Thermo-Mechanical Approach Using LS-DYNA® to Predict Tool Shape for Insert Molded ARPRO® (EPP) Rear Seat Cushion/Riser

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Abstract

Shrinkage and warpage is widely observed phenomenon in molding process where parts are molded at a higher temperatures than the ambient temperature. This paper demonstrates thermo-mechanical approach in aiding to design an insert molded ARPRO® (EPP) seat cushion. When the molded ARPRO® seat cushion is being ejected from press at high temperature than ambient, and, cools down to ambient temperature - it deforms due to thermal shrinkage. This deformation causes final part to warp and results in myriad of issues in achieving good nominal shaped parts. Thermo-mechanical approach using LS-DYNA simulation results were in good agreement with the physical outcome. The presented simulation technique is an efficient tool in evaluating factors related to predicting post-molding warpage.

Background

Benefit of ARPRO® foam in automotive seat:

Conventional Automotive seats are fabricated with a network of heavy wireframes retained by softer foam plus an underside structural closeout frame (Figure 1). The wire network mostly provides structural stiffness and the

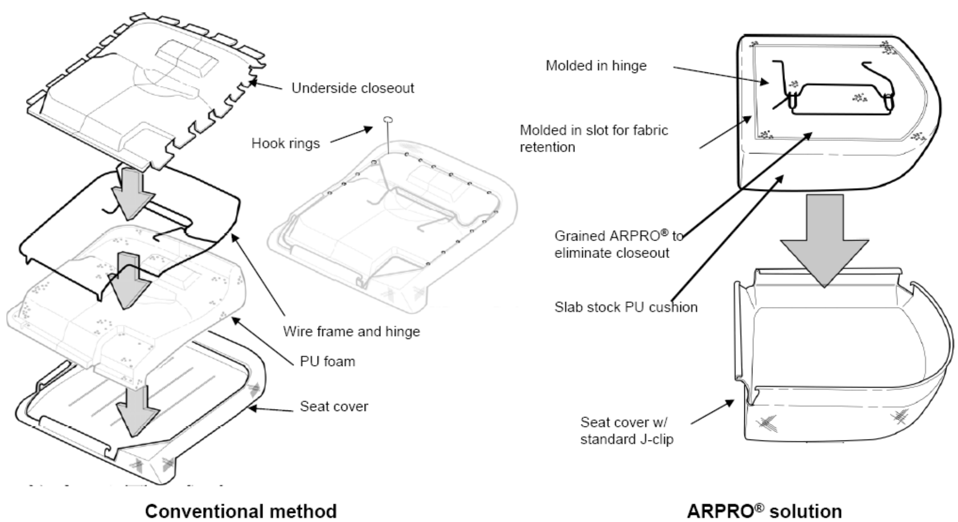


Figure 1. Conventional VS ARPRO® Seat Solution

foam been used mostly for occupant comfort. In recent years, weight reduction is a priority across the auto industry as strict new regulations push for greater vehicle efficiency and reduced CO_2 emission. Due to excellent strength-to-weight ratio, ARPRO® (Expanded Poly Propylene – EPP) is emerging as an alternative option for lighter seat solution (Figure 3) without compromising seat's primary functionality. ARPRO® is environmentally sound, 100% recyclable "green" material. Lighter weight EPP foam offers structural rigidity to seat assembly and can reduce seat weight up to 35% by either eliminating or reducing traditional heavy steel wires, panels etc. This can improve fuel economy and reduce vehicle emissions.

Metal and other plastic wire, bracket or clip can be easily insert molded into ARPRO® components (Figure 2). These insert-molded components can be used as attachment features to the vehicle BIW (Body-In-White) or can

