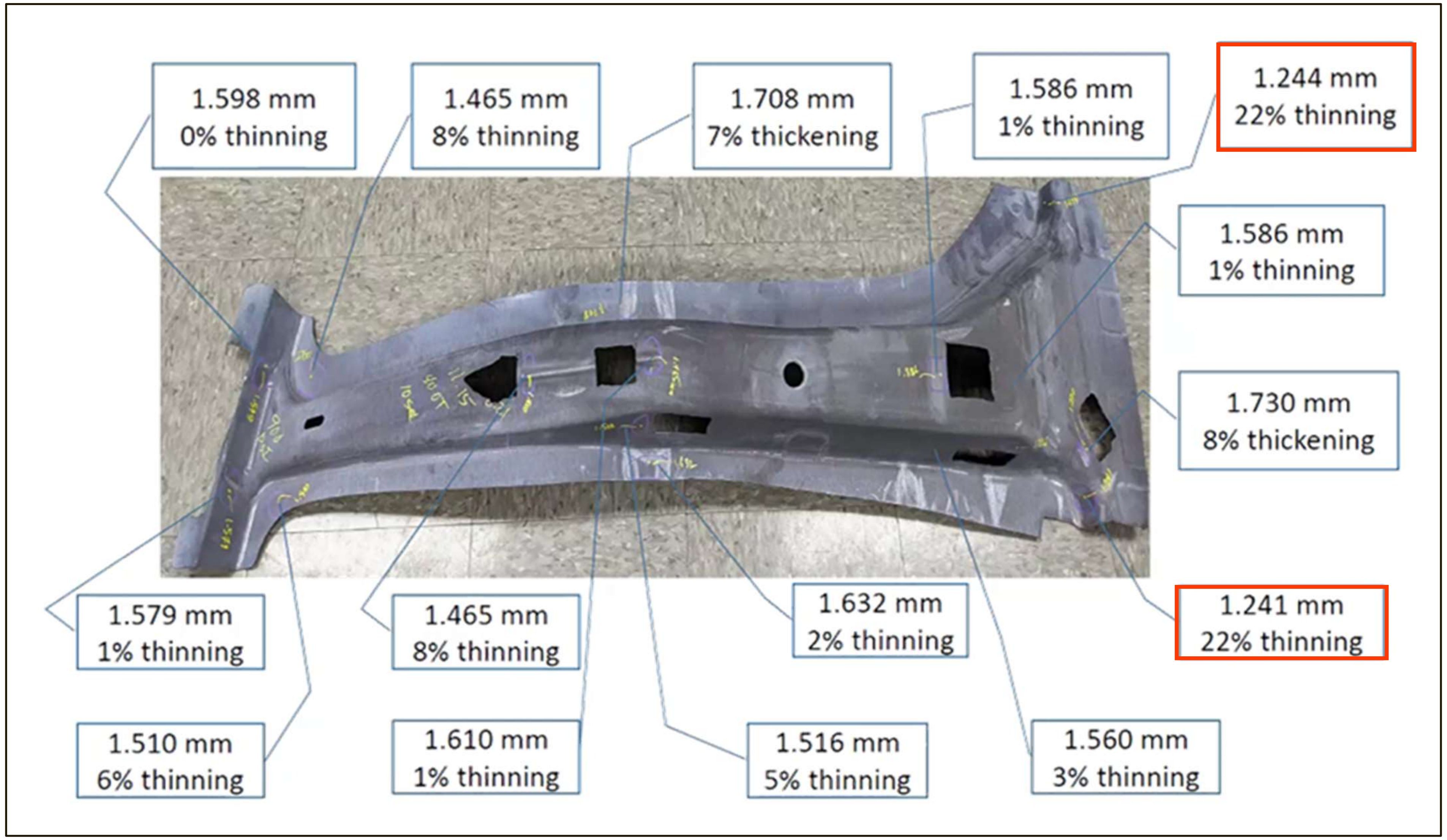


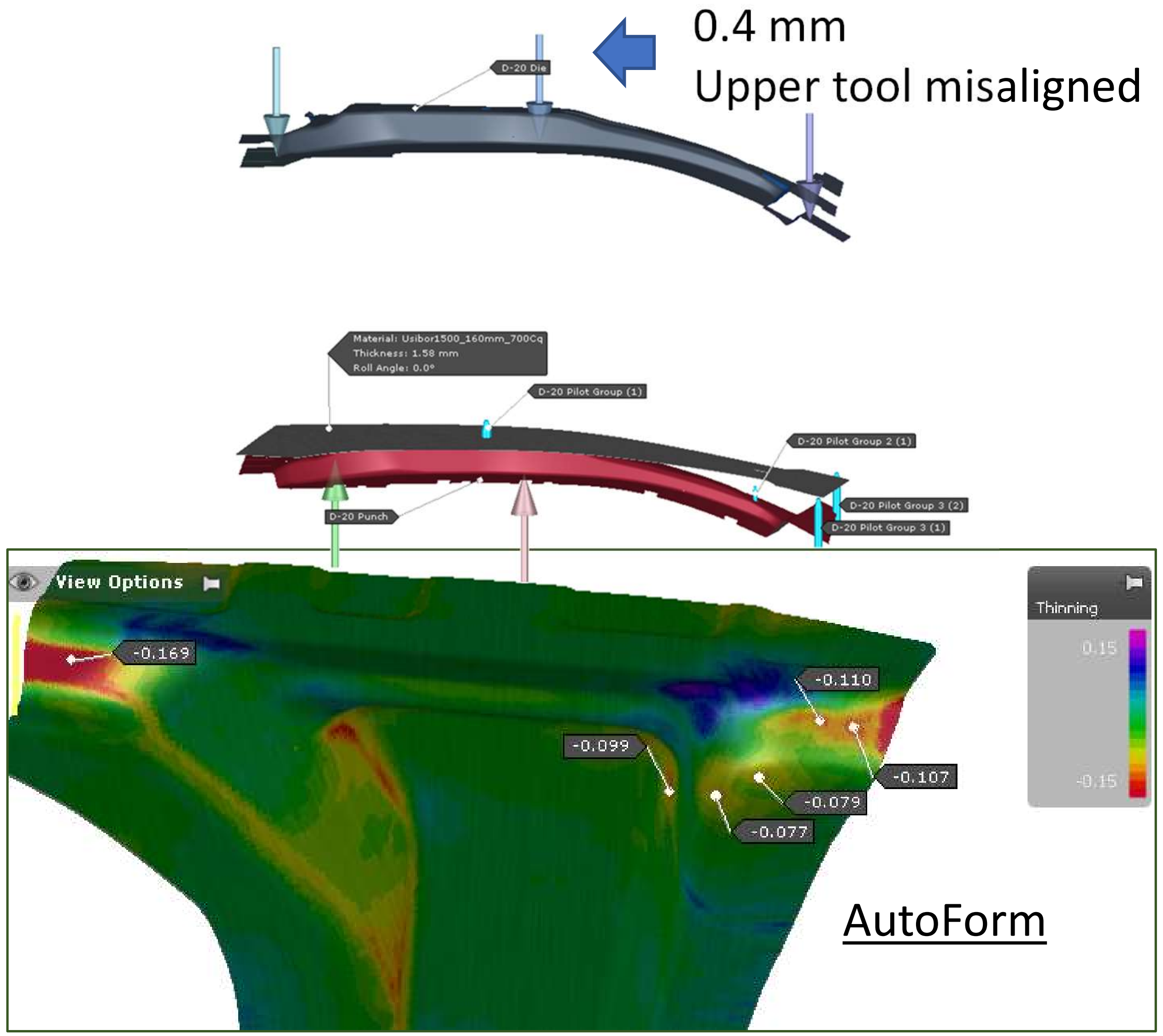




- Requested breakdown panel 3.5 mm from home, and it showed embossment formation
- Simulation predicts no embossment formation if gap pad is working correctly
- Embossment formation predicted for gap pad failure (smaller than expected gap) – matches breakdown panel
- The gap pad cylinder configuration was changed as stated previously

Splitting due to Tooling Alignment

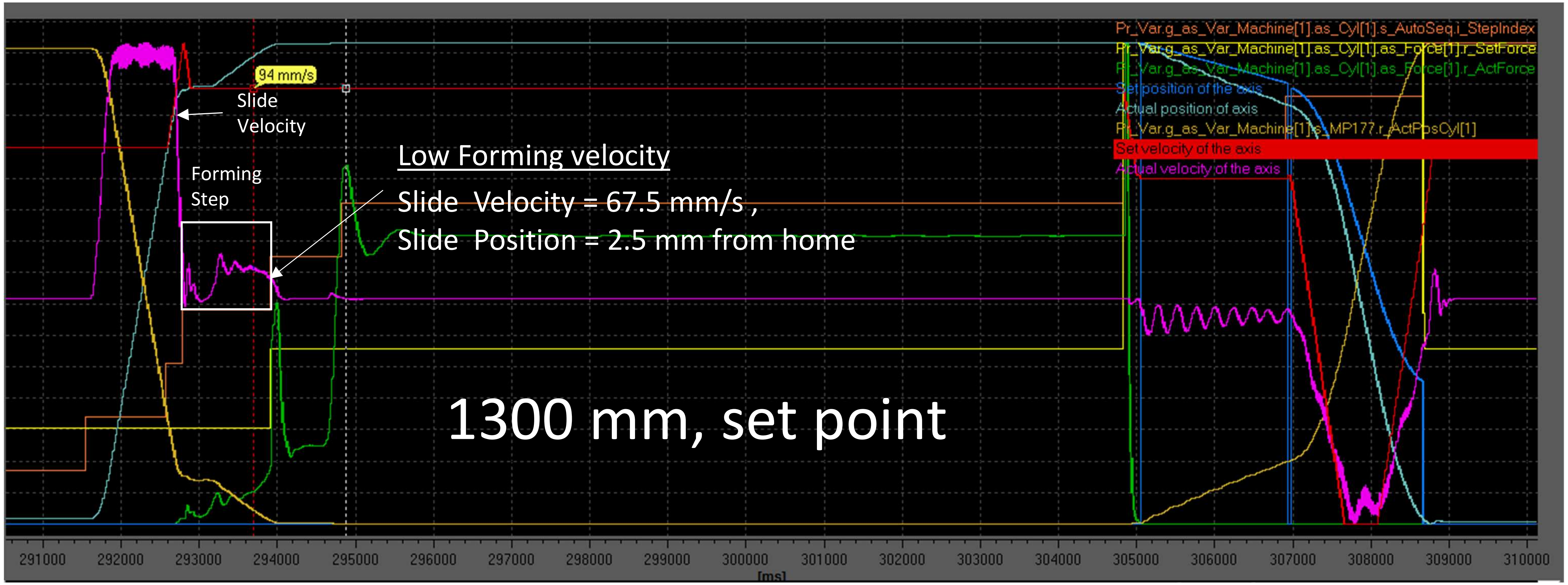




- The tool gap was too narrow at the base of the B-pillar. The tool shop quickly diagnosed and corrected this
- AutoForm simulations could illustrate this problem using thick shell elements

Press "Recipe" Tuning

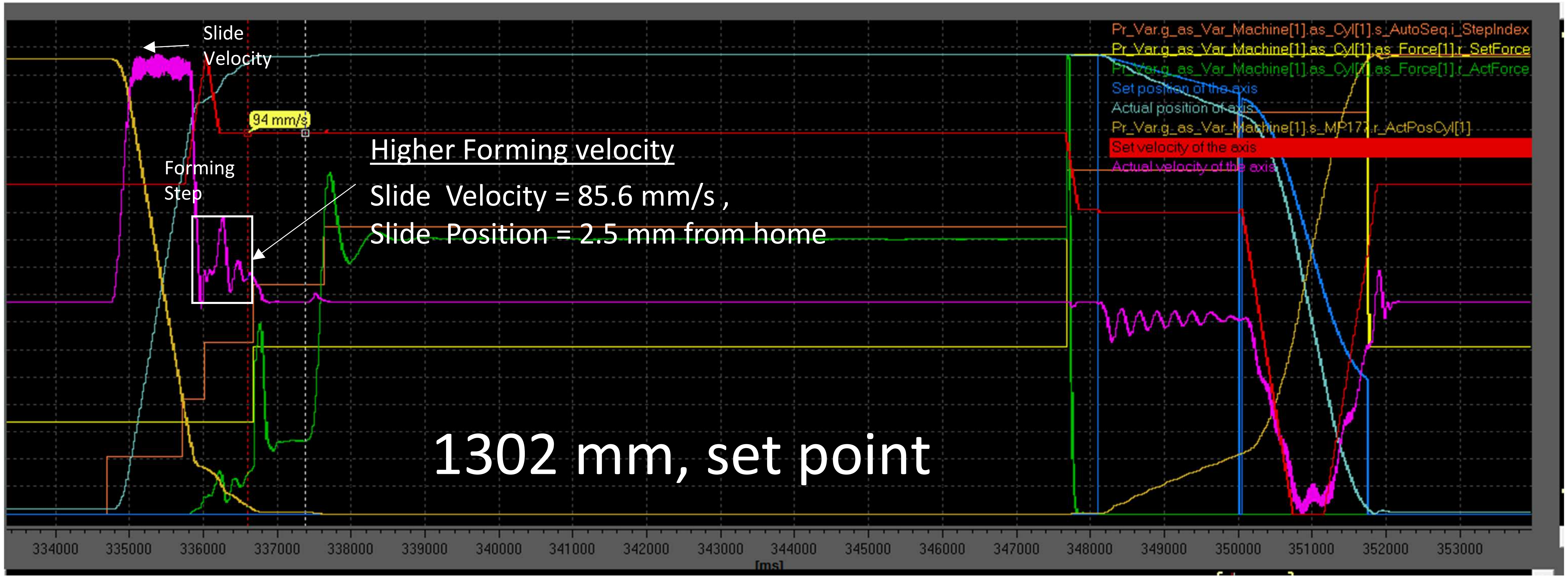
Press Trace: 1300 mm set point



- Forming velocity is not constant, as is often assumed in FEA simulations
- Press stage/step setting (distance off bottom set point) affects forming velocity

