Prototype Development of AHSS Battery Enclosures: Forming Process Insights and Correlation with Numerical Simulation

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GREAT DESIGNS IN STEEL™

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Background and Introduction

Battery Enclosure (PHASE I*)

- ✓ Packaging efficient
- ✓ Vertical walls (Zero-degree draft angle)
- ✓ Thinner gauge for mass saving (0.6 mm)
- ✓ Excellent dimensional tolerance

OEM Feedback

- Higher strength
- Thickness for corrosion resistance
- Retain packaging efficiency

Battery Enclosure (PHASE II)

- ➢ AHSS stamped battery enclosure
- ➢ Maximum possible packaging efficiency
- ➢ Thicker gauge (1 mm)

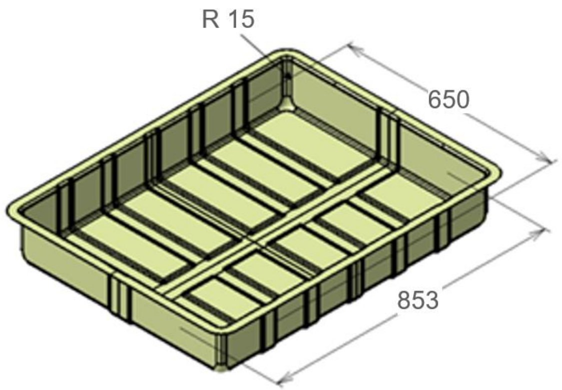
This steel solution challenges the use of extruded aluminum enclosures by providing better water-tightness and enabling a simpler assembly process.

* link to Phase I GDIS presentation

Design Adaptation from Mild Steel to AHSS

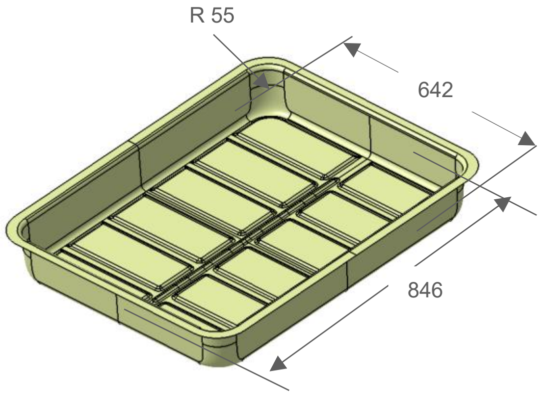
GDIS

Design for mild steel (CR5GI)



Dimensions (mm)	
Length	853
Width	650
Depth	135
Corner radius	15
Die radius	7
Punch radius	10
Draft angle	0 deg

Design for AHSS (CR330Y590T-DP)

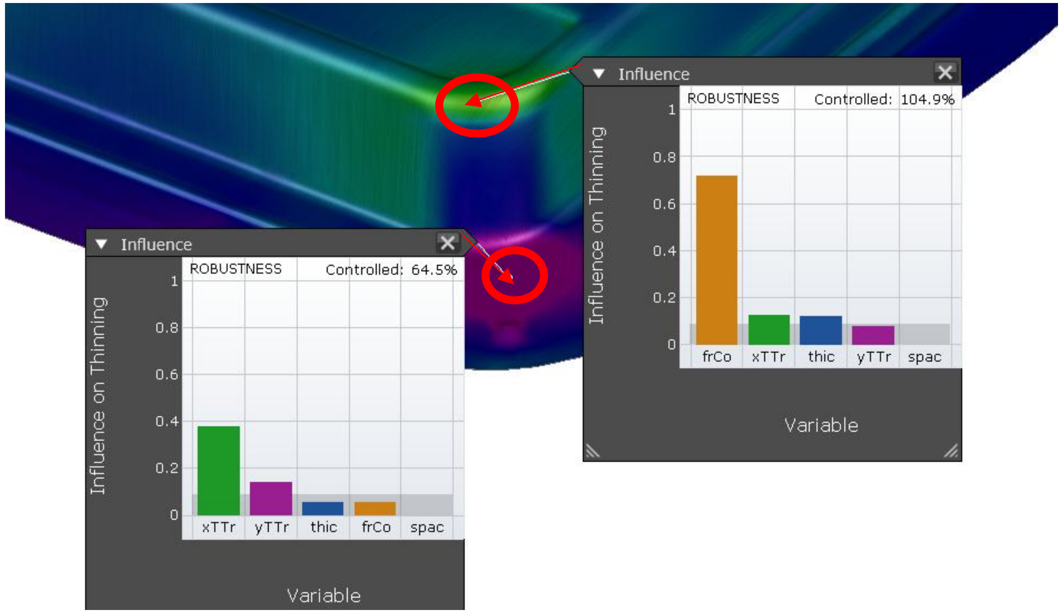


Dimensions (mm)	
Length	846
Width	642
Depth	121
Corner radius	55
Die radius	10
Punch radius	13
Draft angle	1 deg

- Going from mild steel to AHSS, the punch and die radii are increased by 3 mm each
- The significant dimensional change is in the corner (plan view) radius
- The stiffening features/ribs on the long end of the battery tray are eliminated, reducing mating part complexity and eases enclosure assembly