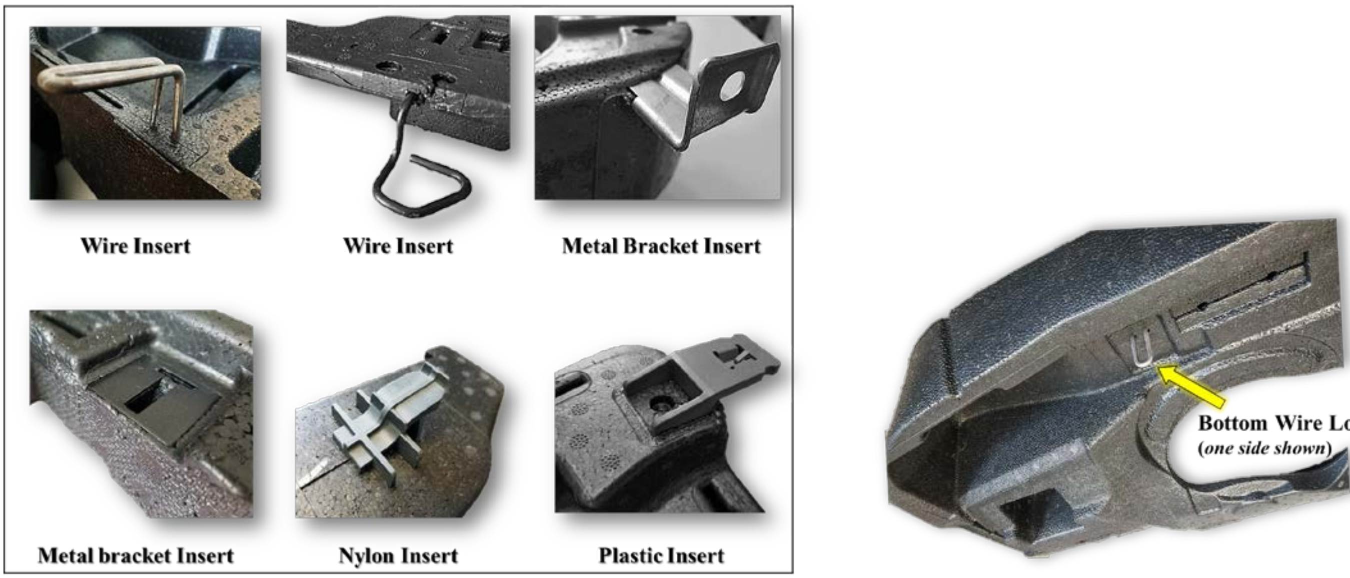


Figure 2. Different types of 'inserts' molded into ARPRO® component

be used for other primary or secondary operations to enhance the part's functionality. ARPRO®'s strong and resilient quality enables seating solution to integrate "anti-submarine" ramp feature into the cushion – which can replace geometric complexity in BIW across platforms with flat simple structure. Easy Shape morphing capability of ARPRO® enables readily engineered seating design for H-points variation across multiple

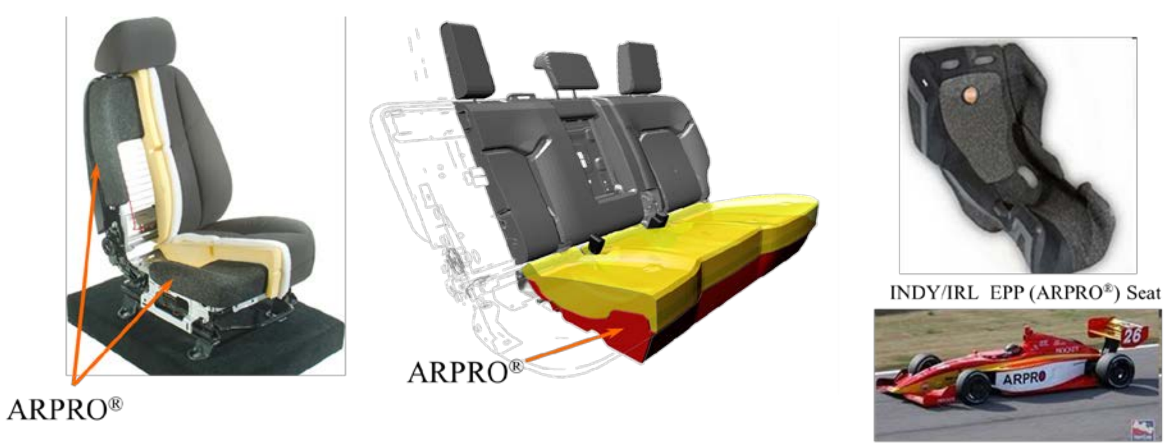


Figure 3. ARPRO® in automotive seating application

platforms; thereby reduces tooling cost and speeds up development process. NASCAR, IRL and Vintage racing cars use ARPRO® in their seat (Figure 3) due to its shock absorbing capability, resistance against multiple impact, light in weight and flexibility into molding complex shaped geometries.

