

# Formability Analysis Predictions for Preform Annealing of Aluminum Sheet

2011-01-0533

Published  
04/12/2011

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doi:10.4271/2011-01-0533

## ABSTRACT

It is important to understand the accuracy level of the formability analysis for any new process so that correct predictions can be made in product and die design. This report focuses on the formability analysis methodology developed for the preform anneal process. In this process, the aluminum panel is partially formed, annealed to eliminate the cold work from the first step, and then formed to the final shape using the same die. This process has the ability to form more complex parts than conventional aluminum stamping, and has been demonstrated on a complex one-piece door inner and a complex one-piece liftgate inner with AA5182-O3. Both panels only required slight design modifications to the original steel product geometry. This report focuses on the formability analysis correlation with physical panels for the liftgate inner, considering both full panel anneal in a convection oven and local annealing of critical areas. For the full panel convection anneal, the mechanical properties are reset to the original incoming properties after annealing, assuming that all cold work has been eliminated. For the local annealing, the mechanical properties are reset to the original incoming properties only for the elements that have been heat treated, assuming a sharp transition zone between the annealed area and the cold worked area. The predictions made in the analysis were verified with physical parts using thickness measurements and mechanical testing. In addition, white light scanning dimensional analyses were compared to springback predictions.

## INTRODUCTION

The preform anneal process is being investigated as an alternative to conventional stamping for aluminum sheet metal parts. Using the preform anneal process enables more formability than conventional stamping of aluminum. Specifically, tighter radii and deeper draw depths are possible with this process. Preform annealing is a three-step forming process for aluminum consisting of the following steps:

1. Preform: partially draw the panel as deep as possible without splitting or necking.
2. Anneal: anneal the preform panel to remove the cold work from the first step.
3. Final form: draw the panel to the final shape.

Figure 1 shows a schematic of the preform anneal process. All forming steps are at room temperature. This process is only applicable to inner panels, using non-age hardenable aluminum alloys such as AA5182 or AA5754. A detailed description of this forming process has been provided by Krajewski [1] and by Lee [2,3].

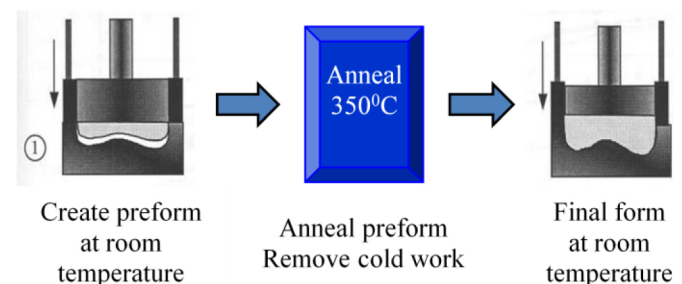


Figure 1. Schematic of Preform Anneal Process

In order for preform annealing to be used, accurate modeling capability is essential. Accurate formability analysis reduces both die design and die tryout time. An earlier study utilizing the preform anneal process on a one piece door inner included formability analysis correlation [2]. In the door inner study, all panels were fully annealed in a convection oven. The formability analysis procedure included (1) creation of the preform panel, (2) resetting all mechanical properties to typical incoming values to represent the annealing step, and (3) forming to final shape. In the door inner study it was found that the formability analysis accurately predicted the thinning, except in areas of high deformation during the preform step, such as the latch and hinge face draw walls. For these areas, actual thinning was greater than the predicted thinning. Tensile samples from these areas showed that these areas were over-annealed,

This report focuses on formability analysis correlation for a liftgate inner panel, using local induction annealing. Induction coil locations were selected to anneal only at areas with high amounts of strain in the first preform step. Liftgate inner panels were also fully annealed in a convection oven for comparison. Predictions made in the formability analysis were verified with physical parts using thickness measurements and mechanical testing, for both heat treatments.

## EXPERIMENTAL PROCEDURE

Formability analysis was done using Pamstamp software. For the full panel oven annealing process, the formability analysis procedure included (1) Preform the panel as far as possible without splitting, 24 mm from home for this case. (2) Reset all material properties to typical incoming values to represent annealing. (3) Form to final shape. For the local induction anneal process, the formability analysis procedure included (1) Form the panel to final shape, identify splitting and critical areas, trace back to preform panel to select local areas to be annealed. (2) Preform as far as possible without splitting, 24 mm from home for this case. (3) Reset material properties to typical incoming value only for the local areas selected. (4) Form to final shape.

The preform anneal process was demonstrated with a one-piece liftgate inner, with AA5182-O3 material. Both the preform and final form were performed in the same die. The preform was achieved by stopping the die 24 mm from the home position in a mechanical press. More information about the forming trials can be found in another report [3].

For the first part of the study, panels were annealed in a convection oven at 350°C, with a 5 minute ramp up time followed by a 25 minute dwell time. Based on previous work [2], this heat treatment provided complete annealing of the panel. Thinning measurements were done in the 12 locations seen in [Figure 2](#), with 10 measurement points each, for 13 panels. Thinning was done with an ultrasonic gage, starting on the inside of the panel, and working towards the outer edge. For brevity, only sections 7, 9, and 12 are discussed in this report.