Process Development - Simulation

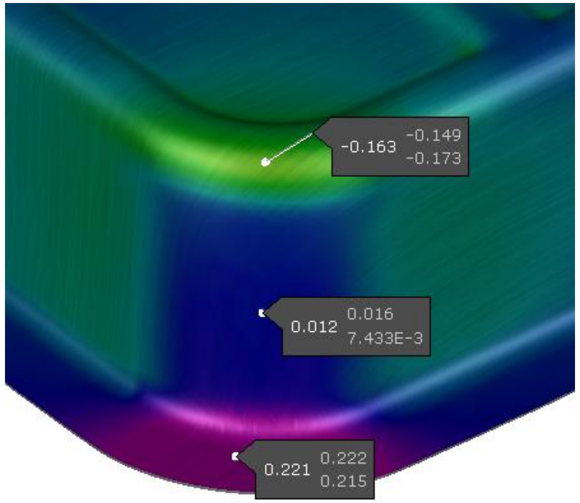
- A stamping process was developed in simulation to maintain safe forming feasibility and minimize springback on the mating flanges
- An experimentally determined FLC was used in the material card
- Robustness study was conducted to include variation in blank thickness, friction coefficient, binder gap, material properties and blank location
- The robustness study indicated that the most influential factors on thinning were the friction coefficient and the blank translation (positioning)



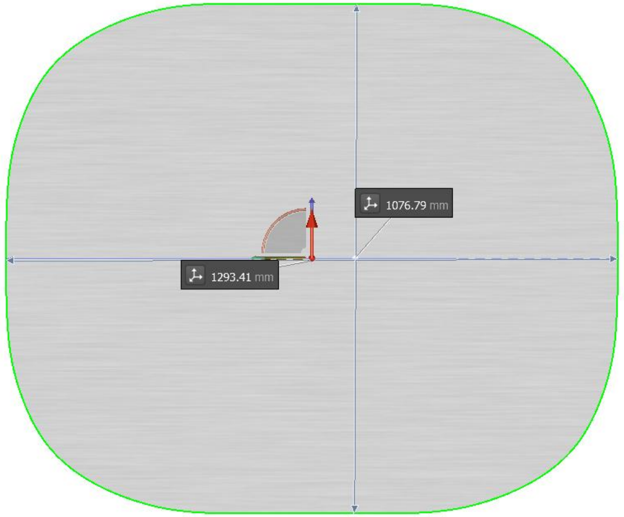
Material Properties			
Material Name			CR330Y590T-DP
Coating			GI
Thickness			0.995 mm
Supplier			ArcelorMittal
Elastic Properties			
Young's Modulus [MPa]			210000
Poisson's Ratio			0.30
Mass Density [Ton/mm^3]			7.68E-09
Plastic Properties			
Yield Stress [MPa]			390.0
Tensile Strength [MPa]			658.0
Uniform Elongation [%]			15.48
Work Hardening			
n (0 - Ag)			0.18
Anisotropy			
r0	r45	r90	rbar
0.80	0.80	0.80	0.80
FLC_0			
19.0%			

Process Development - Simulation

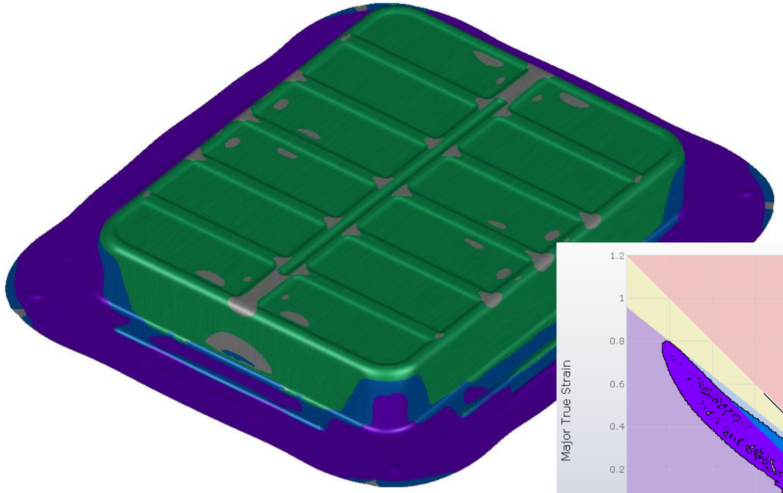
- The simulation results show forming feasibility
- The process was optimized for springback and thinning
- At the end of draw a maximum thinning of 16.3% is seen in the corners
- Springback on the flanges was designed to have a tight tolerance following an OEM specified standard