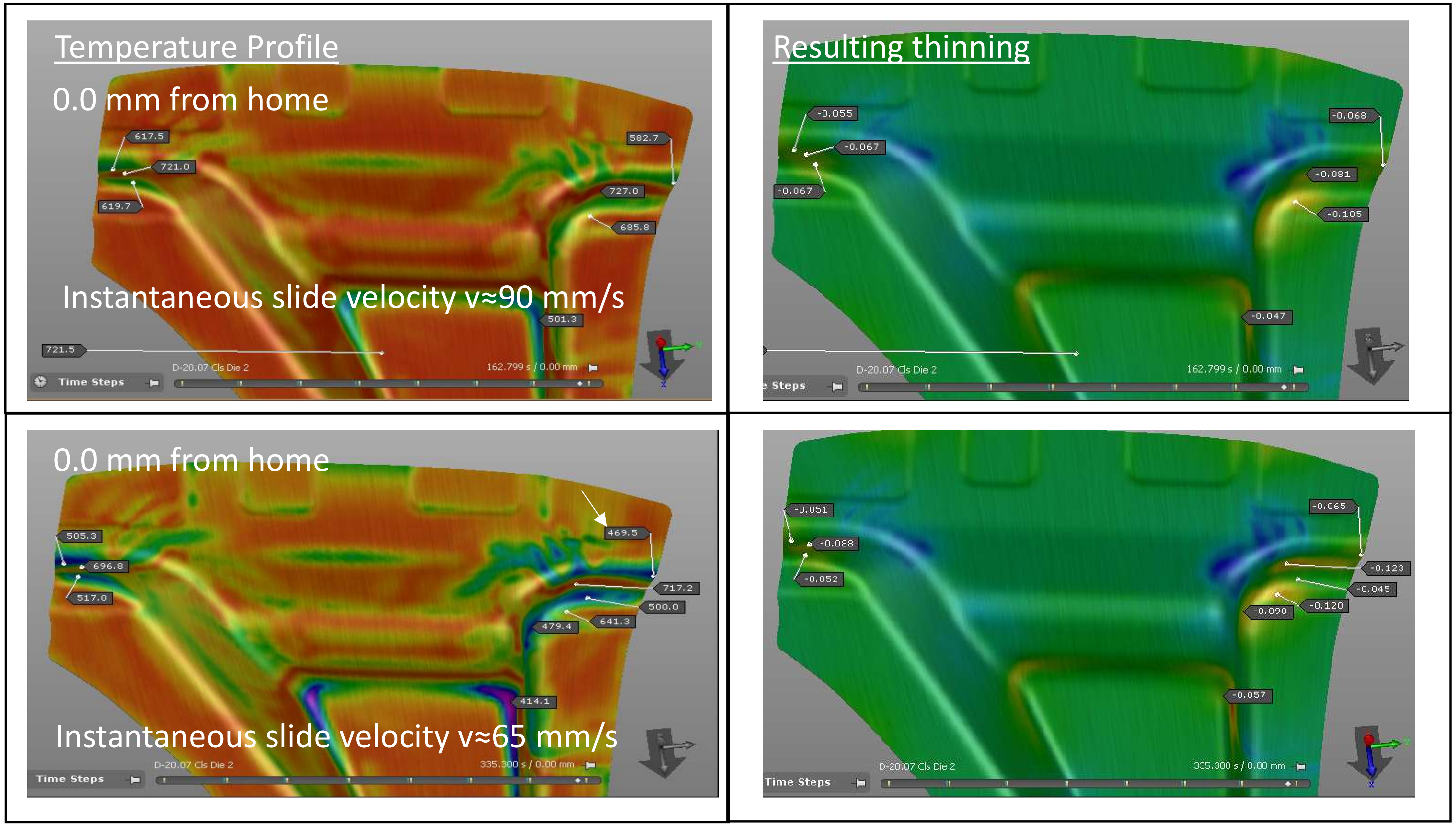
Press “Recipe” Tuning

Press Trace: 1302 mm set point



Change in setting results in higher forming velocity – more desirable since it reduces thinning

Press "Recipe" Tuning

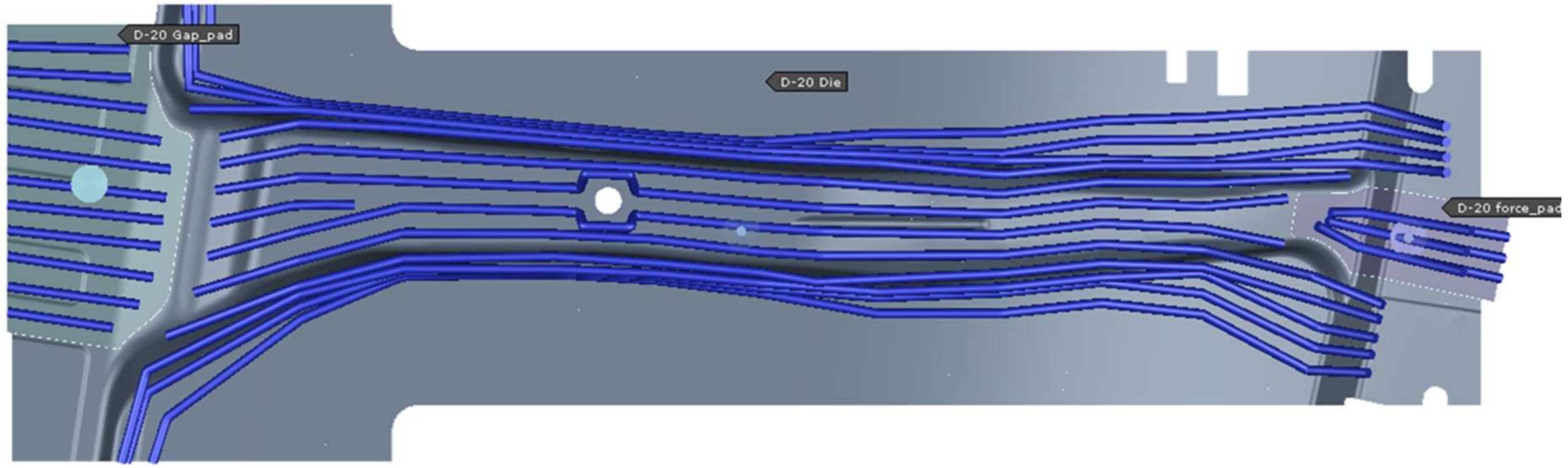


FEA insight – Lower slide velocity results in more cooling at radii and localized thinning

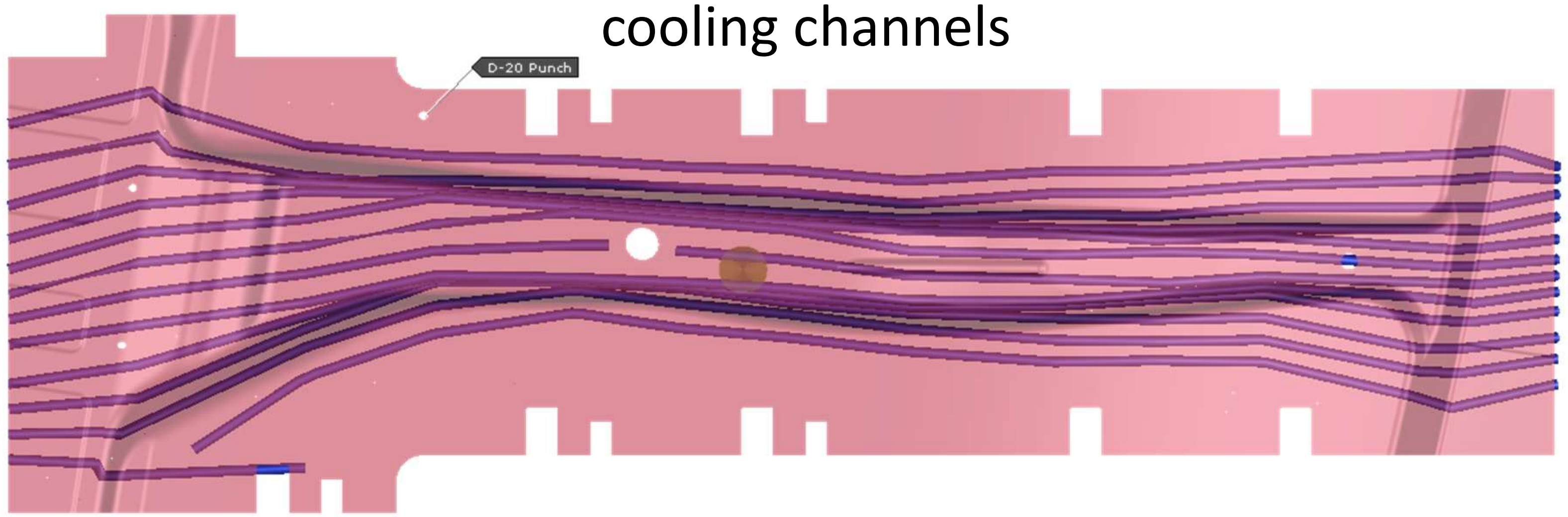
AutoForm 3D Simulations

- Potential tool for evaluating hot spots, cooling channel design
- ATC designed channel system (much work in optimizing)
- 100 mm solid element tooling in AutoForm
- Cycle (cumulative time):
  - Start t=0 s
  - Tools home (end of forming) = 3.46 s
  - Quenching (10.02 s) =13.46 s
  - Tool opened (3.06 s) = 16.54 s
  - Wait for next blank (33.9 s) =50.44 s