ARPRO® (EPP) Foam Fabrication [5]:

Expended Polypropylene is closed-cell foam. Its molding process is slightly different from the traditional thermoplastic molding processes as it uses pre-expanded foam beads injected into mold cavity. A flow process of the EPP manufacturing is shown in Figure 4. Polypropylene (Base resin), combined with other additives, is

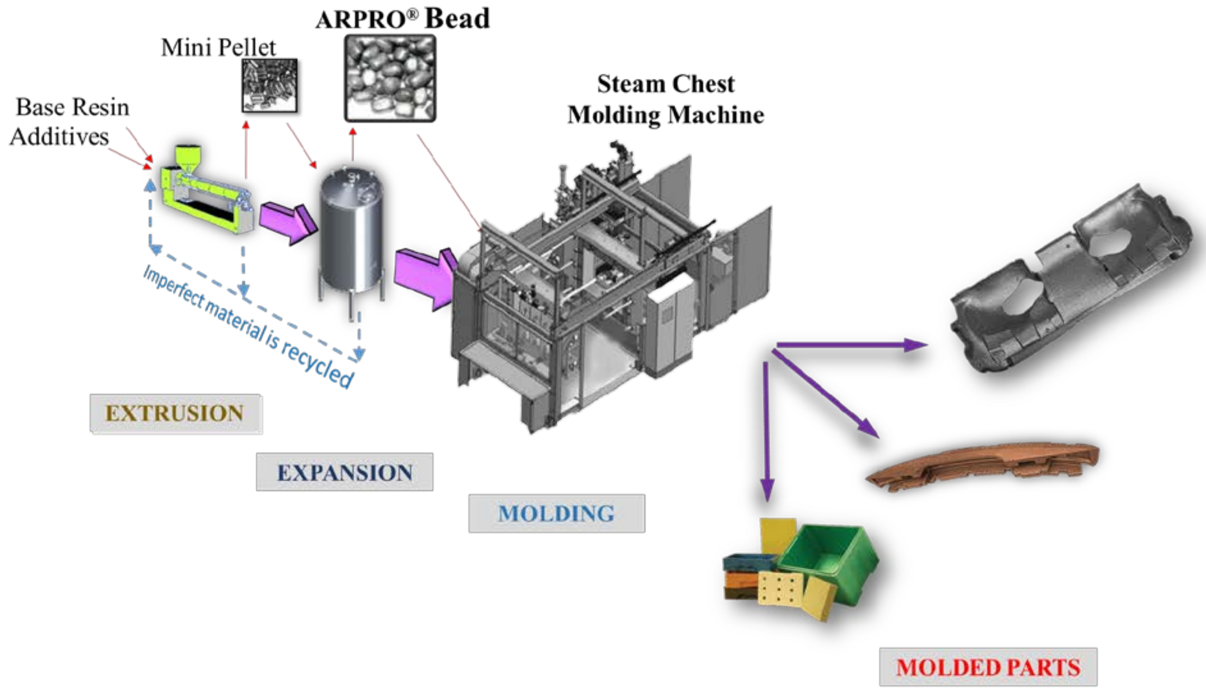


Figure 4. EPP Manufacturing Process

extruded thru an extruder into filament shaped thin strands. These strands are then chopped into mini pellets. Added with an inert blowing agent inside the expansion chamber, these mini pellets expand into more consistently shaped closed cell expanded polypropylene ARPRO® Beads. These beads can be expanded up to 50 times their original size. Due to the flexibility at the expansion phase, any density bead ranging from 18 g/l to 300 g/l can be produced. In final phase, expanded foam beads are injected into multi-cavity Steam Chest molding machines, where it goes thru cycles of cross-steaming and cooling stages. During molding phase, pressure and steam heat fuse the beads into a finished shape solid part.