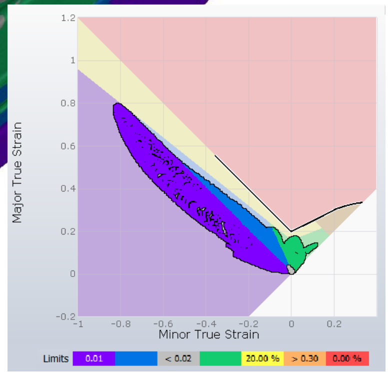


Thinning %



Blank dimensions	**1293.4 x 1076.8 (mm)**
Part weight	**7.60 kg**


Draw Panel



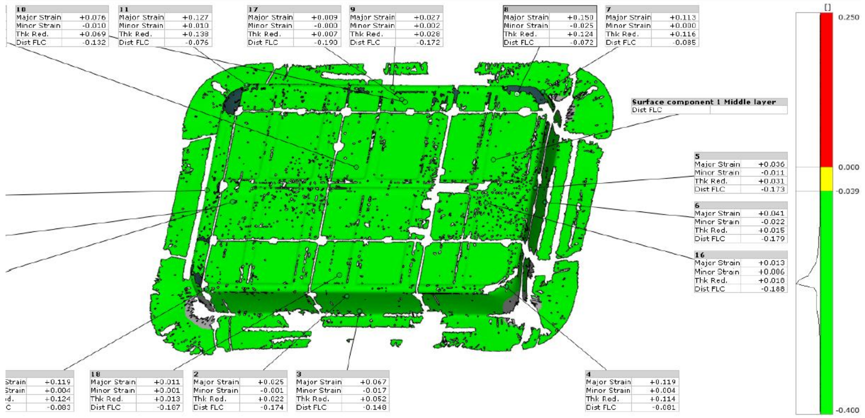

Trimmed Panel

Physical Stamped Prototype Part

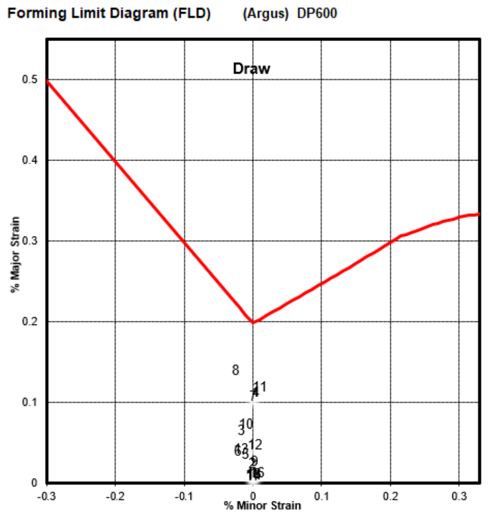
- A single action mechanical press with a maximum capacity of 2400 tons was used
- The tooling process utilizes a kirksite three-piece conventional draw die with four shape set (stake) beads - one located along each side of the tray.
- Industrial grade lubricant (Ferrocote 61 MAL) was applied on the blank before stamping
- Binder pressure was applied using free standing nitro cylinders
- The part was produced using a production intent process, hit once over bottom
- A total of 10 panels were stamped and laser trimmed
- The flanges were hand qualified, as typical in prototyping
- Typically, in production a restrike operation would be in place
- The total applied binder pressure was 115 tonf, 18.5% higher than predicted force in simulation

Evaluation of Stamped Panel

- The prototype demonstrates safe forming feasibility for DP600GI at 1.00 mm
- The panel strains were measured using Argus, with grids applied by chemical etching
- The portions on the panel that could not be captured by Argus were further assessed by CGA
- The maximum thinning on the prototype was 12% in the corners under biaxial strain conditions
- The final panel was assessed for flange flatness and sidewall curl
- The flanges exhibit good flatness and are quantified in a dimensional study
- A slight bow was detected on the base of the battery tray which is further analyzed in correlation study
- Some wrinkles on the flange are detected in the corners attributed to uneven gap on the binder, confirmed through a lead check procedure

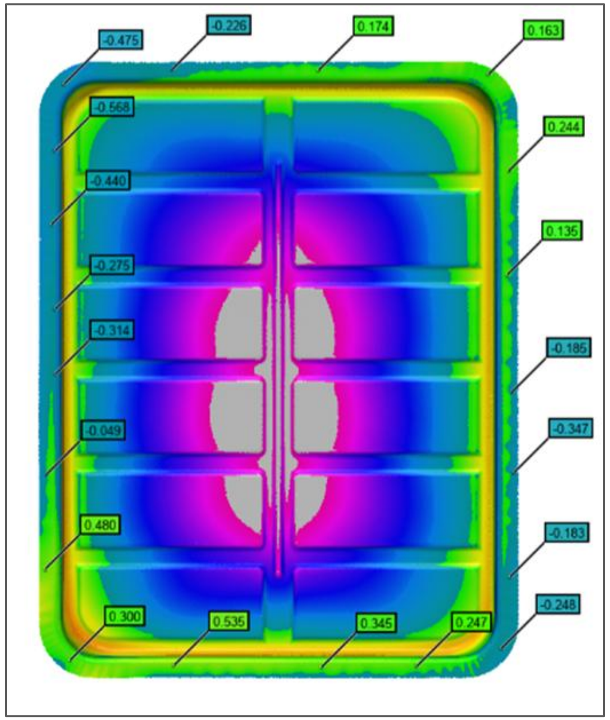


Physical Panel - Argus Evaluation

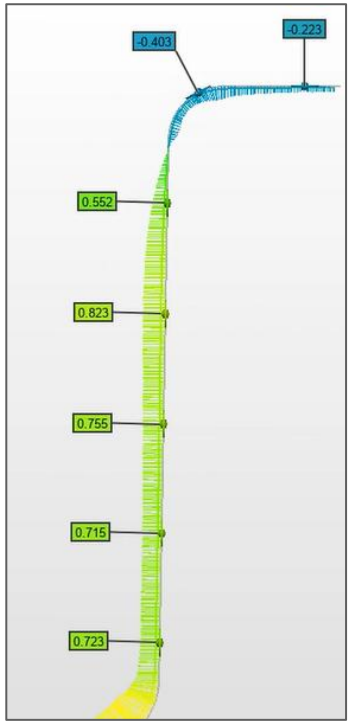


Dimensional Tolerance

- Three stamped and trimmed panels were scanned in free state and assessed for dimensional tolerance
- The scanned data were then measured against the reference CAD surface
- The flanges, which are critical mating surfaces for the battery tray were designed to have minimum springback; overall, they showed springback of less than ± 0.5 mm
- The rate of change (waviness) of the attach flange was 0.0053 over a distance of 511 mm (short edge)
- The rate of change of attach flange along the long edge is 0.00083 (over the same distance)
- Over the depth of the tray (sidewalls), a springback of less than 1 mm was observed