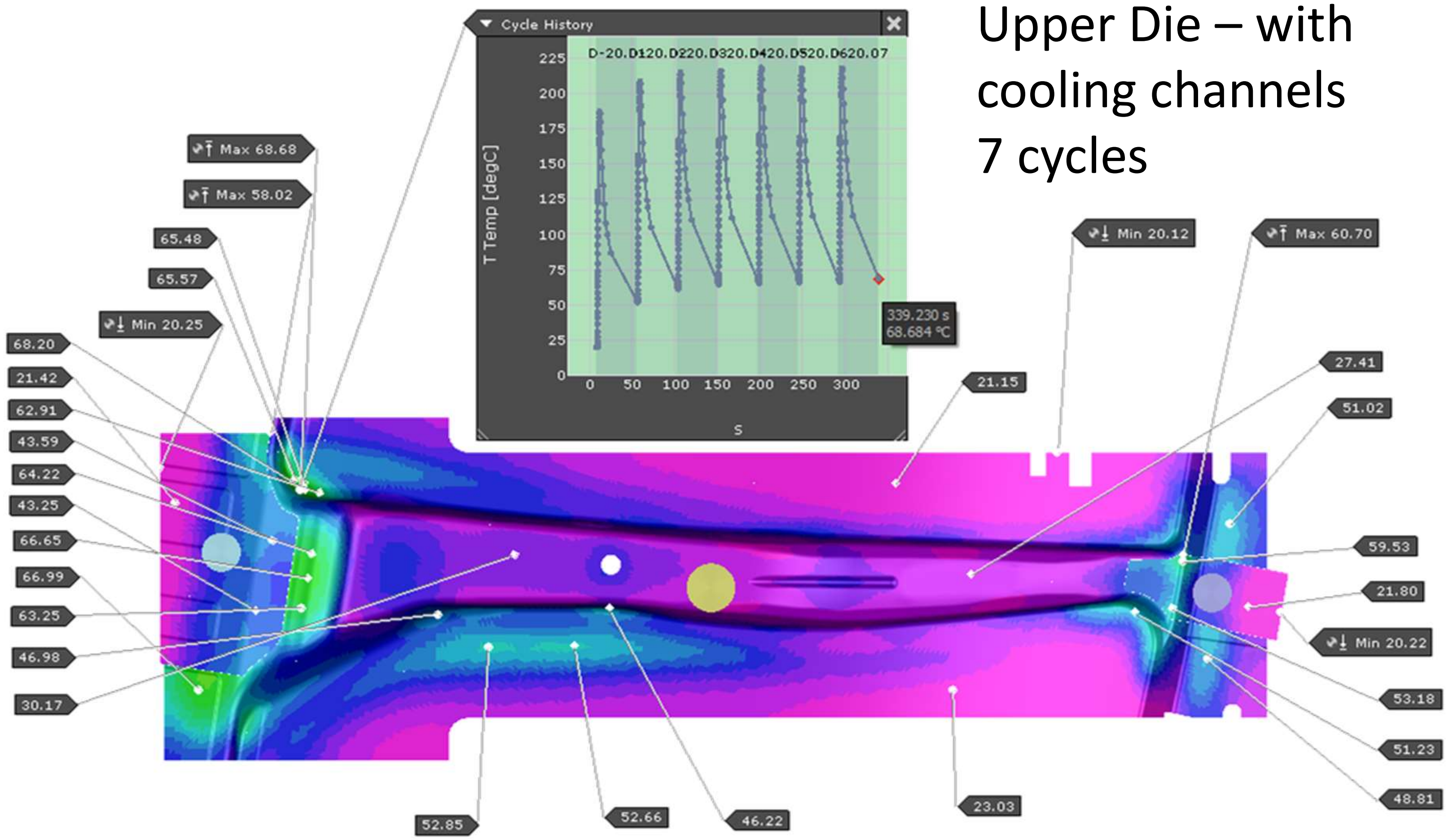
Upper Tools – with cooling channels



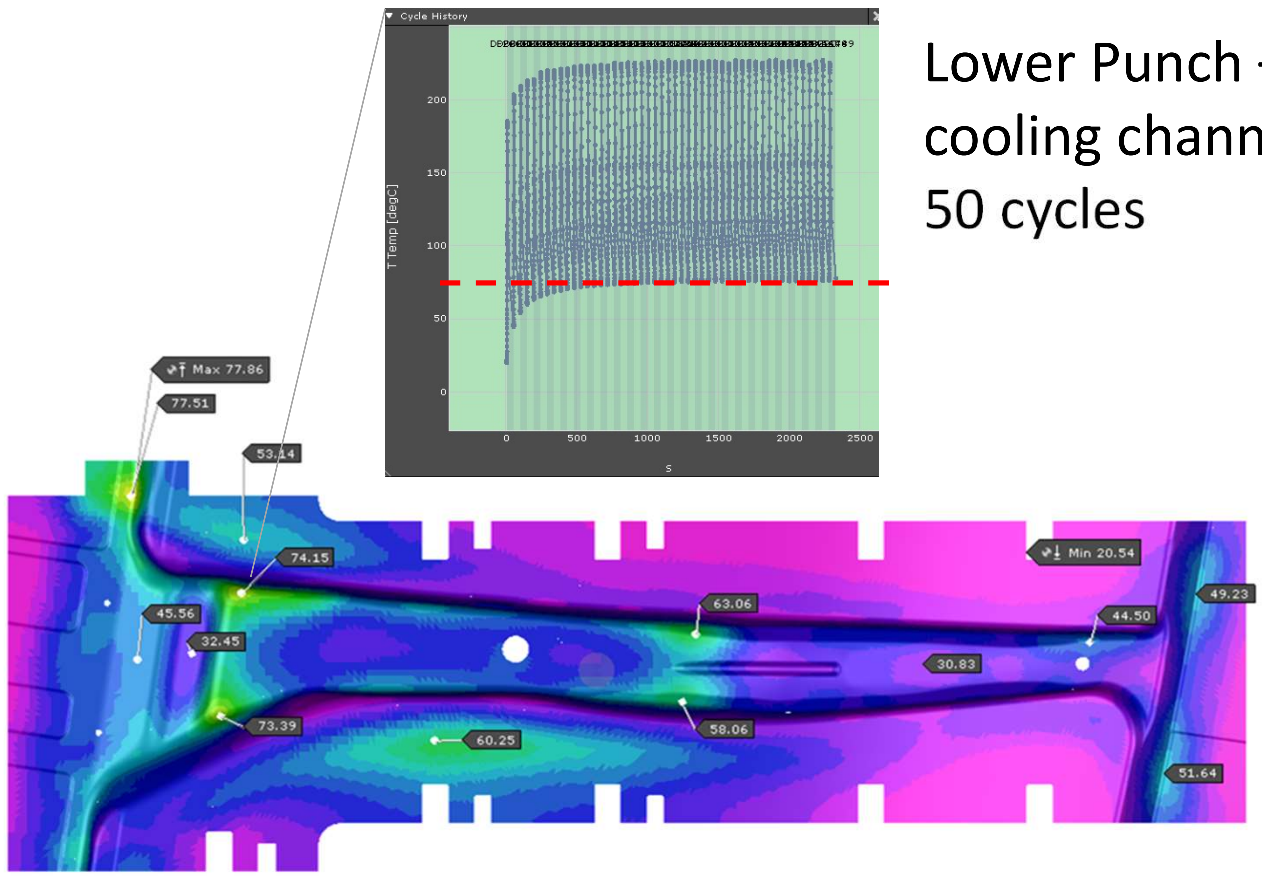
Lower Tools – with cooling channels



Steady State Tool Temperatures



Upper Die – with cooling channels 7 cycles

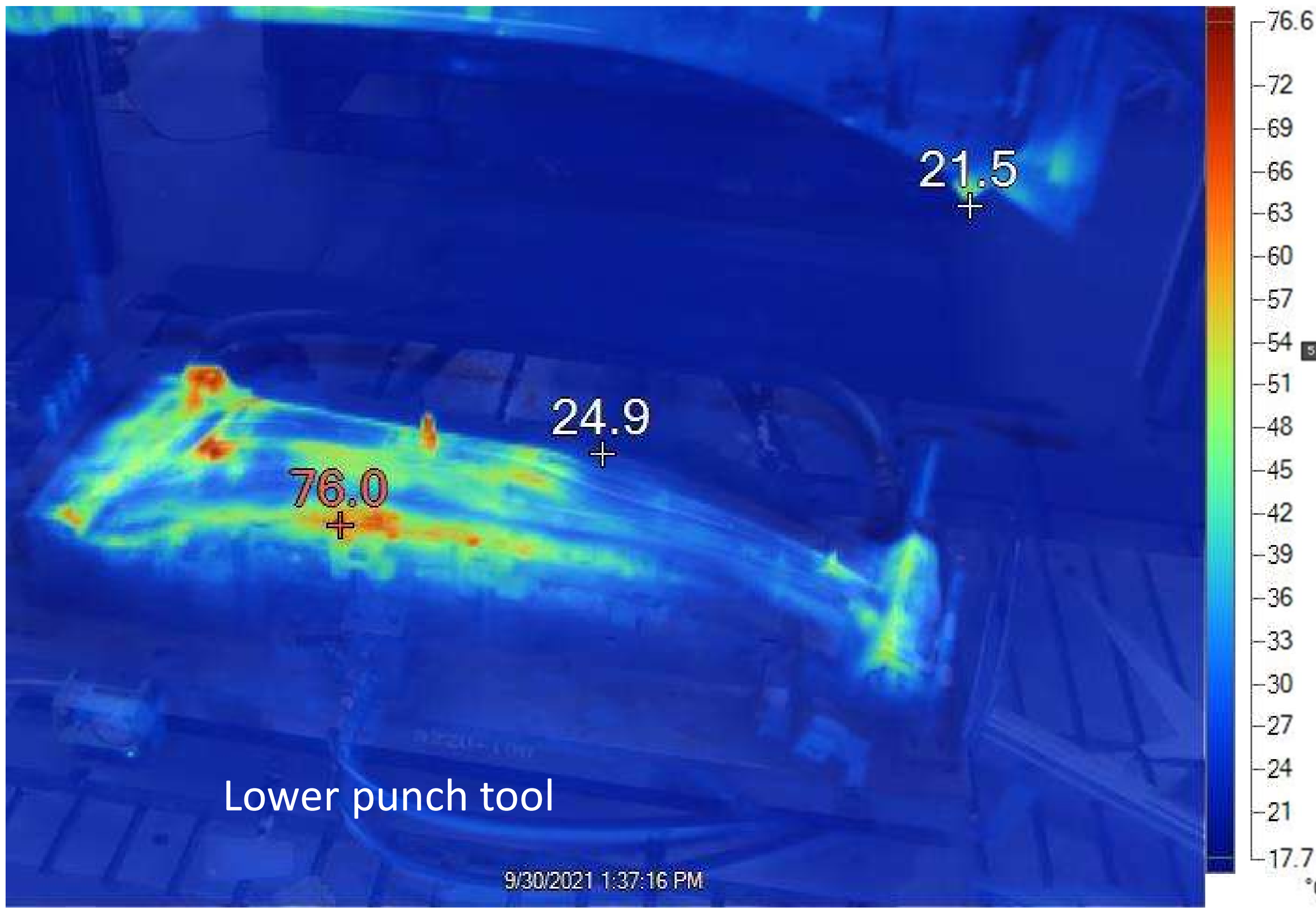


Lower Punch – with cooling channels 50 cycles

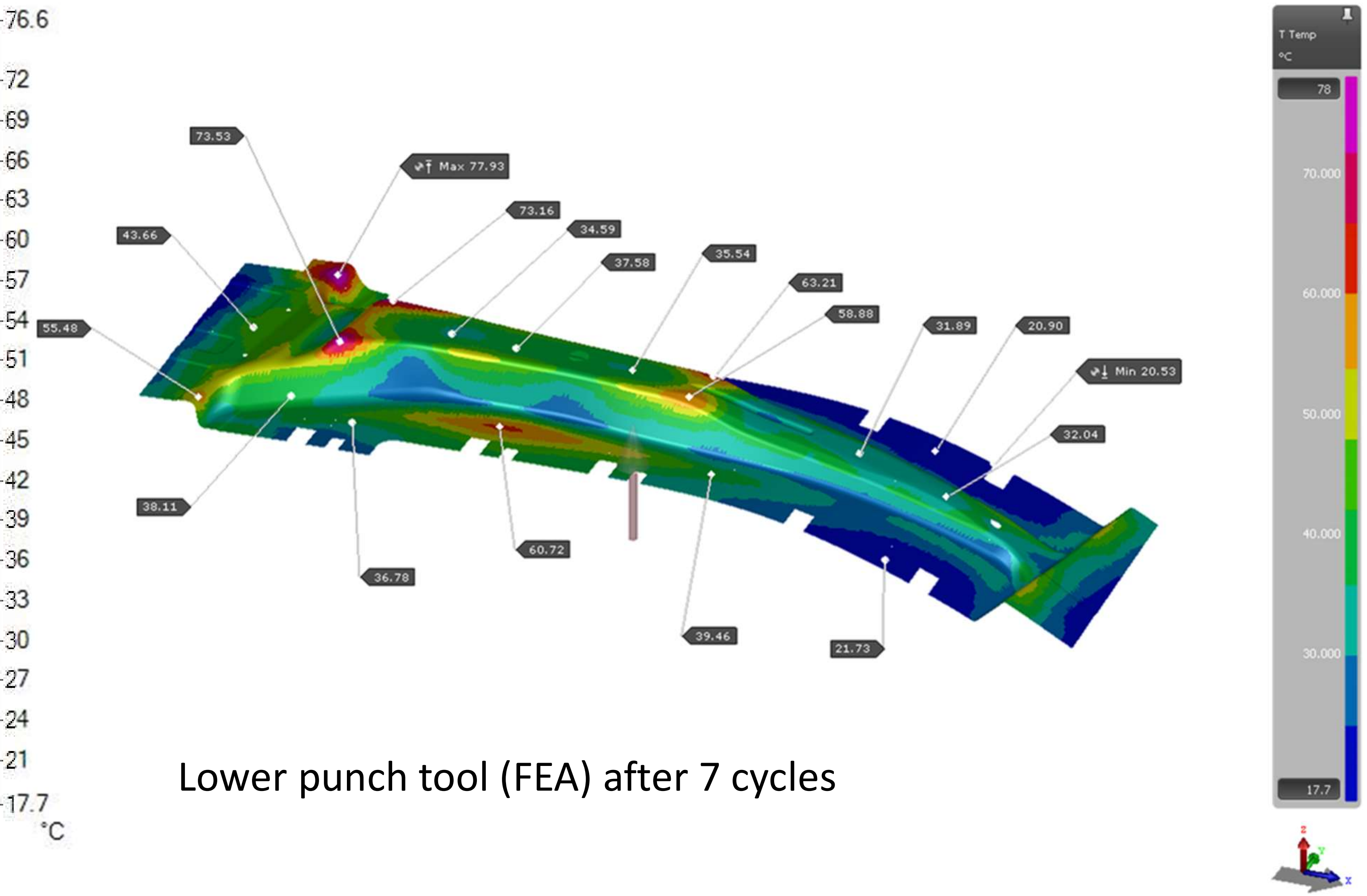
- Simulations using tooling CAD
- Predicted tool temperatures reach steady state at about 7 cycles/parts (76 - 77°C in the punch)
- Recommended to run 7 parts to warm up the tool immediately prior to buy-off trial