Challenges with Post-fabrication ARPRO® automotive seat:

Even though the molding process goes thru several cooling cycles, Molded parts are ejected at a higher temperature (80ºC) than the ambient. While these parts naturally cool down on the cooling rack to ambient temperature, parts experience volumetric contraction. Typical values of ARPRO® shrinkage is between 2.0% and 2.6%. If the shrinkage throughout the part is uniform, the molded parts will not deform or warp, and it will simply become smaller. So counter measure in designing the mold cavity is to accommodate post-fabrication shrink, which is relatively easy for such EPP-only simple designed parts. Post-fabrication shrinkage is unpredictable for parts molded with inserts and/or parts with variable thickness. i.e large automotive rear seat cushion with insert molded metal or plastic part inside EPP. Molded parts like this experience warpage from the shrink during cooling, which results in distorted overall shape (Figure 6) and critical anchor hooks end up getting misaligned with the BIW anchor positions (Figure 5). JSP used to design molding cavity for such insert-molded parts with tedious hand calculations and myriad of design reviews. Several expensive trial and error stages were required before achieving acceptable final form that would comply with 'qualities' acceptable limits. Cavity molds are expensive and mostly all trial cavity molds created during development stages, get discarded. Any major part design change would further stretch out already long development schedules and drive up cost.

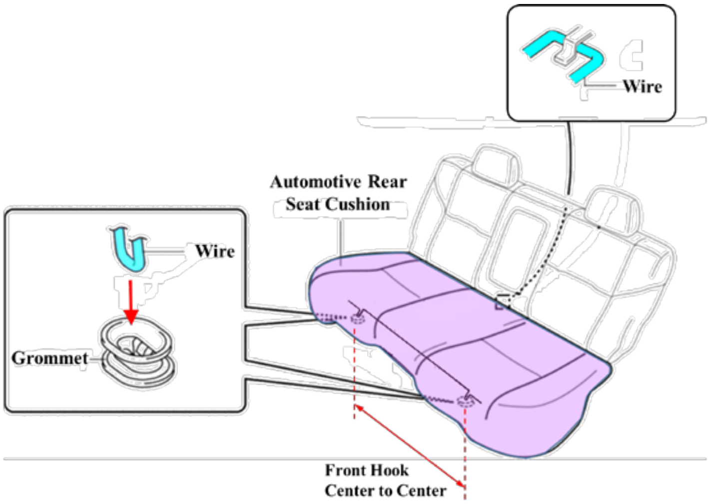


Figure 5. Molded Part (Desired shape/Tolerance) [6]

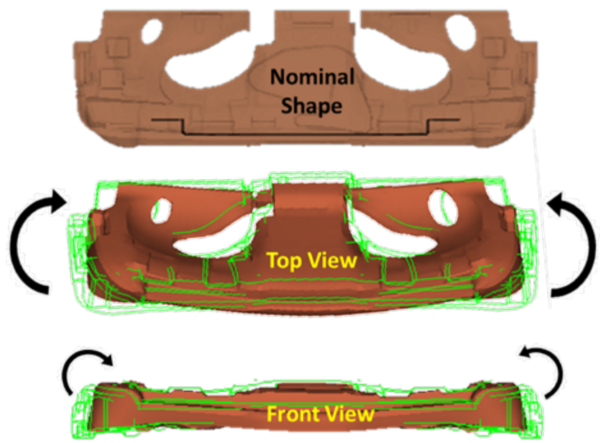


Figure 6. Distortion due to Shrinkage

Modeling

Method Development:
Shrinkage is unpredictable and complicated for geometrically complex shaped parts with insert molds, and, hand calculation based on linear or volumetric shrinkage numbers are not reliable. Final shrinkage in this case is