Deviation of Flange Surface

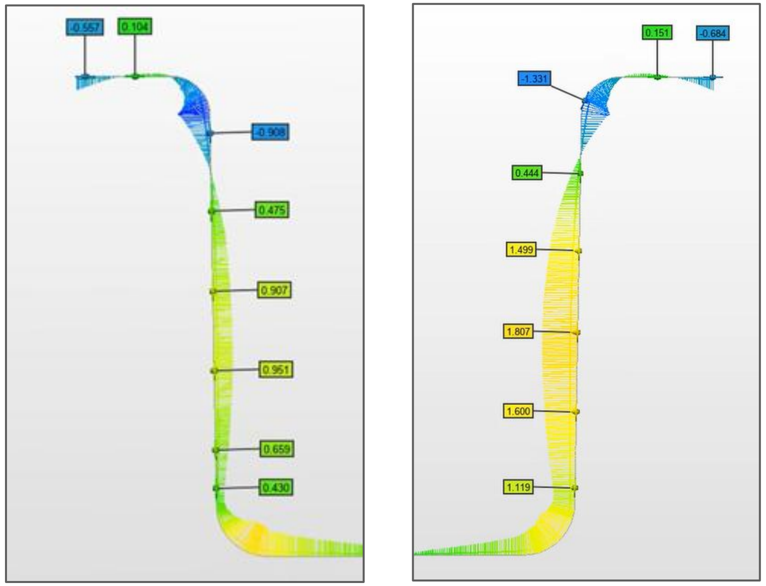


Tolerance of Side Wall

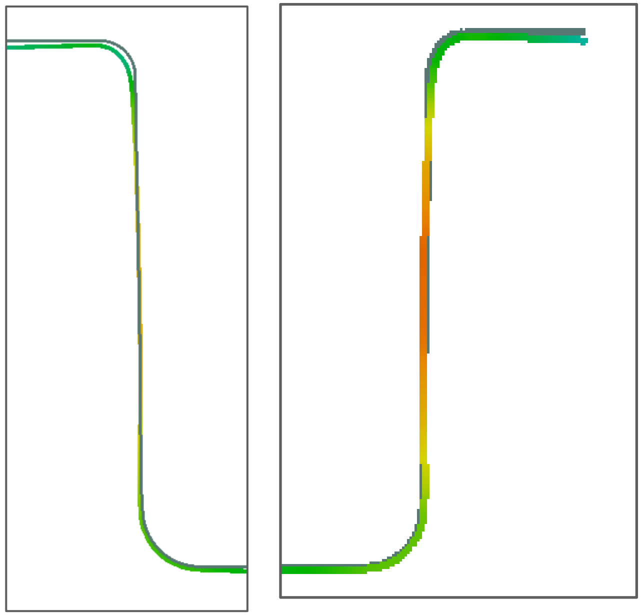
Effect of Bead Penetration Height

- From the analysis of a panel during tryout, it appears that one side of the tray had more side wall curl as opposed to the other
- After physical measurements it was determined that the incorrect bead penetration height caused the curl to be more prominent