Tooling Temperature Distributions

FLIR Tool image



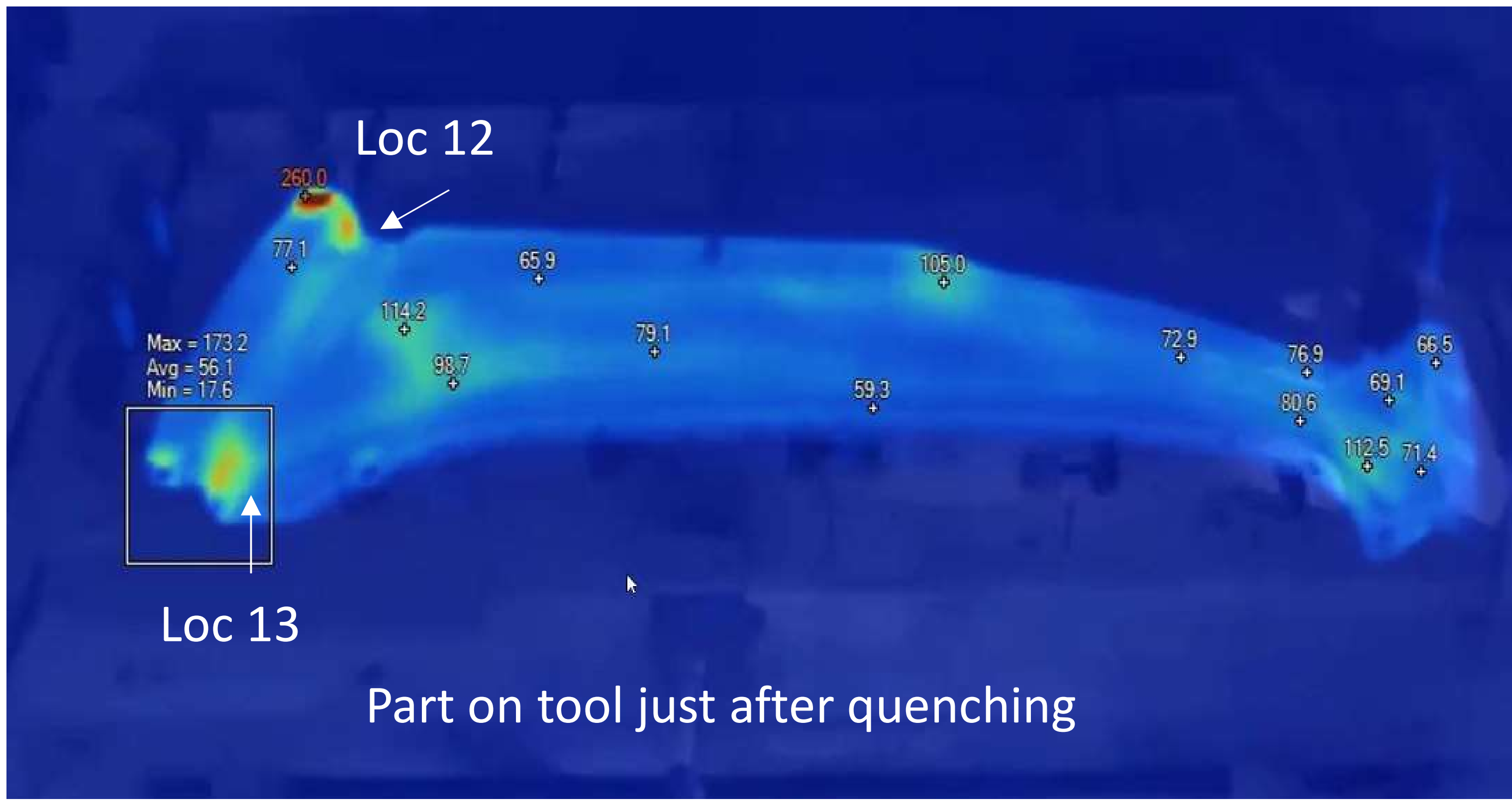
AutoForm



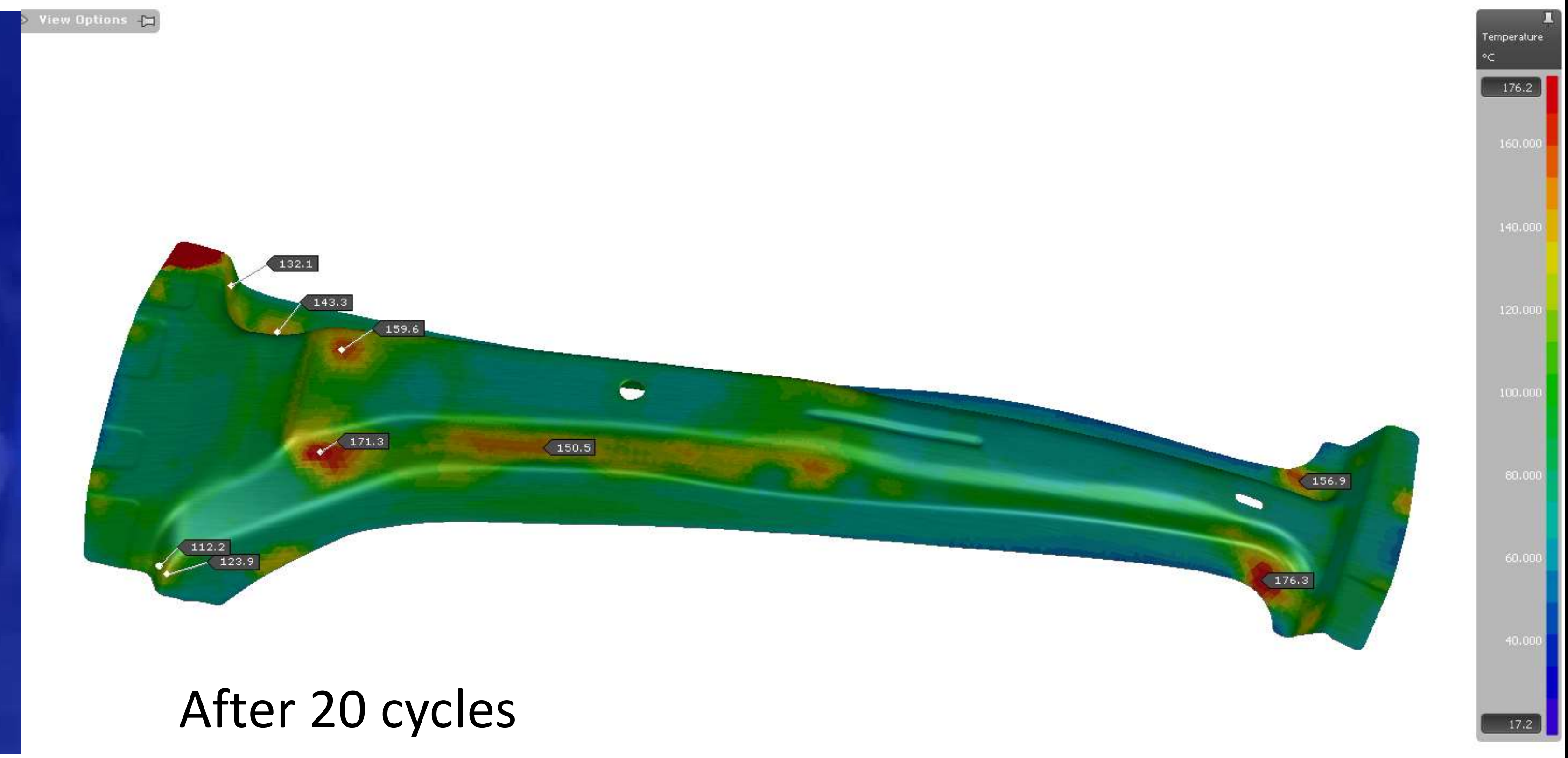
Fairly good agreement

Part Temperature Distributions

FLIR Part image



AutoForm



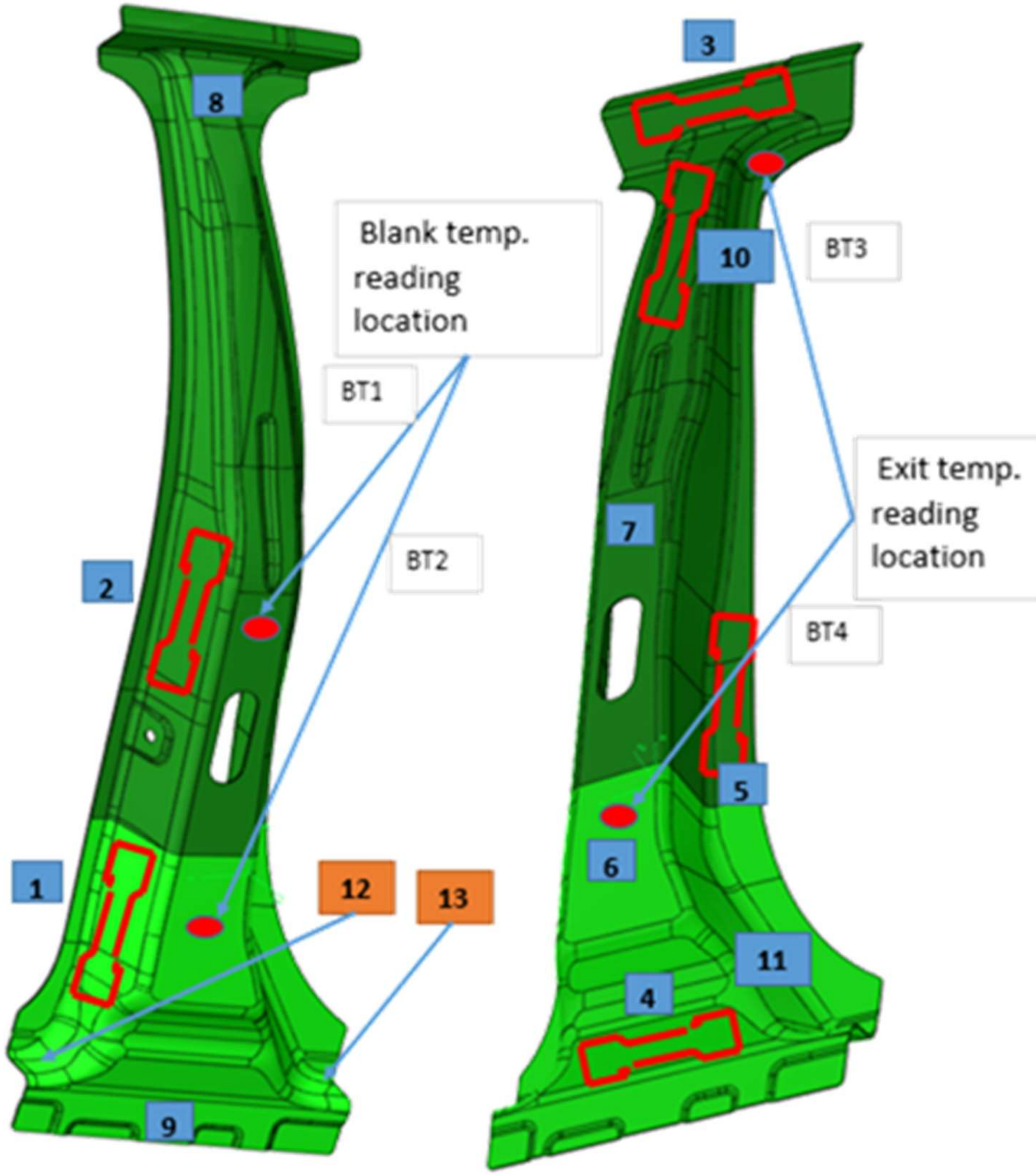
- AutoForm simulations predicts areas of higher temperatures in the part

Tooling Buy-off Trial

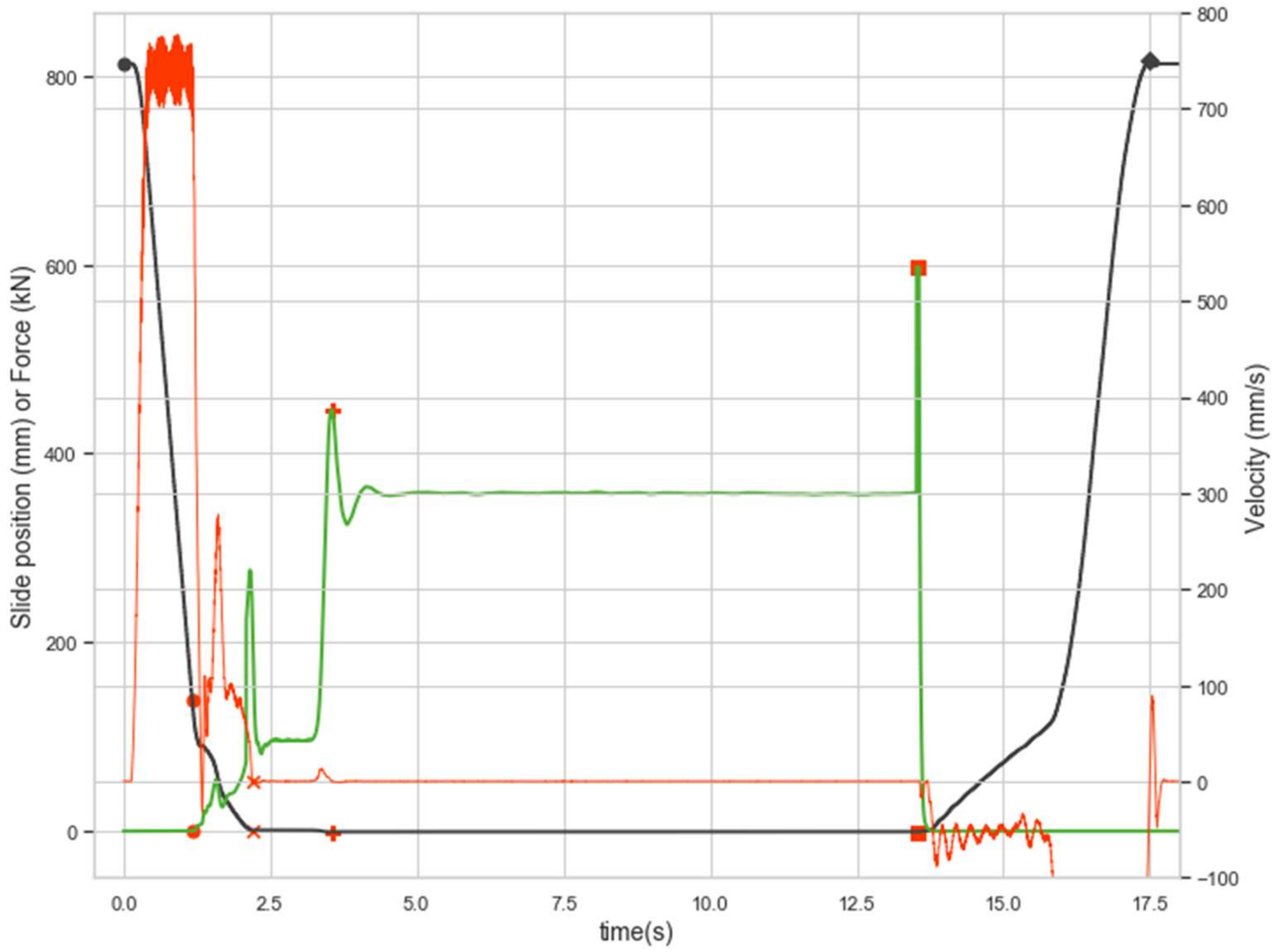
42 Piece Run for Tooling Buy-off

- 7 pieces run to "warm up" tools/press
- Additional 42 pieces run
- Blank heating to 930°C – soak for 300 sec
- Blank transfer time
  - 750 °C blank temperature on tool
- <u>Trial Data</u>
  - Part temperatures (spot pyrometers):
  - BT1, BT2 blank temperature just before forming
  - BT3, BT4 part temperature just after quenching
  - Thinning was measured in the walls for locations 12, 13
  - Sub-size tensile tests performed

Nominal Cycle Time	
Stage	Time (sec)
Start: Blank on tool (blank actually sits on tool and it takes bout 1.1 s fir the first contact by the upper die)	0
Total Motion down (home)	3.56
Quench time	9.97
Tool opened	3.95
Wait for new blank	30.5
Total	48 sec



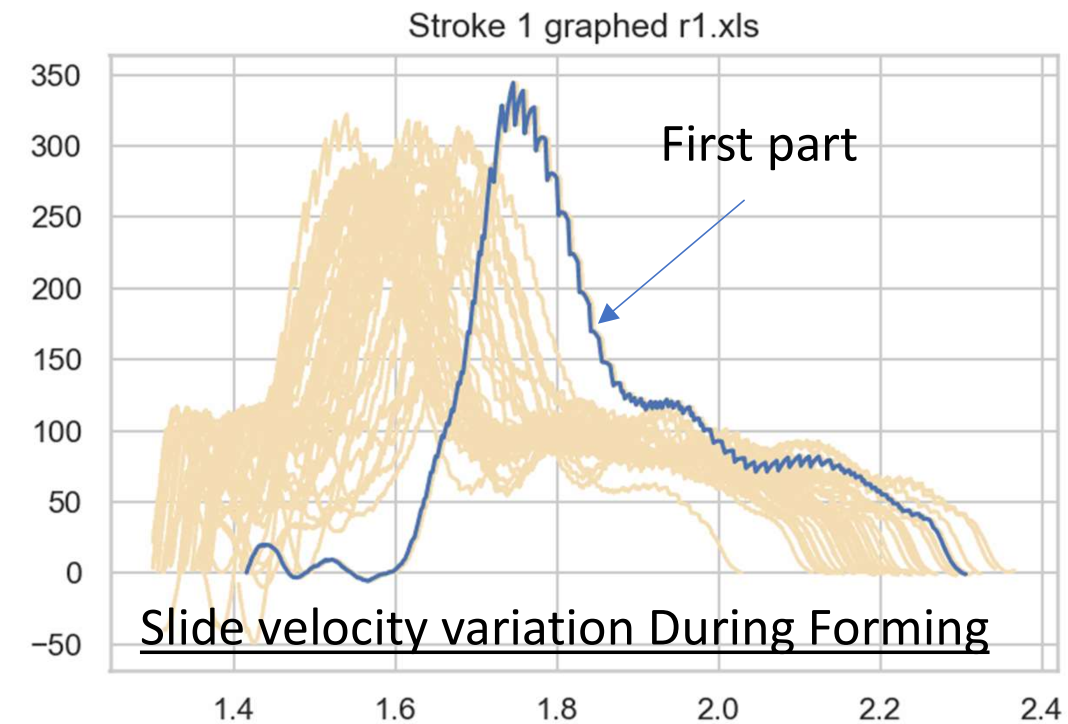
Buy-off Trial Press Data



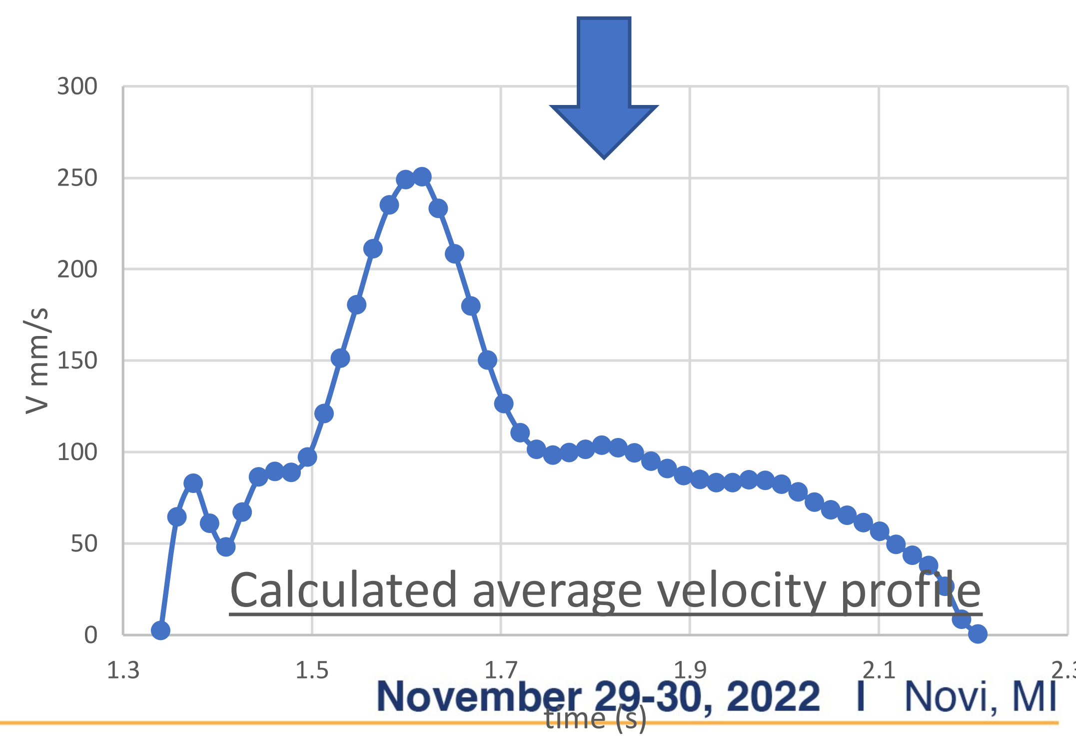
- Press data collected for each press stroke
- Semi-automatic analysis (Python script)
  - Slide displacement/velocity
  - Time for forming/quenching
  - Quench force
  - Cycle times
  - And more
- 42 spreadsheets, ≈ 9000+ entries per sheet