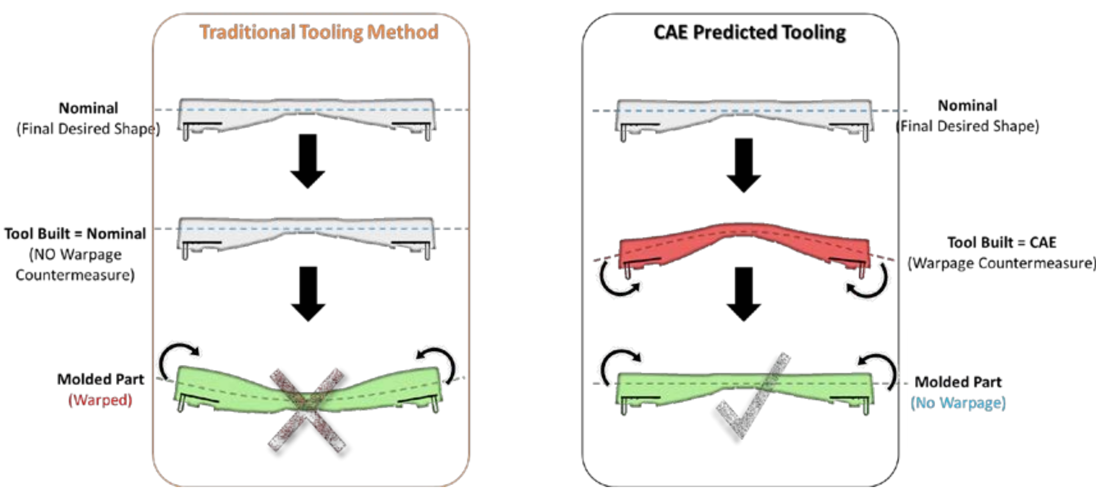


Figure 7. CAE tooling method with thermal shrinkage by JSP

a result of thermally contracting dissimilar materials at different cooling rate and different shrinking rate – called differential shrinkage. Non-uniform and asymmetric cooling across different part thickness can also induce differential shrinkage. This differential shrinkage of insert-molded parts cause distortion in the final molded component from the intended design shape. This complicated 3D differential shrinkage phenomenon can only be reliably handled using CAE. From nominal geometry (desired shape), FEA can predict estimated distorted tool shape (Figure 7). This way, the design of molding cavity incorporates shrinkage into account. The distorted tool will impose reverse distortion into the molded parts – which results into shapes that will conform to the nominal part dimensions.

FE Modeling:

In LSDYNA®, model was setup as Implicit, Transient thermo-mechanical heat transfer analysis. Same model was also setup as Explicit with reasonably close outcome. ARPRO® Seat cushion and all inserts were modeled