Stake Bead - Final Height Measurement



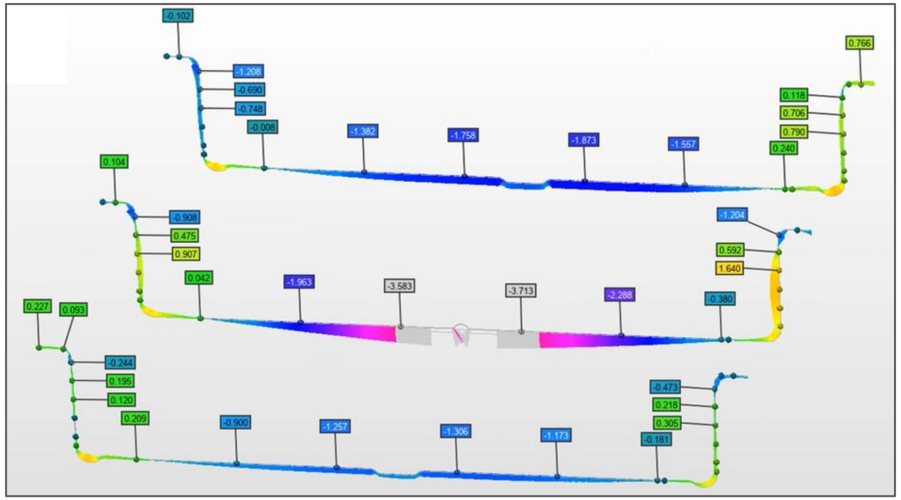
Sidewall Curl – LHS vs RHS



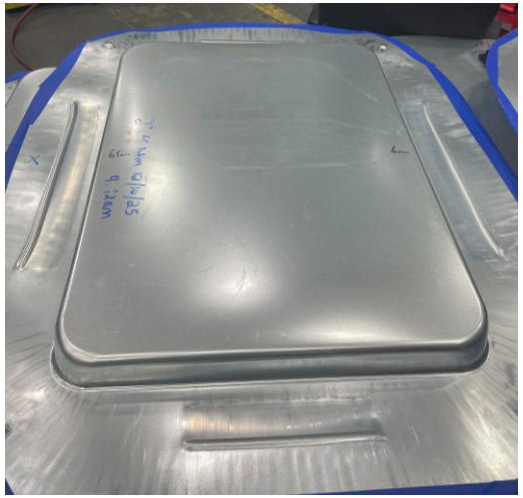
Recreated In Simulation

Correlation - Simulation vs Physical Panel

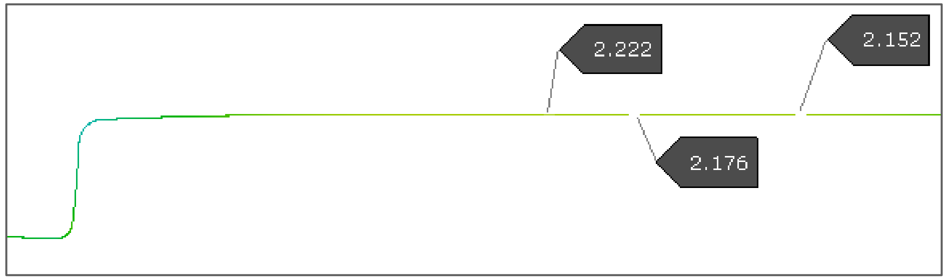
- In physical tryouts a bow was detected at the base of the battery enclosure, concentrated at the center (shown by the cross sections on a panel drawn to home position)
- On another panel, drawn up to two inches from bottom, the bow was still observed (*center image*)
- Based on the correlation data, this condition is attributed to a combination of mismatched draw-in as well as limitation in simulation prediction
- This unfavorable condition was alleviated by improving the blank in-flow (draw-in) at the corners; however, it could not be eliminated



Part Deviation - Drawn To Bottom



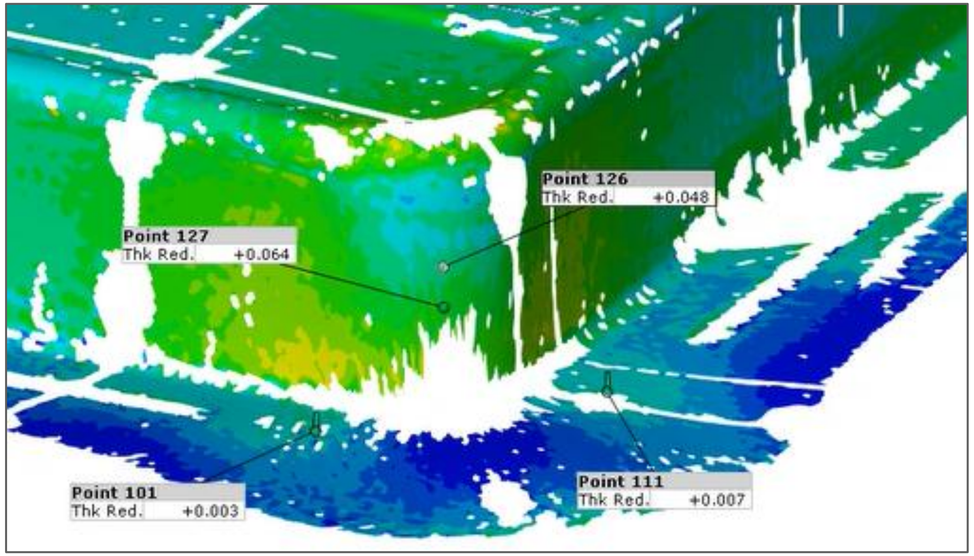
Panel Drawn Two Inches From Bottom



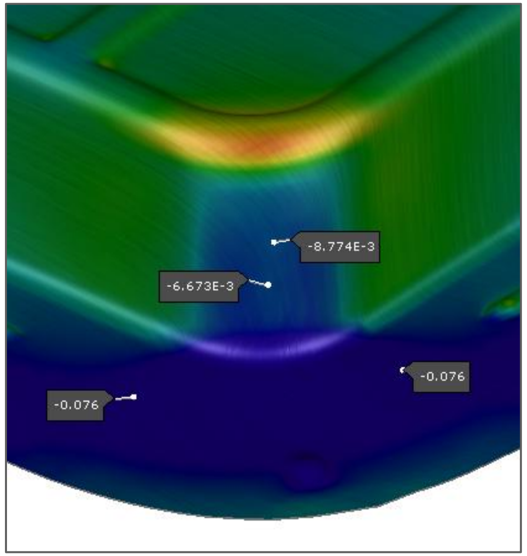
Simulation Prediction On Panel

Correlation Physical Part vs FEA - Thinning

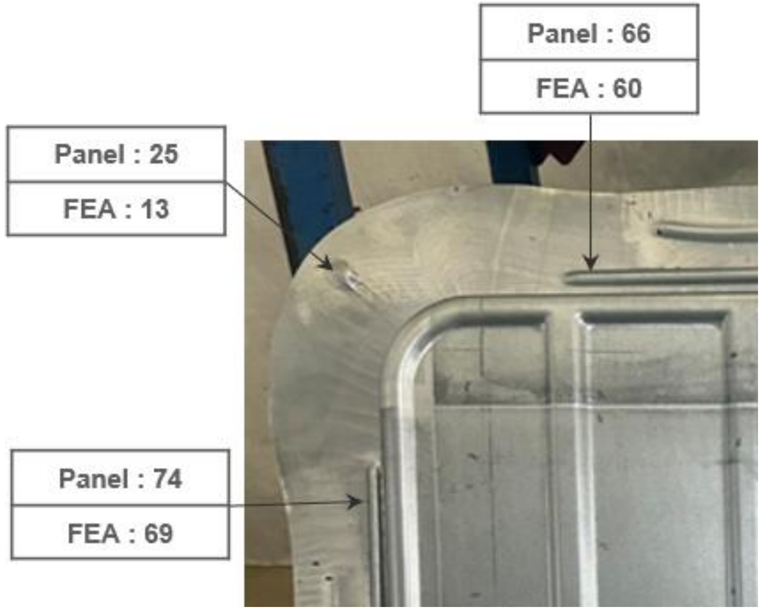
- On the binder area and along the wall there is more thinning observed on the physical panel
- For the same area, the simulation predicts thickening
- Measurements were made to understand the "draw-in"/material in-flow
- The tryout part shows less draw-in thereby increasing the stretch, resulting in more thinning
- However, this trend reverses at the punch corner radius; Sim – 16.3% > Prototype – 12%. This is attributed to the lower major strain in that location contributed by the "bow" effect