Buy-off Trial Press Data

	Cycle Time (s)	Oven Temp (°C)	Transfer Time (s)	Part Temp start, on tools (BT1, °C)	Quench time (s)	Part Temp, tool opening (BT4, °C)	Press Tonnage (kN)
Med	48.5	933.0	12.1	753.5	9.98	122.5	3589
Min.	45	931.4	12.1	747.0	9.95	103	3558
Max.	56	936.8	12.2	756.0	10.01	132	3626

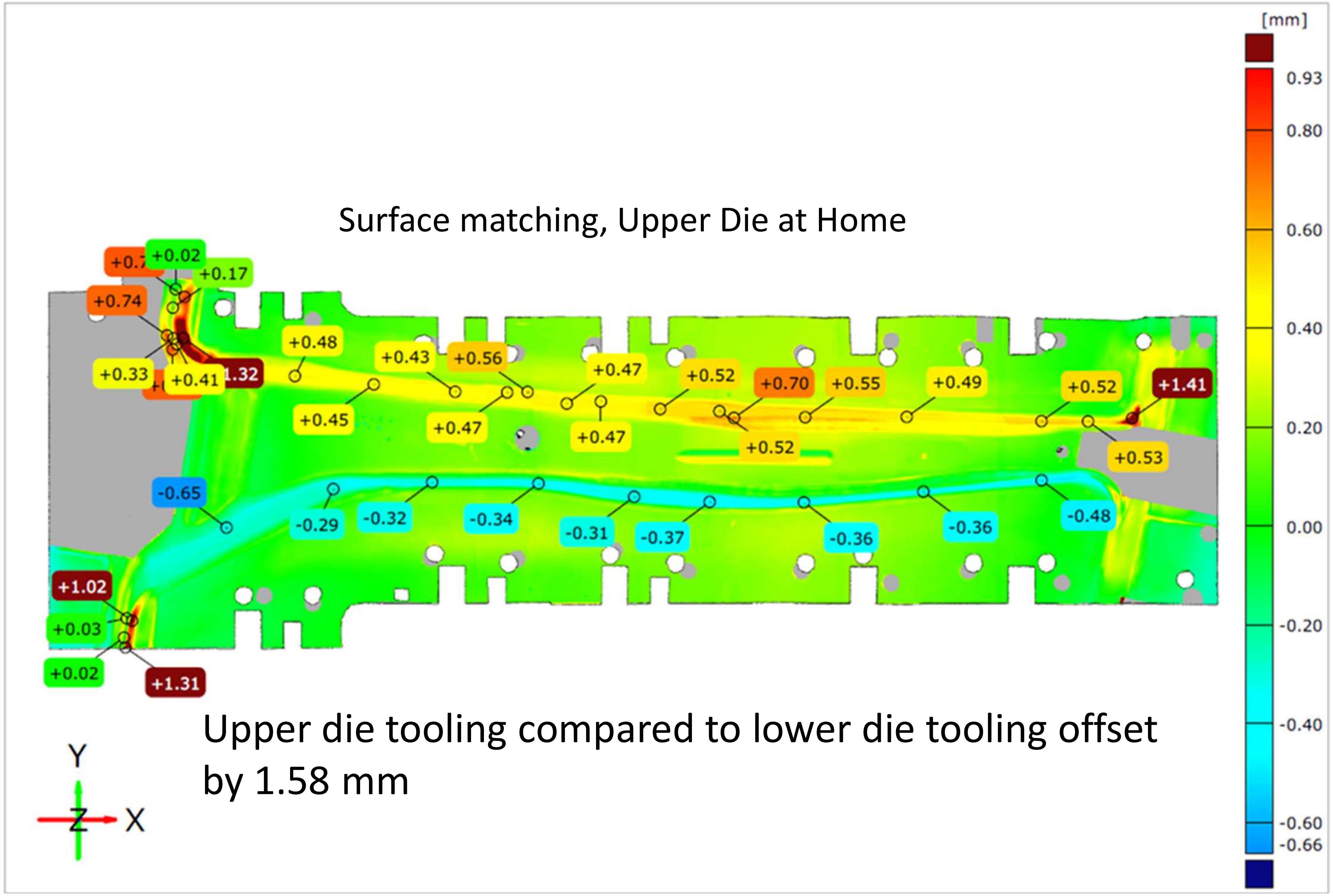


Slide/Upper die velocity is not constant as often used in FEA



Buy-off Trial Tooling Scans (STL)

- STL (blue light scan) data of tools are different from CAD
- Gaps, interference will affect forming/quench pressure
- More accurate to use STL scan data for tools in FEA



Buy-off Trial Part Data (n= 5 parts)

Cooled Part STL Scans compared to CAD

	Positive (above CAD) (mm)	Negative (below CAD) (mm)
med	2.24	-0.58
min	1.72	-0.6
max	3.34	-0.48

Thinning

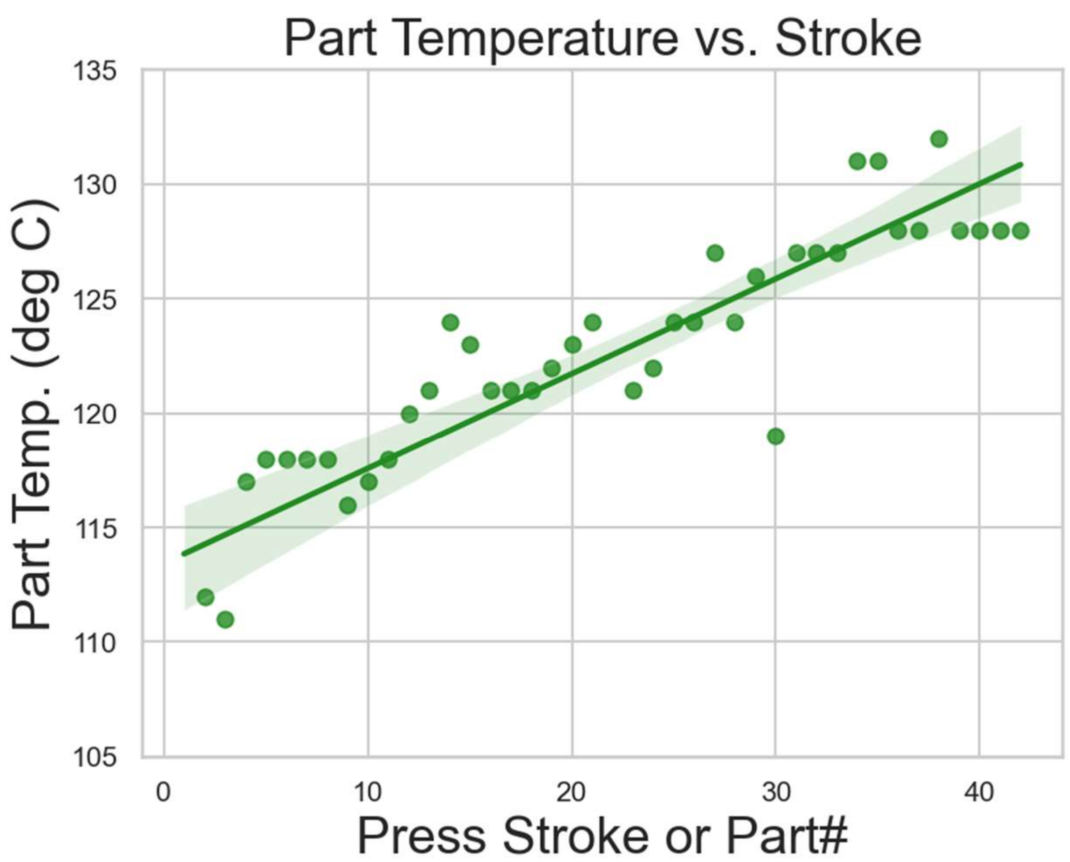
	Thinning (loc 12) Dt/t	**Thinning (loc 13) Dt/t**
med	-0.085	-0.106
Min	-0.109	-0.137
Max	-0.055	-0.08

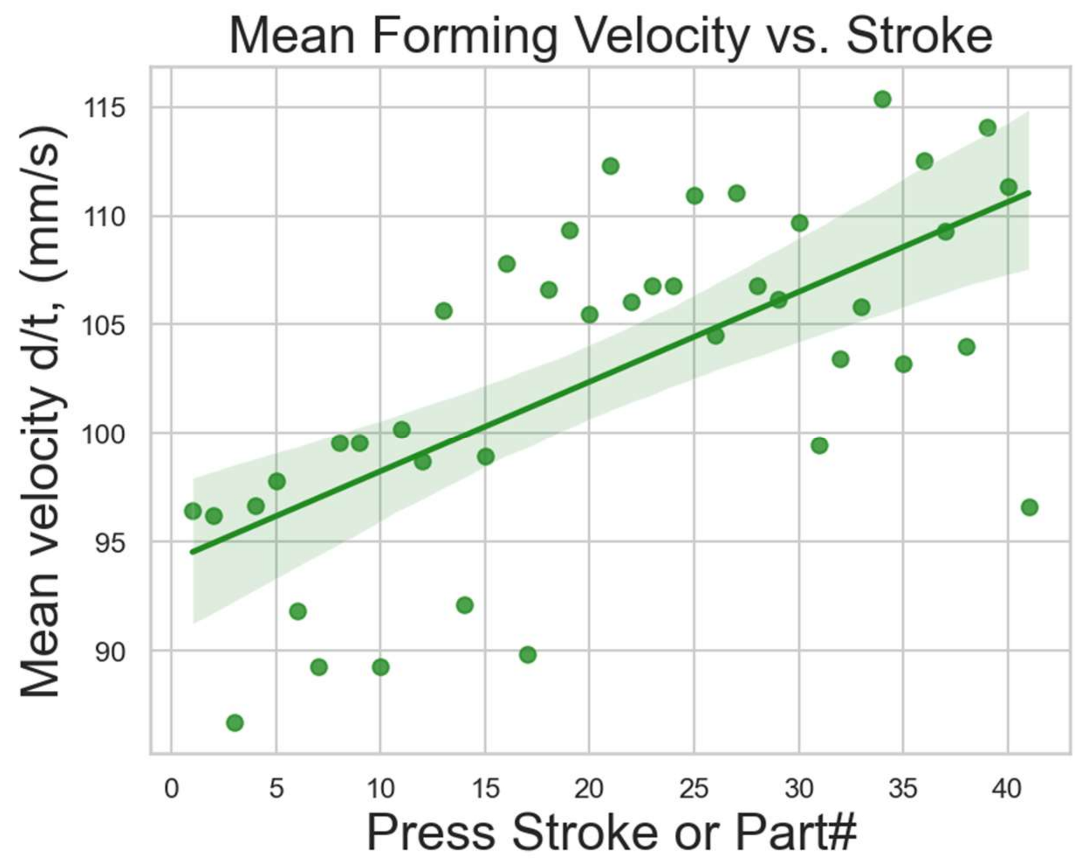
Mechanical Properties

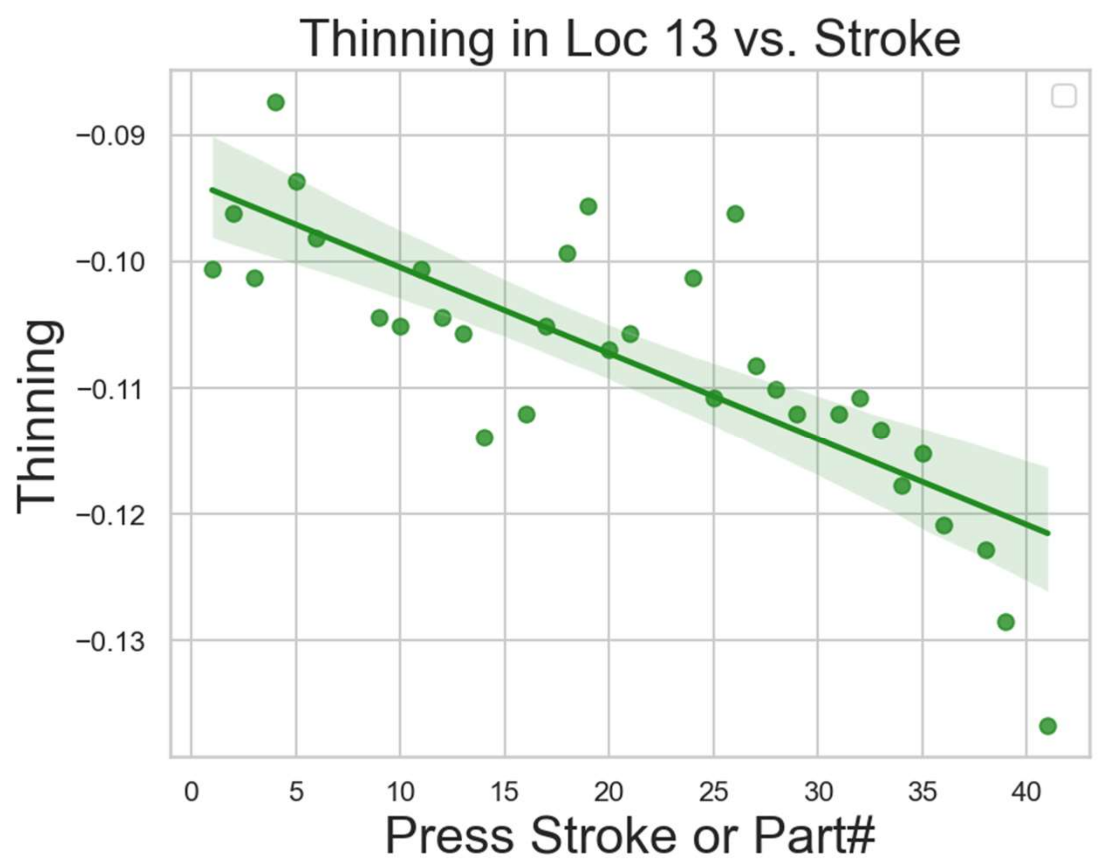
	YS(MPa)		TS(MPa)		TE(%)	
	Walls	Flat areas	Walls	Flat areas	Walls	Flat areas
med	1045	1030	1510	1495	6.1	6.8
min	1010	960	1460	1460	5.4	5.3
max	1110	1090	1560	1520	6.9	7.2