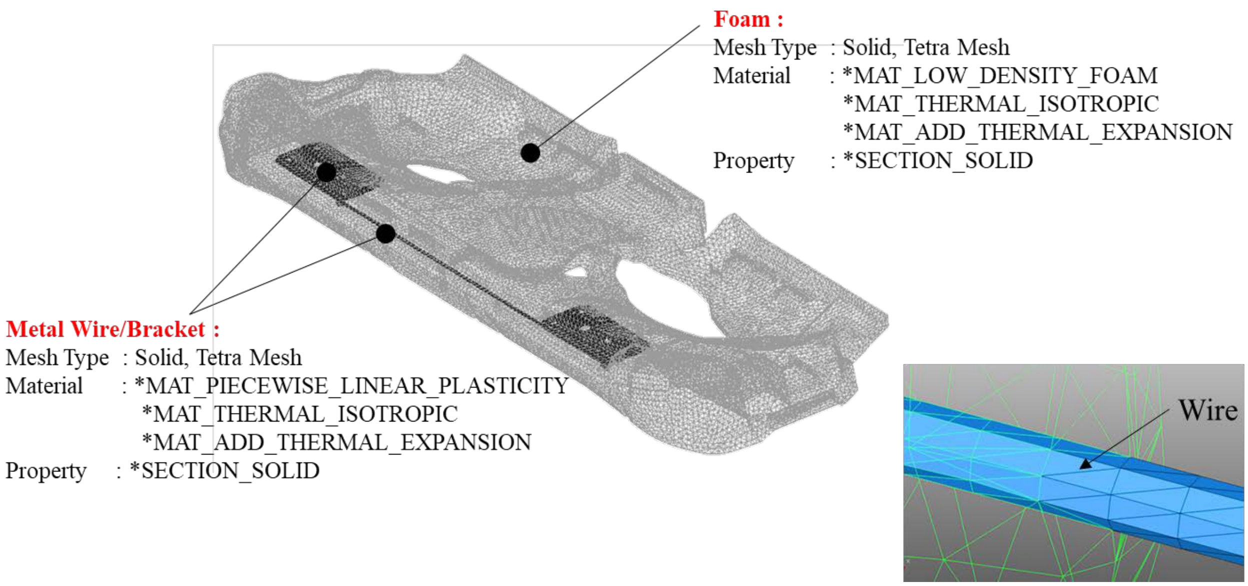


Figure 8. FE Modeling Details

with Solid Tetra mesh (Figure 8). For the simplicity of the analysis, EPP and insert molded components were modeled with shared nodes. However they can be modeled with overlapping nodes with necessary contact and appropriate thermal boundary conditions. Each component was assigned with thermal and mechanical material properties. Thermal expansion is assigned via *MAT_ADD_THERMAL_EXPANSION card [2]. All the

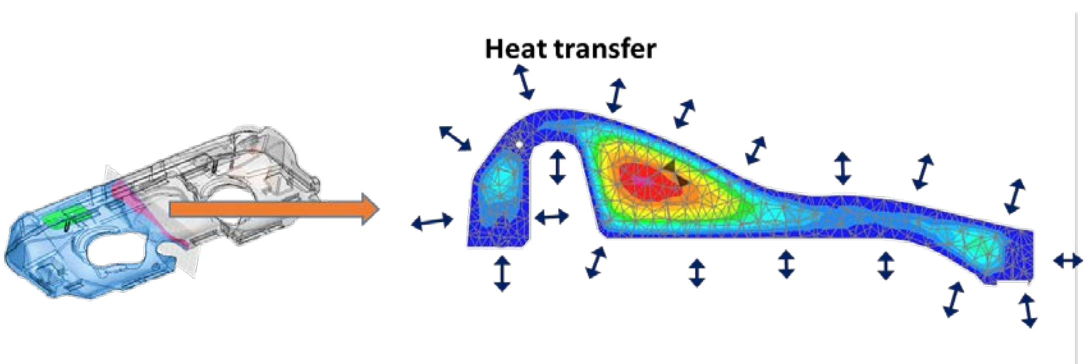


Figure 9. Concept of cooling/heating by Convection or Radiation Heat transfer [1]

exposed surfaces are considered to be transferring heat to the environment using either *BOUNDARY_RADIATION or *BOUNDARY_CONVECTION keyword (Figure 9). Same model was also ran with imposed temperature boundary condition, i.e. cooling/heating all nodes of the model using *BOUNDARY_TEMPERATURE_SET keyword. At the time analyses were run, it was discovered that the Thermo-Mechanical Implicit runs with MPP (rev 9.2 & rev 10.0) are repeatable compared to SMP (rev 9.2 & rev 10.0) runs.

Result and Discussion

Parameter Validation:

A rectangular prism shaped ARPRO® slab (without any insert) was molded with different densities (Figure 10; slab dimension 620.4 x 620.4 x 77.9 mm^3). Dimensions of the molded part and some limited scoped temperature measurements were recorded with time as out-off-the press samples cooled to ambient temperature.