Thickness Reduction - Argus



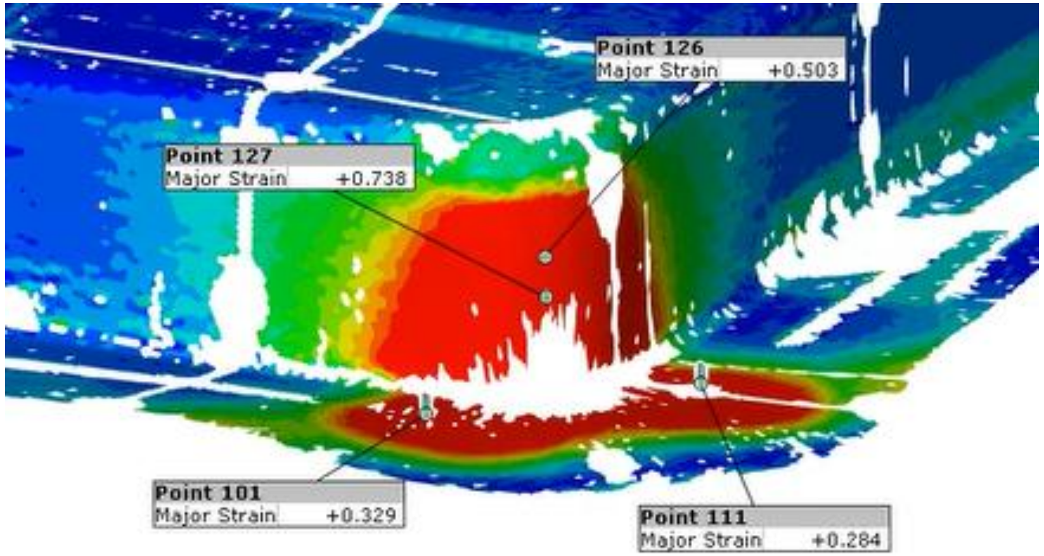
Thickness Reduction - Simulation



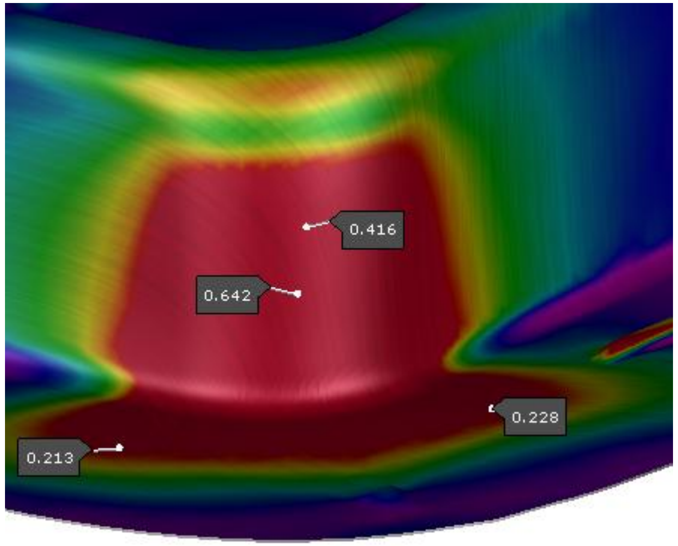
Blank In-flow (mm) - Physical vs FEA

Correlation Physical Part vs FEA - Major strain

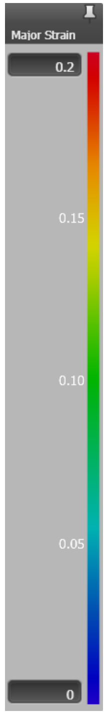
- Overall, the major strain on the panel were higher than those predicted by simulation, specifically on the walls and binder area in the corners
- For these locations, the Argus evaluation is compared to the FEA predictions, with Argus showing higher numbers indicating more strain
- This is consistent with the blank flow i.e., less draw-in on the corners compared to simulation, leading to more thinning on the physical part (binder and wall area)
- The major strain condition is also reversed at the punch corner radius (Argus < FEA) confirming the presence of more material present due to the “bow”