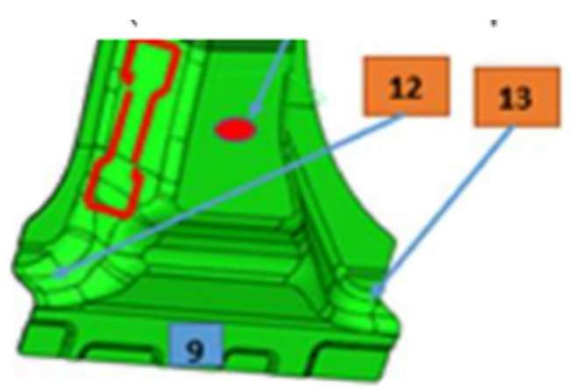
Formability is safe, mechanical properties, dimensional performance are acceptable

Buy-off Trial Part Data





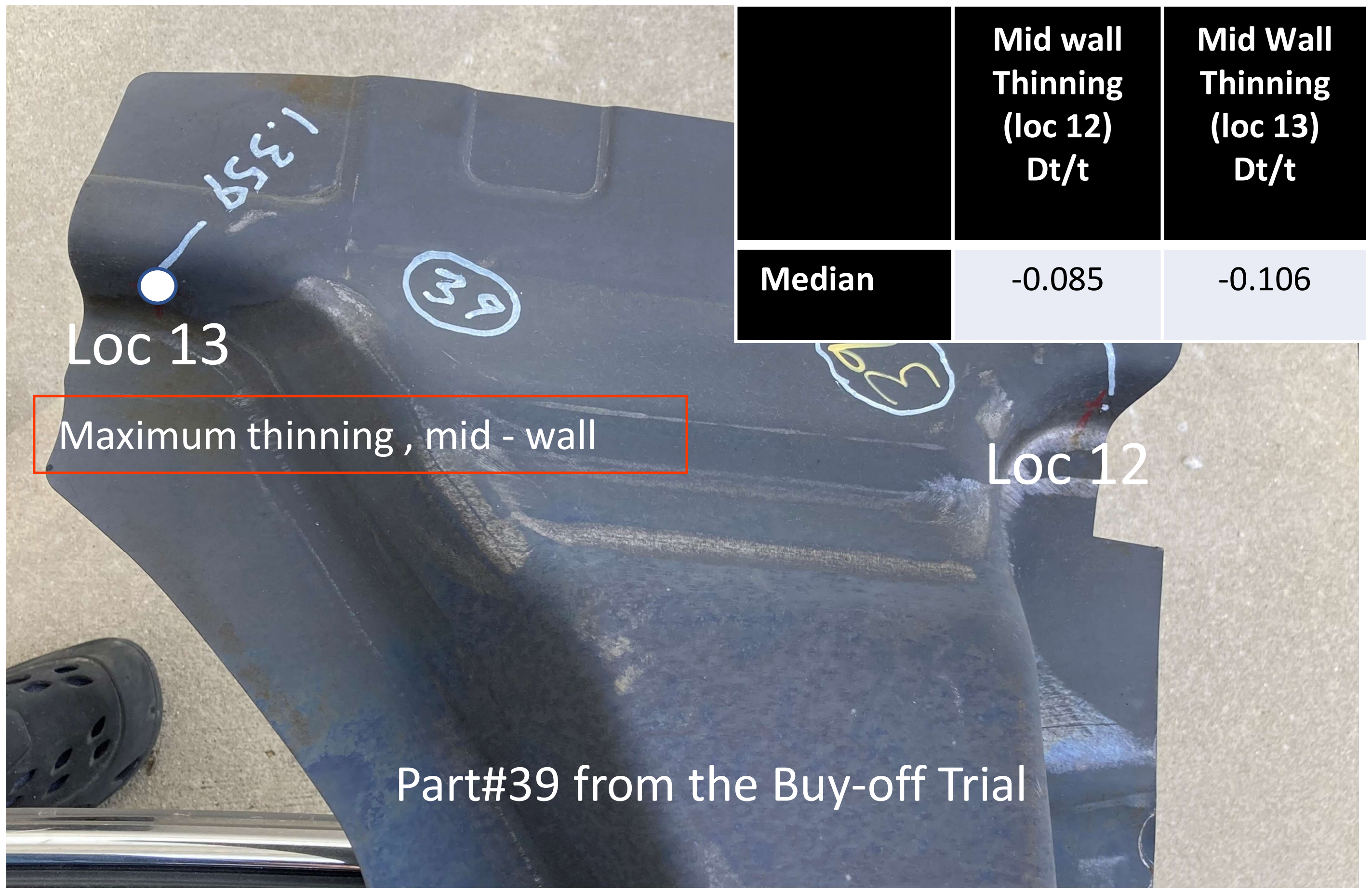


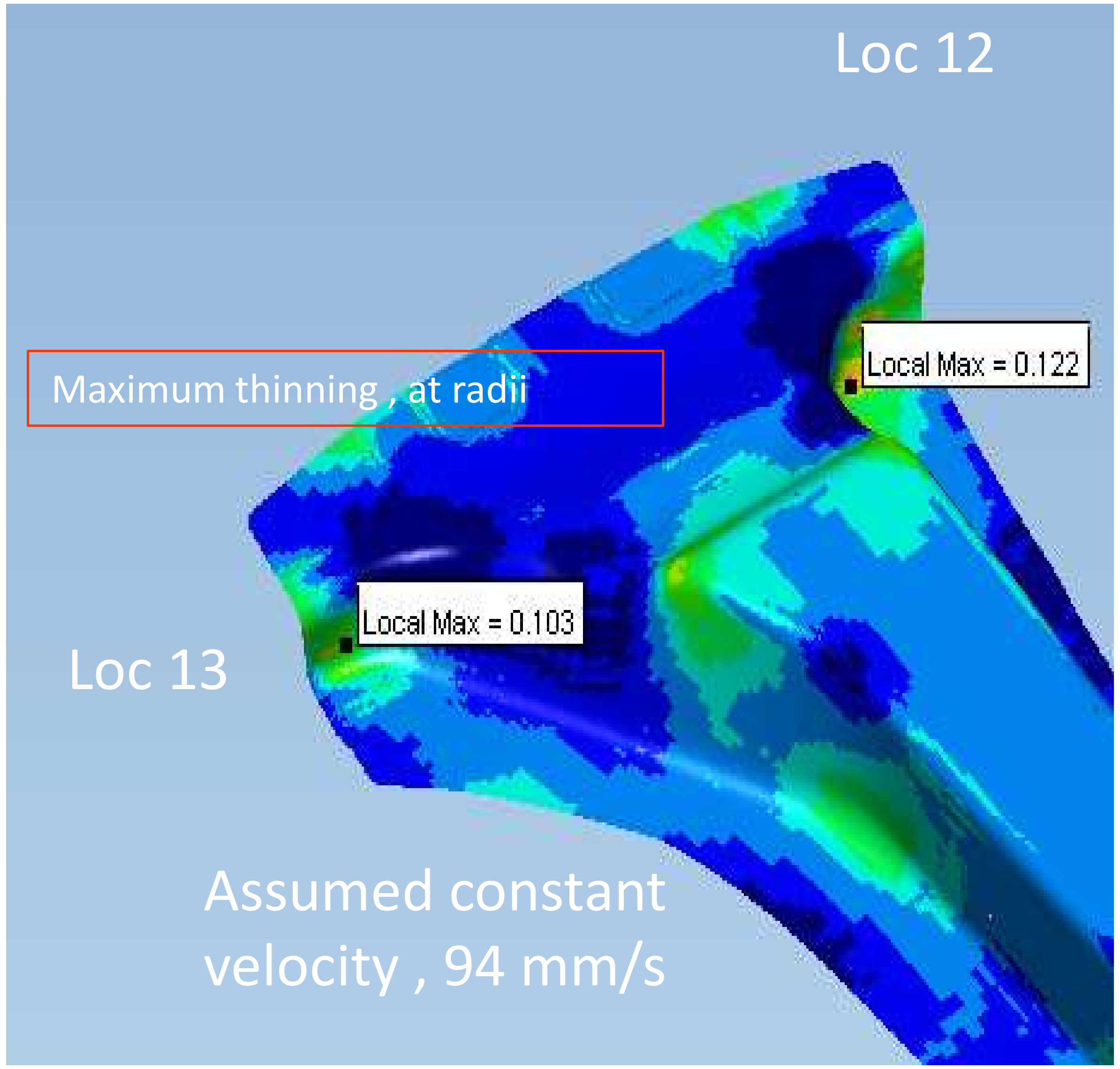


- Part temperature increases slightly with each stroke/part
- Mean forming velocity increases (forming stroke distance / forming time) – conversely time to form the part decreases
- Thinning magnitude in Loc 13 increases
- Thinning in loc 12 was random with press stroke (not shown)

PAM-STAMP FEA Using Constant Velocity Assumption and Tooling CAD

	Mid wall Thinning (loc 12) Dt/t	Mid Wall Thinning (loc 13) Dt/t
Median	-0.085	-0.106