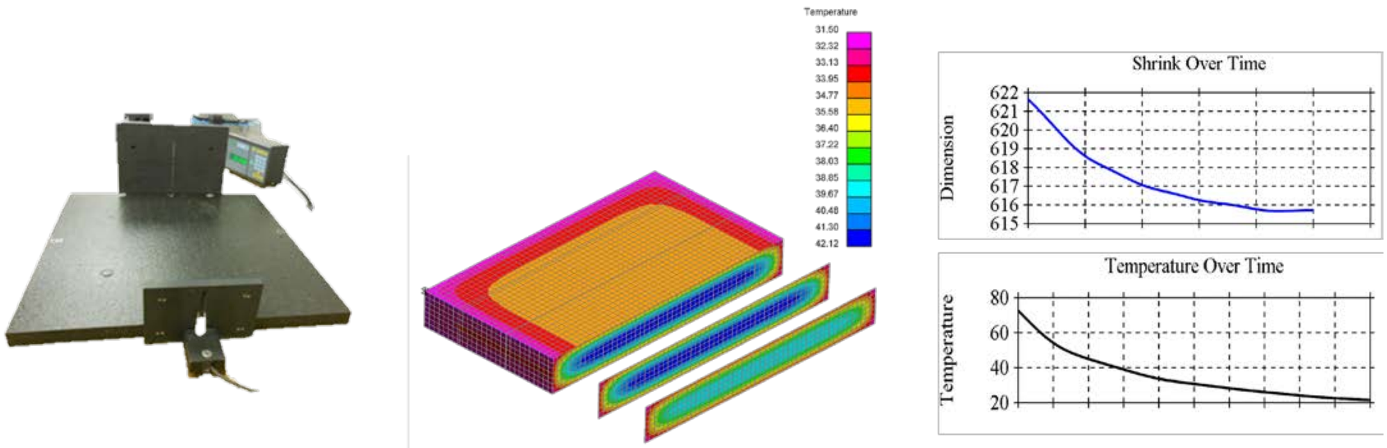
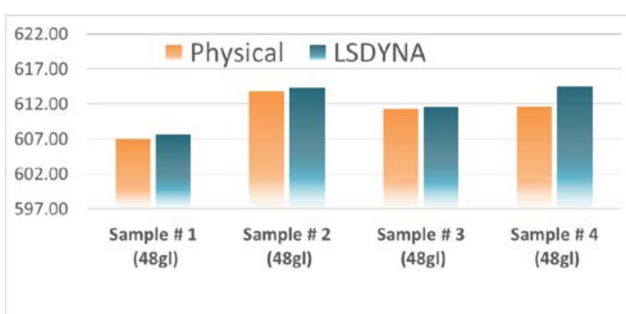


Figure 10. CAE model for Test Sample

FE model for this mold shape was prepared to test and validate different parameters. Graph-1 shows final shrunk dimension comparison for tested data to CAE data across samples. Due to the limitations at the production floor, starting point for the initial data collection varied across the samples – which resulted in



Graph 1. FEA to Test Correlation for 48 g/l density EPP

varying final shrunk values across samples. Thermal loading condition in LS-DYNA models were matched for corresponding sample's collected data. Satisfactory correlation was established with FE to test.
CAE Model for insert molded ARPRO® was tested against several automotive rear seat cushion projects. Different projects with unique insert types were selected for the tests. CAE analysis was performed with LS-DYNA and ESI® VSS software [3], [4]. Both software predicted similar outcomes (Figure 11). Trends predicted by both software are within molded part's acceptable tolerance limit for all test projects.

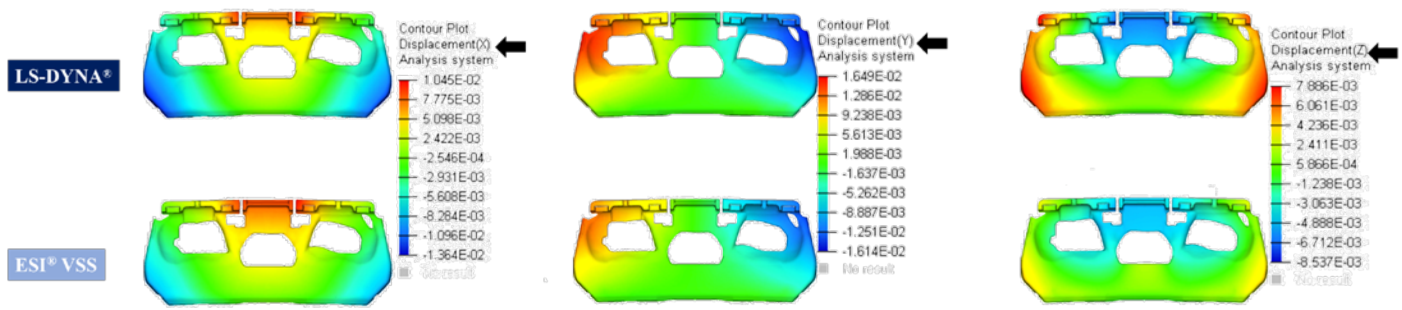


Figure 11. CAE model validation using LS-DYNA and ESI® VSS

Method Validation:
After several satisfactory project correlation with CAE results, JSP engineers gained the confidence to fabricate a tool cavity based on FEA prediction. CAD generated from the output of FE analysis mesh was used by the