Major Strain - Argus

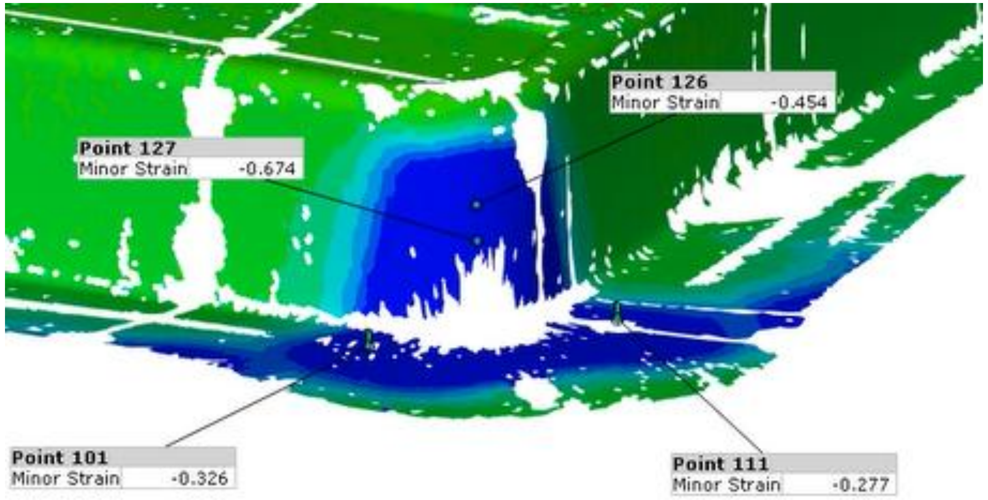


Major Strain - Simulation

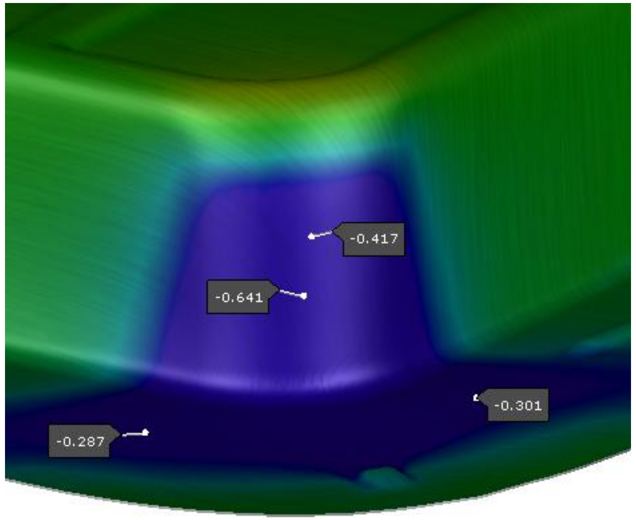


Correlation Physical Part vs FEA - Minor strain

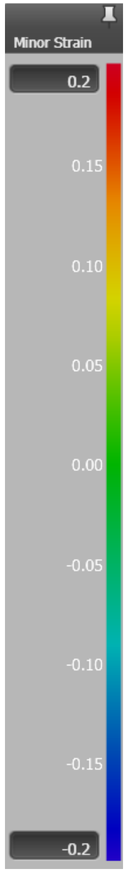
- In the corners of the battery enclosure there is more negative minor strain on the panel in comparison to the simulation prediction
- For the same locations, the Argus evaluation is compared to the FEA predictions, with Argus showing higher numbers indicating more compression



Minor Strain - Argus



Minor Strain - Simulation

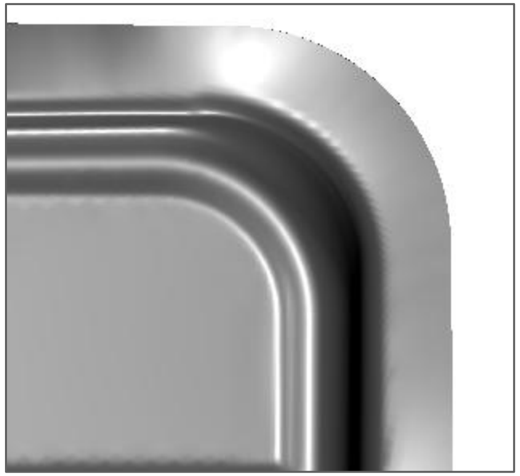


Correlation Physical Part vs FEA - Wrinkles

- During tryout, wrinkles appeared on the flange around the corners on the enclosure
- A lead check was performed on the tools to measure the gap between the upper cavity and binder
- It was found that the tool gap was inconsistent along the binder, and some areas indicated an additional gap close to 20% of material thickness
- In simulation, recreating the inconsistent binder gap and using the true surfaces of the tools the wrinkles are captured more accurately

Lead Check

	Formed panel thickness (mm)	Lead thickness (mm)	Difference
1	0.947	1.219	0.272
2	0.927	1.194	0.267



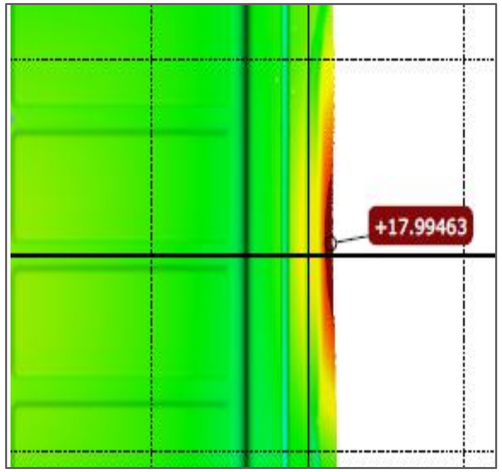
Simulation - Consistent Gap

Simulation - True Tooling Gap

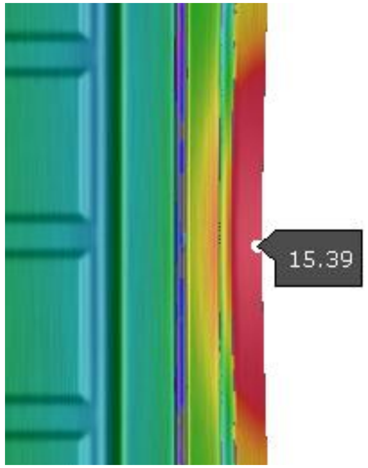
Correlation - Springback Prediction

- The simulation predictions for springback are lower than what was observed on the final panel
- A draw panel was scanned in its free state and measurements were made with reference to the original CAD
- Two simulations were run; one using isotropic hardening and the other with kinematic hardening(KH)
- In certain locations the KH model predicts much closer values to the physical measurements in comparison to the isotropic model