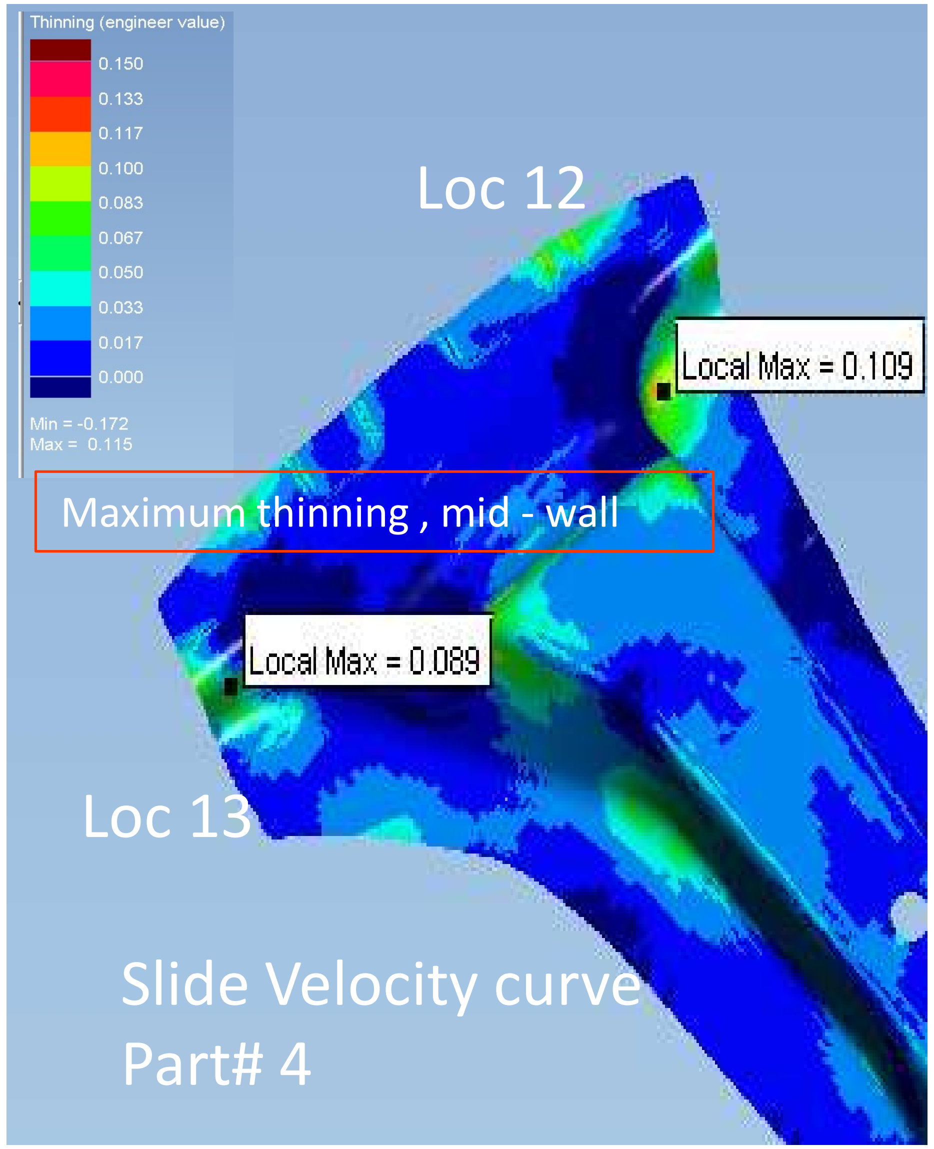


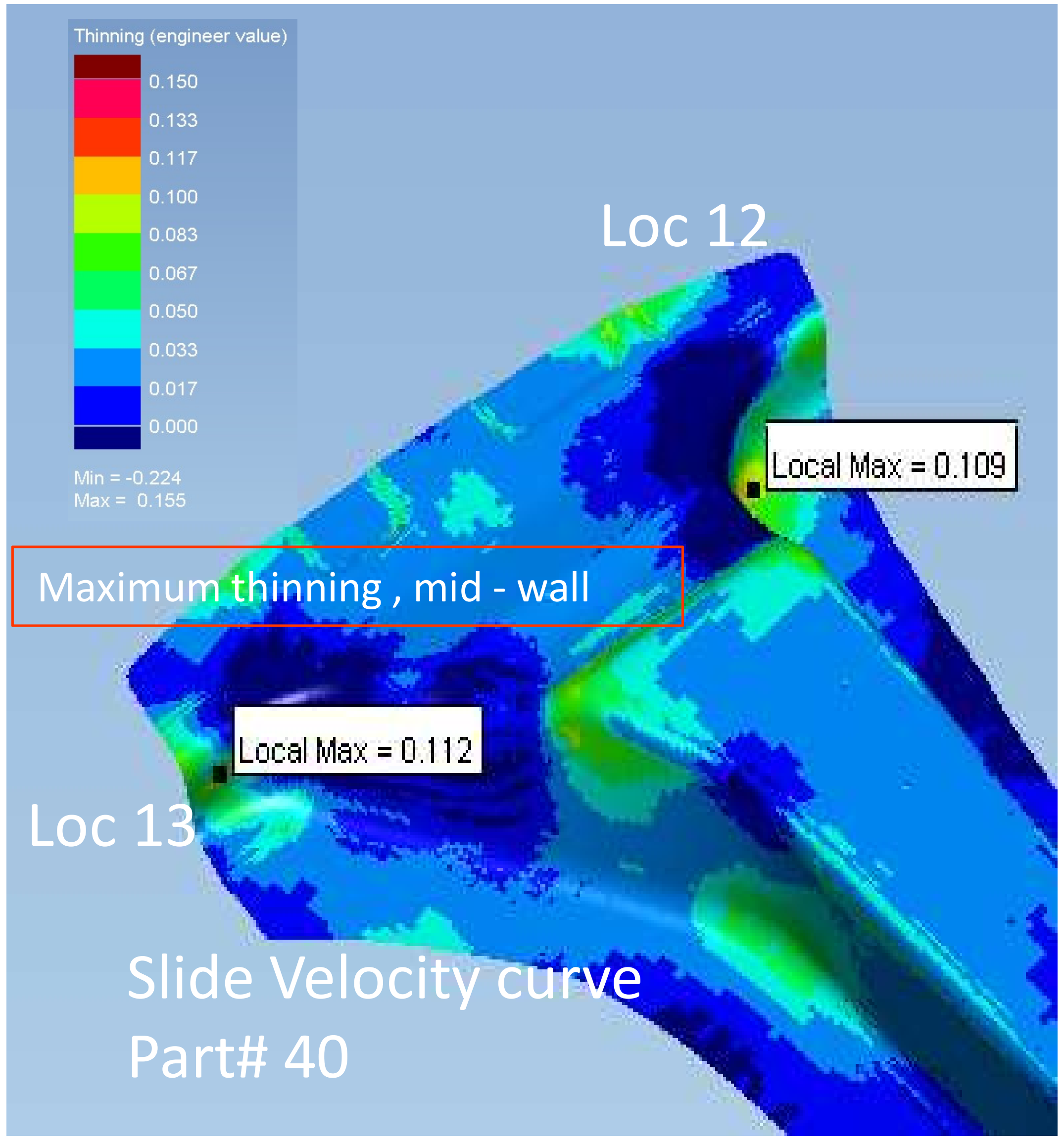


FEA predicts different location of maximum thinning vs. the buy-off trial

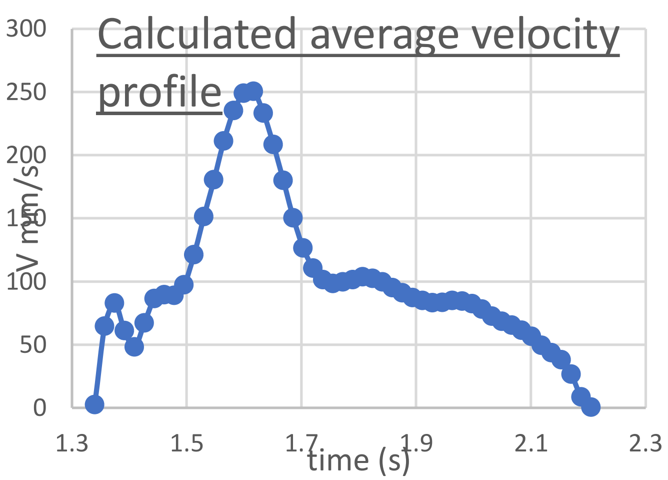
PAM-STAMP FEA using STL, Actual Press Slide Velocity Curves - Better Thinning Predictions

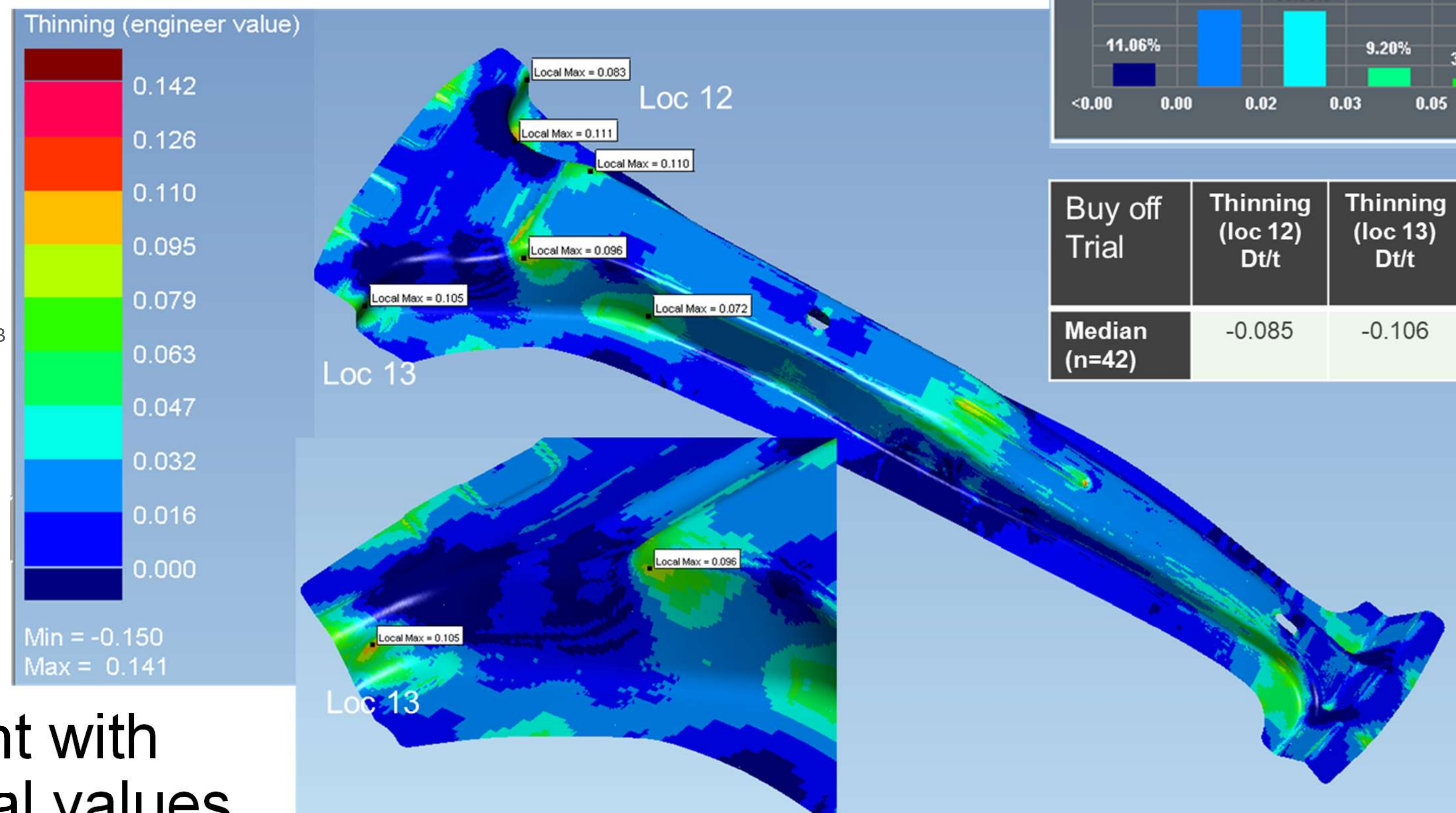
- Part Data, Buy-off Trial:
  - Maximum thinning , mid-wall location 13
  - Max thinning at Loc 13 increases from -0.087 (Part#4) to -0.137 (Part#40)
- FEA using actual velocity curves (Part#4, Part#40):
  - Matches the location of maximum thinning from the trial
  - The thinning trend from the trial is reproduced in the FEA

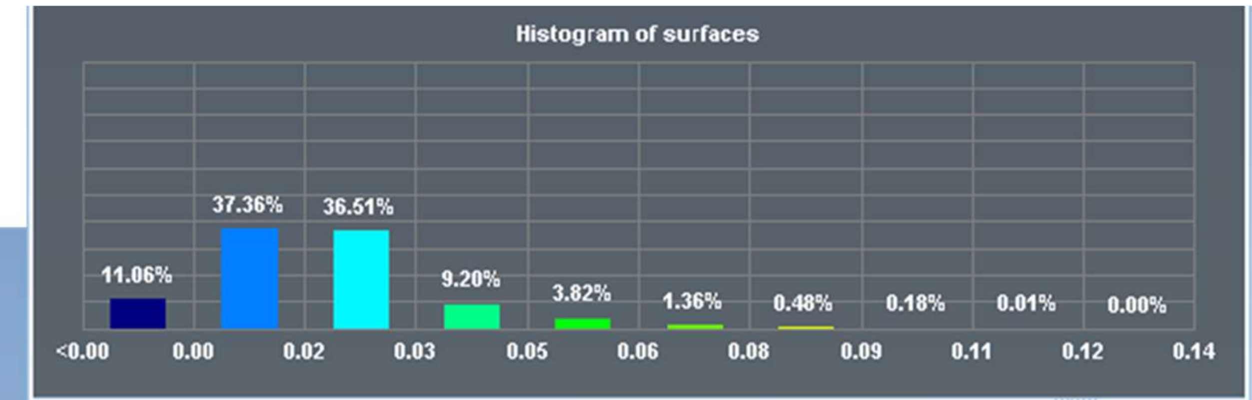




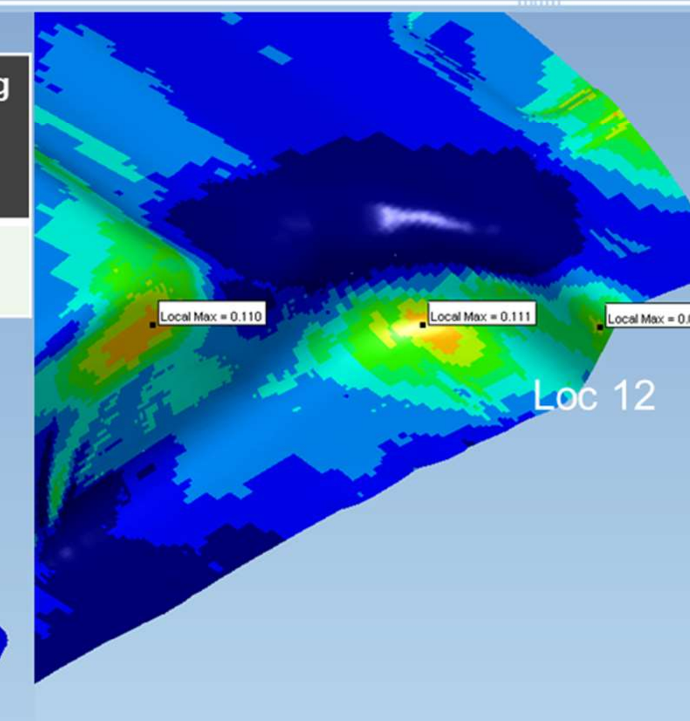
PAM-STAMP Thinning using STL, Calculated Average of Press Slide Velocity Curves







Buy off Trial	Thinning (loc 12) Dt/t	Thinning (loc 13) Dt/t
Median (n=42)	-0.085	-0.106



Good agreement with location, and trial values

PAM-STAMP FEA using STL, Measured Press Slide Velocity Curves: Quenched after 10 s, 3600 kN