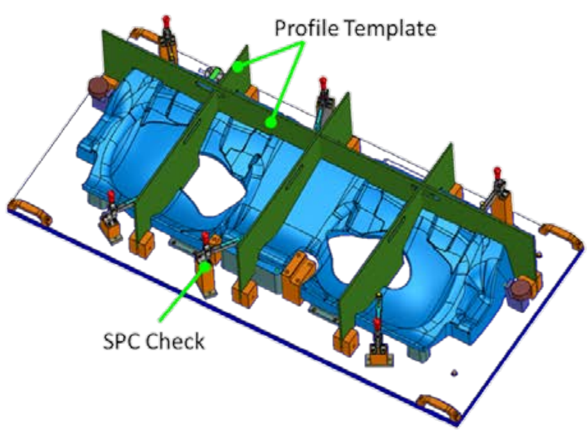


Figure 12. Typical EPP Seat Cushion Gage

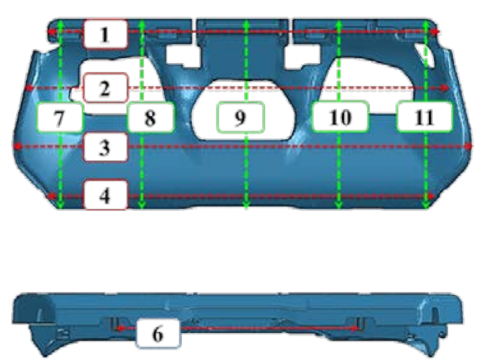
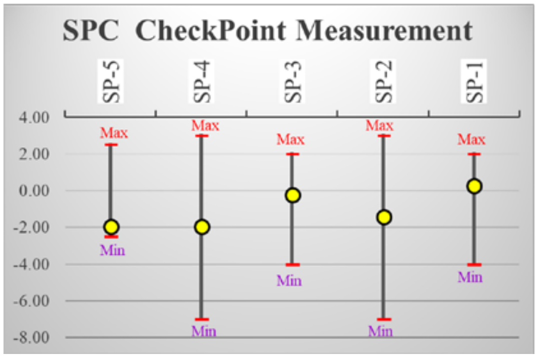
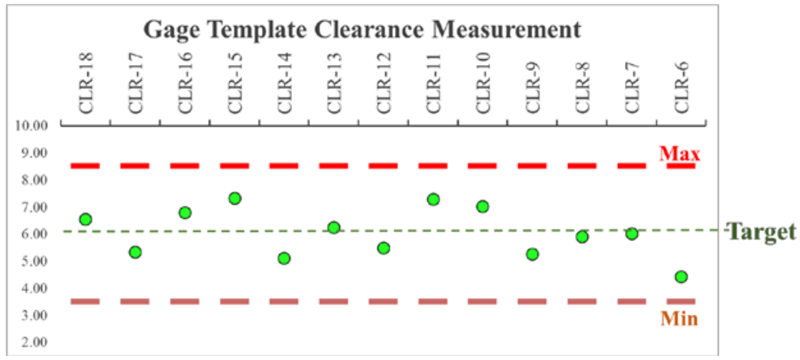


Figure 13. SPC & Template check locations

tool shop as baseline to finalize molding cavity shape. After the molding, a gage (Figure 12) is used to check the molded parts to make sure the parts are within specification and final parts conform with the desired 'nominal' shape geometry. Final 'quality' data is summarized in graph-2 with SPC measurement data and graph-3 with Gage template measurement data. All the measurements are within tolerance for the parts molded from the first trial tool designed using FEA. No major tool revisions were necessary.



Graph 2. SPC Measurement Summary



Graph 3. Gage Template Measurement Summary

Discussion:
Understanding part shrinkage is important in steam chest molding process to design reliable part, particularly in applications requiring tight tolerances. CAE Methodology developed for predicting tool shape enables produce dimensionally capable insert molded ARPRO® parts. This has the potential to eliminate costly tool revisions - resulting in saving time, resource and money.

Acknowledgement

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Key

EPP = Expanded PolyPropylene
g/l = Grams per liter (units of density)

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