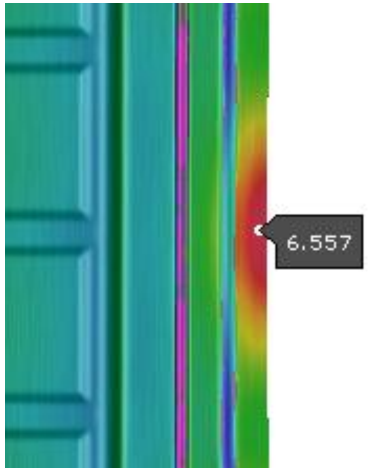
Note: KH/ Advanced material modelling does not always yield results closer to physical tryouts, this could be heavily dependent on the process and part design15



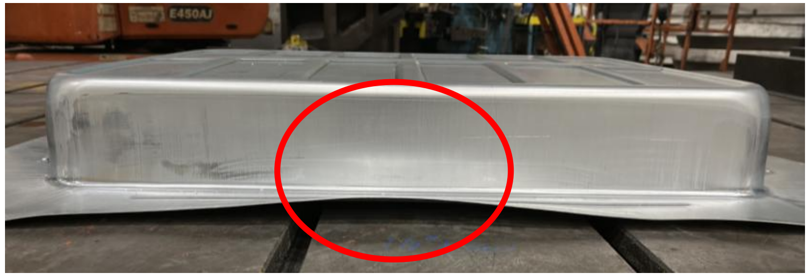
Physical Panel



Kinematic Hardening



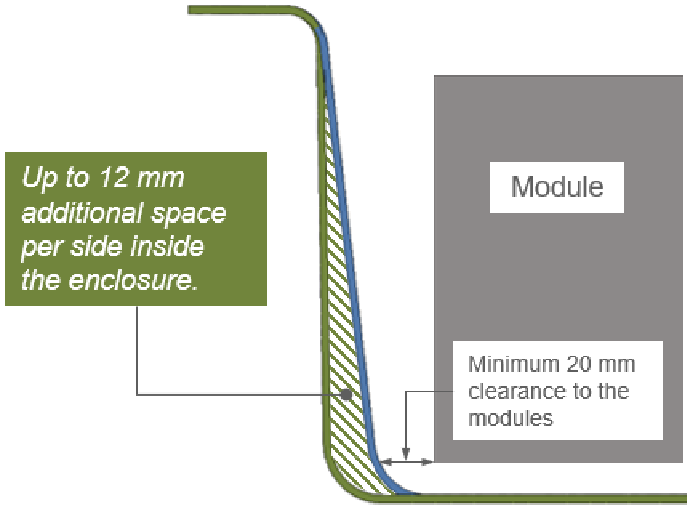
Isotropic Hardening



Improved Packaging Efficiency

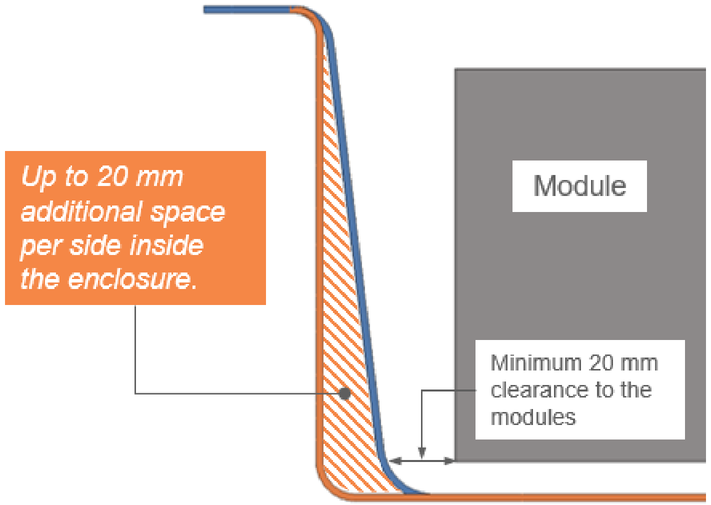
Phase 2 packaging efficient stamped tray concept

- DP600; t = 1.0 mm; draft angle = 1°
- Tray volume increased by 3%
- Up to 12 mm additional space per side



Phase 1 packaging efficient stamped tray concept

- CR5; t = 0.63 mm; draft angle = 0°
- Tray volume increased 6%
- Up to 20 mm additional space per side



Comparisons based on a stamped tray with a 7° draft angle

Conclusions

- Prototype of an AHSS stamped battery enclosure was successfully developed using DP600GI at 1.00 mm, in a single action mechanical press, hit once over bottom followed by laser trimming
- The physical part exhibits good formability with acceptable thinning as measured by Argus and CGA
- Dimensional tolerance on the flanges and sidewalls is well within the range prescribed by an OEM standard
- The rate of change of deviation (waviness) over the flanges is very good
- A correlation study was conducted between simulation predictions and results of physical tryouts
- The physical part from tryout showed a bow on the base of the tray which was not detected in simulation, attributed to a combination of inconsistent draw-ins and limitation in simulation prediction
- Some wrinkles appear in the corners on the flange due to improper tooling gap confirmed by a lead check in try outs
- Simulation under predicts the binder tonnage by 18.5%
- Increased penetration of stake beads improves the side wall curl
- The difference in thinning observed between simulation and physical part is attributed to the difference in strain state in corners of the binder arising from incomplete spotting (hard marks) that was confirmed with blank in-flow measurements

Future Work

- Trials to be continued for further process improvements
- Continued correlation studies to improve agreement between simulation and tryout results
- Potential of a prototype battery enclosure with Fortiform®980 Gen3 steel

For more information

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Visit our booth at GDIS!

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