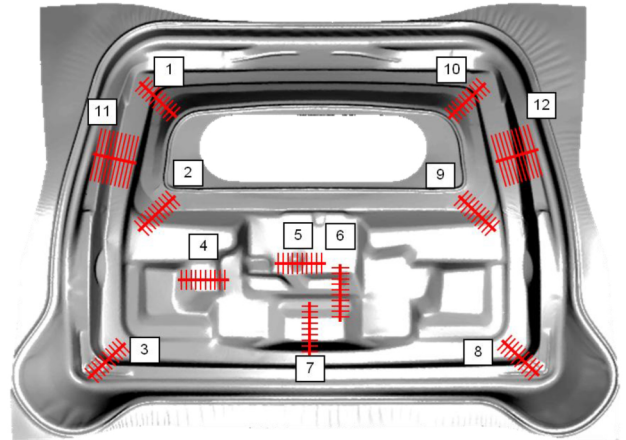


**Figure 2. Locations of thinning measurements for formability correlation. Note that the panel view is in die position, not car position.**

For the second part of the study, panels were locally induction annealed at key locations. These locations were selected based on the strain from the first preforming step. [Figure 2](#) shows the location of the induction coils on the preform panel.

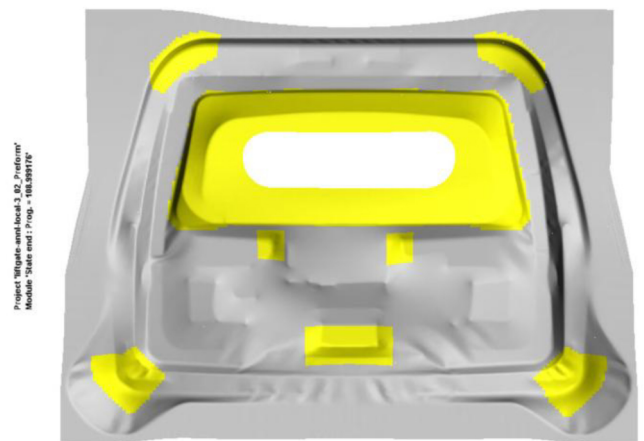


**Figure 3. Areas where material properties were reset in the Formability simulation. These areas correspond to the locations of the induction coils.**

Table 1 shows the four induction annealing cycles evaluated. Additional information on the induction annealing process may be found in another report [3]. The panels were then returned to the die and formed to the final shape.

**Table 1. Summary of induction annealing cycles evaluated in this project.**

| Anneal Trial | Target Temperature (C) | Ramp Time (sec) | Dwell Time (sec) |
|--------------|------------------------|-----------------|------------------|
| 1            | 398                    | 5               | 10               |
| 2            | 371                    | 5               | 5                |
| 3            | 371                    | 5               | 10               |
| 4            | 371                    | 5               | 15               |

Thinning measurements for the induction annealed panels were taken in the same 12 sections shown in Figure 2 with a Krautkramer CL3 DL handheld ultrasonic gauge. However, there was only one panel for each of the induction heat treatments. For this paper, only sections 7 and 9 will be discussed. An attempt was made to measure the same points for the convection annealed and local induction annealed panels, but it was difficult, using only photographs from the convection annealed panels in the first part of the study.

To better understand the annealing process, hardness measurements and microstructural analysis were done in the annealed areas of the preform panel, prior to the second forming step. Sections were removed from each preform panel, using a laser cutting tool to reduce the amount of heat or work hardening put into the panels while cutting. Each section was cut 25 mm outside the coil edge to allow for testing of the resultant properties across each induction annealed section. For comparison an unannealed panel and a fully convection annealed panel were also sectioned to determine the baseline level of hardness prior to anneal. Superficial Rockwell® Hardness was measured with a Wilson/Rockwell® Series 500 Hardness Tester, Model 524T. Ten measurements were taken on the incoming sheet before any deformation, and the starting hardness was 61 HR15T, with a 95% confidence interval of 0.8 HR15T.

Optical micrographs were taken of high stress regions of each panel and were compared to low bend areas to compare the microstructure of the panel sections before and after anneal. Specimens were etched using Barker's anodizing method (1.8% HBF<sub>4</sub> in H<sub>2</sub>O) for grain structure at 30 Volts for 15 seconds [4]. Samples were then viewed with cross polarizers and a quartz lambda primary sensitive red tint filter.

## RESULTS & DISCUSSION

### FORMABILITY ANALYSIS - CONVECTION VS LOCAL INDUCTION ANNEAL

Figure 4 shows the Formability simulation prediction for the preform to 24 mm from home. Recall that this step involves partially drawing the panel as deep as possible without splitting or necking. The areas in red are the high strain areas, and additional forming causes failure in these areas. Figure 5 shows the same panel after full panel annealing in a convection oven, followed by forming to final shape. The thinning in this figure is the cumulative thinning, so many areas are in excess of 20% thinning. Figure 6 shows the same panel after local induction annealing at the locations shown in Figure 3. Note that Figure 6 is similar to Figure 5, the thinning contour map for full convection anneal. The similarity shows that placement of the induction coils in the high strain areas provides sufficient annealing to produce the same final panel.

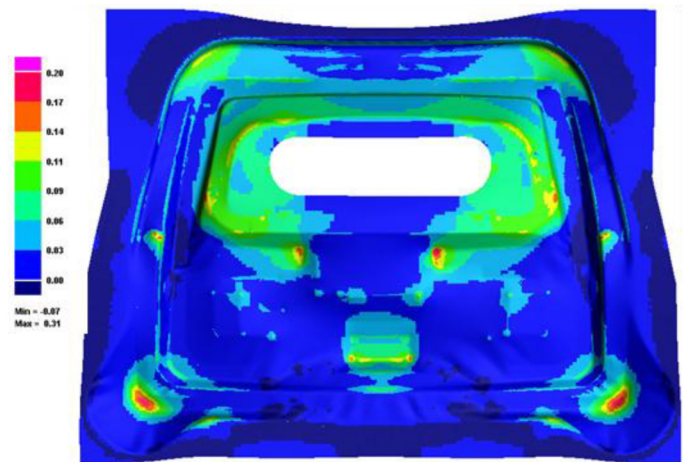


**Figure 4. Formability predictions of thinning for the preform panel, 24 mm from home position**