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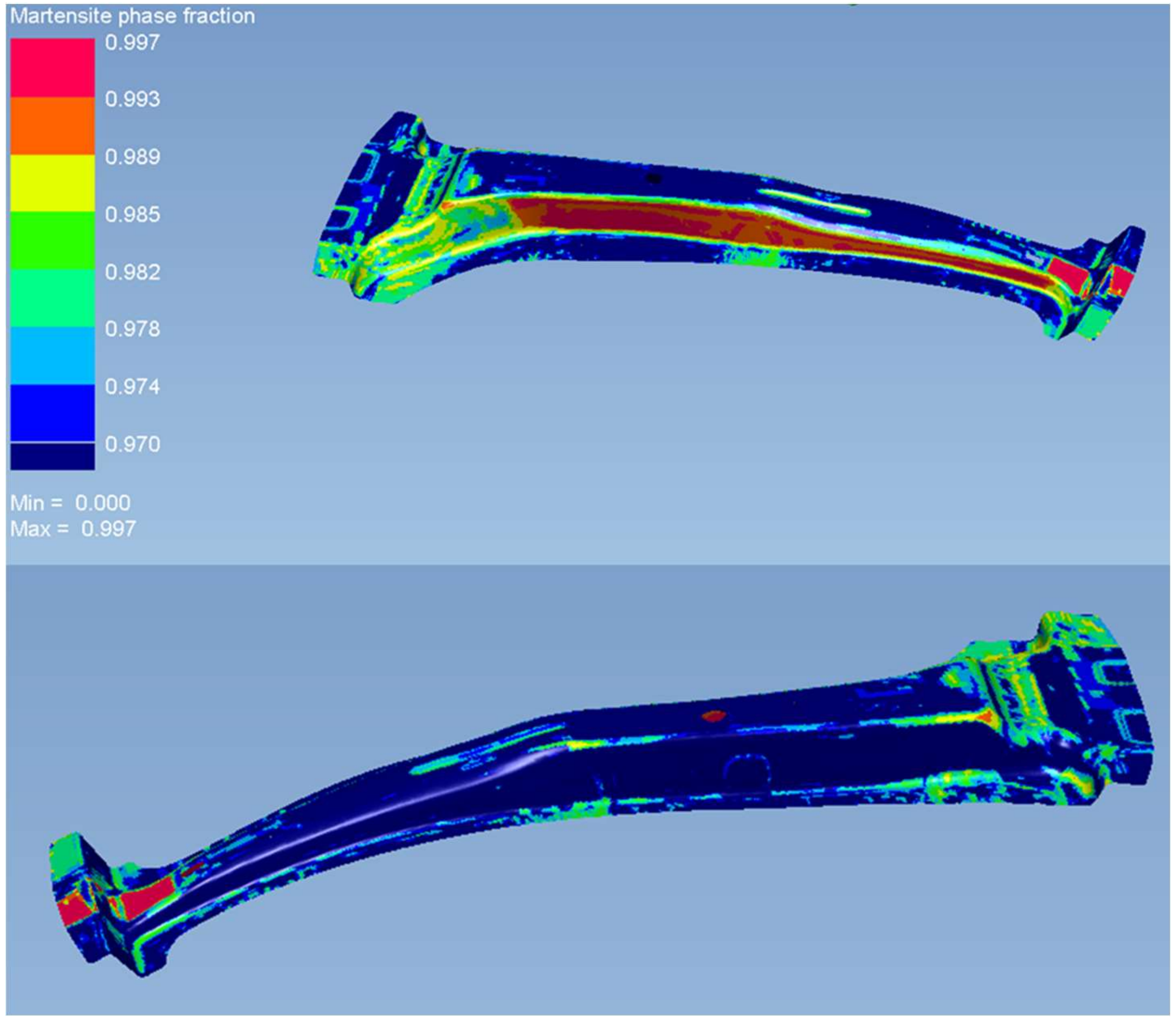
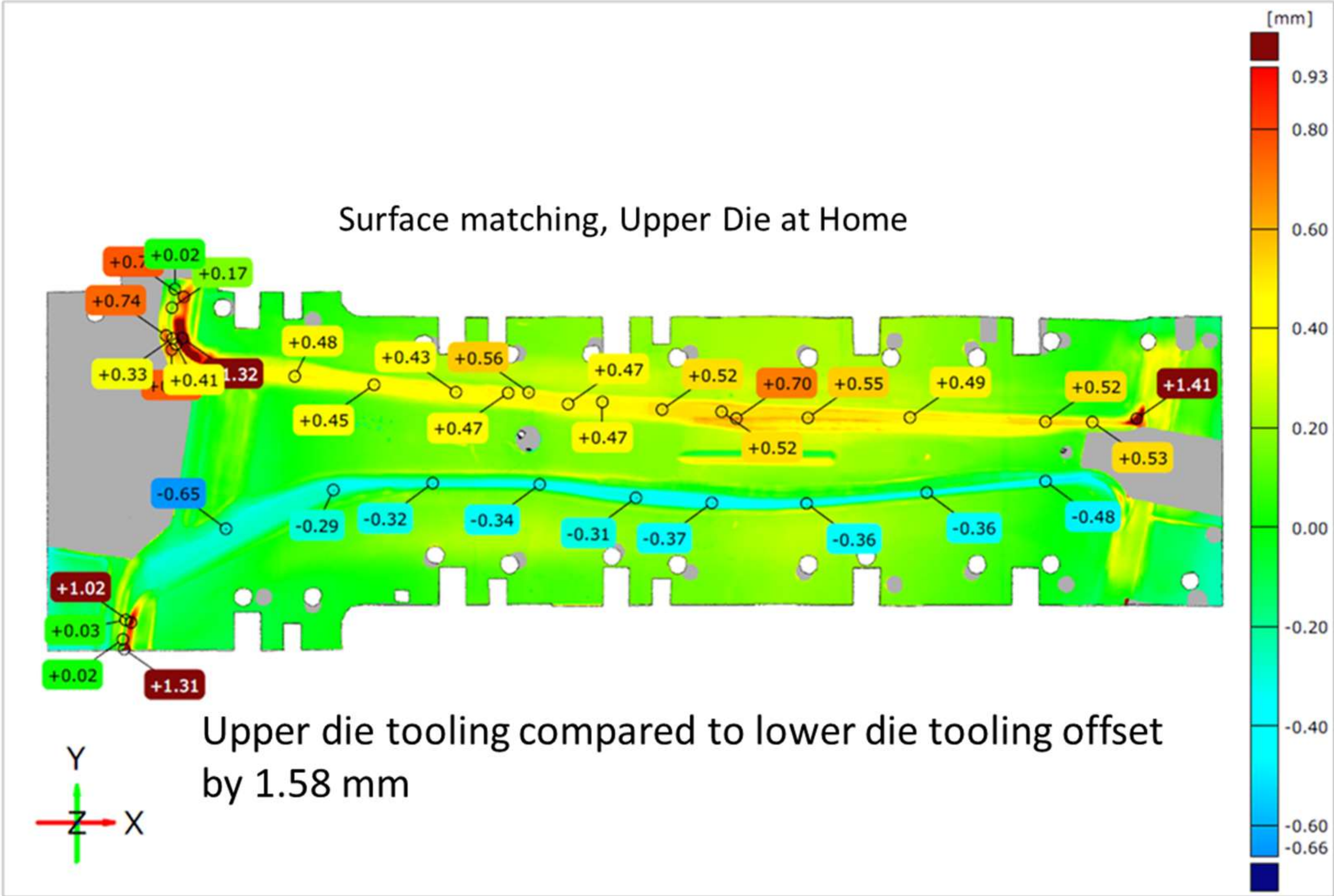
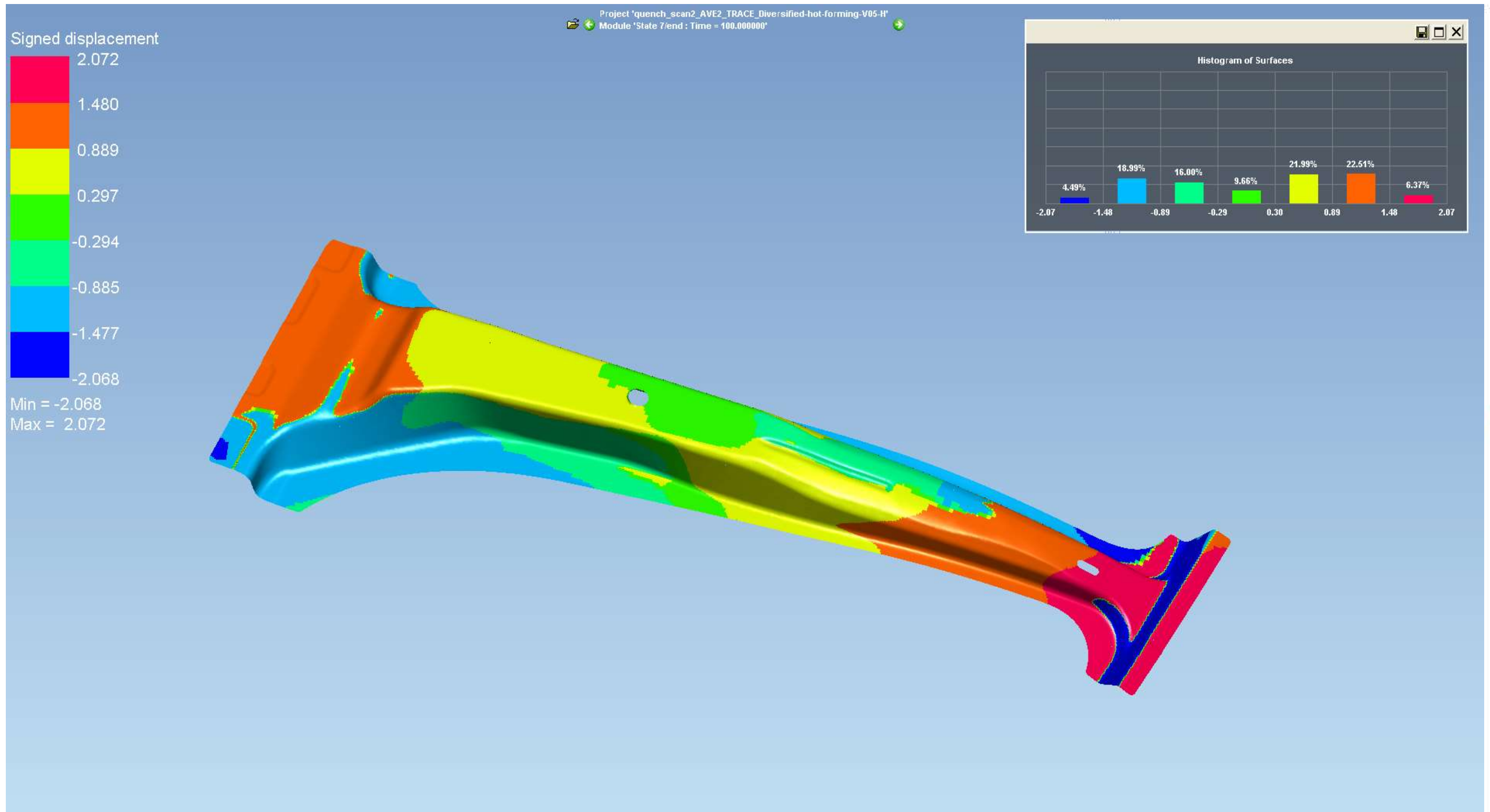
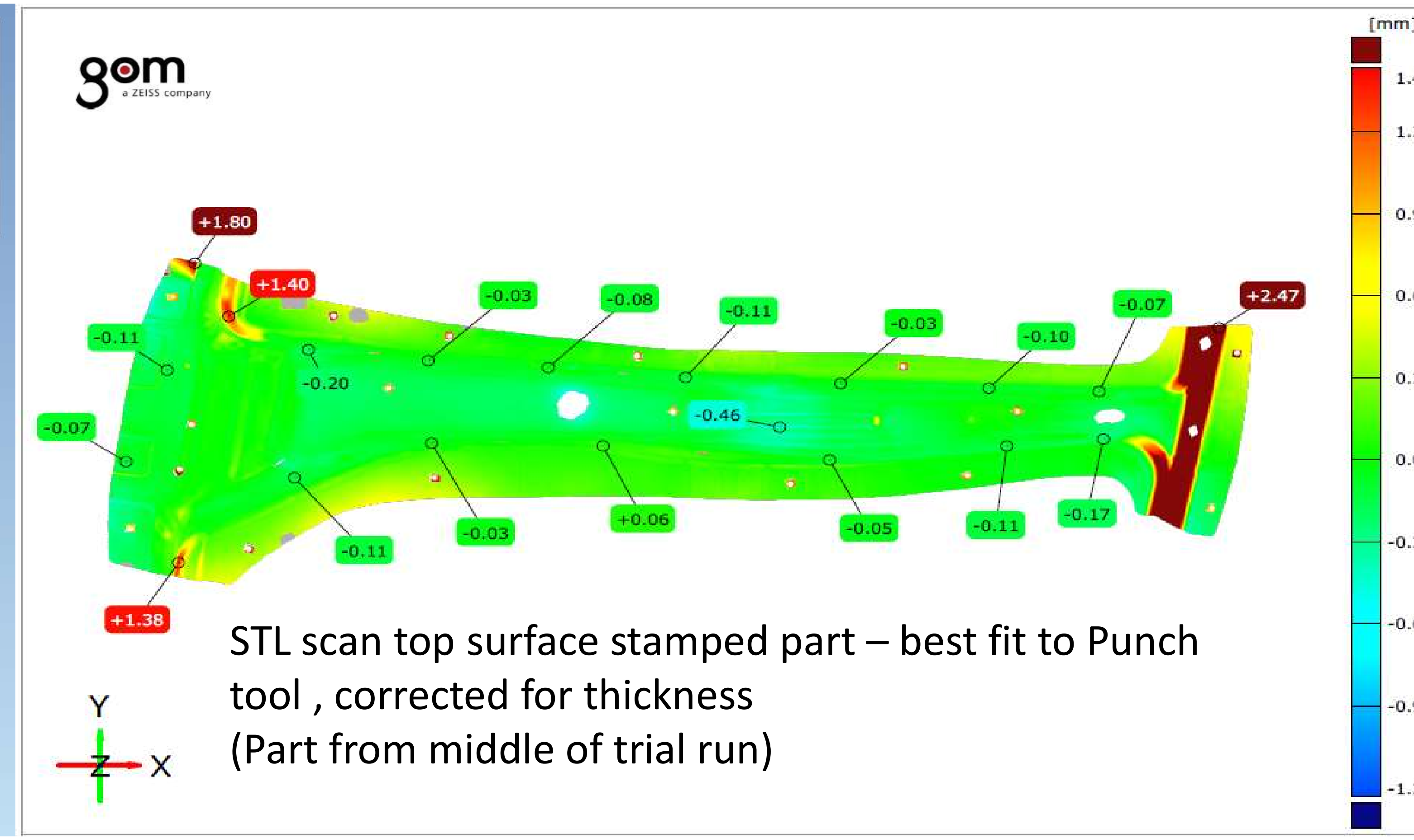




- The part is > 97% martensite, in alignment with the good mechanical properties from the trial
- The effect of tooling gap in the walls in the scanned (STL) tools is reflected in the simulation quenched results

Distortion Relative to the Scanned Tooling





- PAM-STAMP, min/max predicted distortion magnitudes are less than that seen in the trial
- Also, the pattern of distortion is different than that seen in the trial

Summary, Future Work and Next Steps

Summary

- Benefits of FEA simulation of tooling commissioning demonstrated in:
  - Assessing production intent tooling CAD vs. concept CAD
  - Diagnosing gap pad failure
  - Assessing the effect of misalignment
  - Aid to making decisions for the press “recipe”
  - 3D thermal simulations show promise to determine hot spots on tools. Work is needed to develop capability to examine hot spots on the part
- Tooling buy–off:
  - Good parts made using 1.6 mm Usibor® 1500 AS
  - Able to measure press stroke variations (slide velocity, quench force, timing)
  - Good agreement between simulation and trials,
    - FEA predictions for thinning were more in agreement with the trial results when actual velocity curves from the trial were used in the simulation instead of assumed constant velocity.
    - Predicted martensite fraction in-line with good mechanical properties measured in parts from the trial
  - Predicting part distortion (with FEA) is a challenge as results did not match that in the trial

Next Steps

- Model stamping process noise effects on stamped product consistency
  - Development of FEA robustness (Monte Carlo) simulations of the hot stamping process incorporating process variation
  - Net shape hot stamping modeling, stability of the part edge with respect to holding part tolerances.
- Ongoing process window for new grades, new coatings etc.
- FEA modeling ongoing improvement:
  - Development and validation of material cards, and prediction of mechanical properties
  - Improve understanding of heat transfer and part distortion

Questions, Remarks?

Parth Patel P.Eng, Project Manager-PHS
ArcelorMittal, Global Research and Development
parth.patel2@arcelormittal.com

Mike Austin , Director - Manufacturing Engineering
Diversified Tooling Group, Inc.
maustin@diversifiedtoolinggroup.com