

A Demonstration of Local Heat Treatment for the Preform Annealing Process

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ABSTRACT

The preform annealing process is a two-stage stamping method for shaping non age-hardenable (i.e. 5000 series) aluminum sheet panels in which the panel is heat treated in between the two steps to improve overall formability of the material. The intermediate annealing heat treatment eliminates the cold work accumulated in the material during the first draw. The process enables the ability to form more complex parts than a conventional aluminum stamping process. A demonstration of local annealing for this process was conducted to form a one-piece aluminum liftgate inner panel for a large sport utility vehicle using the steel product geometry without design concessions. In prior work, this process was demonstrated by placing the entire panel in a convection oven for several minutes to completely anneal the cold work. However, the use of local annealing at critical areas of the panel via induction heating coils reduced the cycle time of the annealing step from 20 minutes to less than 15 seconds. This liftgate inner panel was successfully formed in one piece with AA5182-O sheet, which was not possible with conventional stamping.

INTRODUCTION

Vehicle mass reduction is becoming increasingly critical to improve fuel economy in order to meet aggressive targets driven by government regulation and customer requirements. Aluminum is an attractive material to achieve mass reduction goals for body and closure panel systems. However, the lower formability of aluminum relative to steel creates limitations for the stamping process, which is the preferred manufacturing method for body-in-white panels. One method to overcome this limitation is the preform annealing (PA) process, which improves formability by annealing the panel between two draw operations in the forming line. The

annealing step eliminates or reduces the strain hardening that accumulates during the first draw allowing for additional formability in the second draw [1]. The process was designed for non-age hardenable aluminum panels, and has been demonstrated using convection heating with a side door inner panel [2]. A key disadvantage of convection heating is a relatively long cycle time to reach temperatures necessary for recovery of the initial strain. Test trials required 20 minutes in the oven to gain sufficient formability to stamp the challenging shape of the door inner panel. Such an annealing treatment in a stamping line would increase cycle time to a point that it may be cost prohibitive.

Induction heating has been suggested as a potential annealing method for this process to enable shorter cycle times and higher production volumes. Induction heating techniques have been used for many decades in nearly every industry that processes metals. In very basic terms, a coil (or inductor) is positioned in close (but non-contacting) proximity to the work piece. An alternating electric current is passed through the coil to generate a magnetic field. This magnetic field induces an opposing magnetic field in that work piece which, in turn, generates electrical eddy currents. It is the dissipation of these eddy currents within the work piece that provide heat via the Joule effect [3]. One requirement for induction heating to occur is that the work piece must be electrically conductive. For the special case of heating portions of a thin aluminum sheet panel, a “pancake” coil fabricated with copper tubing to match the shape of the features to be heat treated may provide the most efficient process.

In a prior study on the mechanical behavior of 5182-O after PA [4], uniaxial tensile testing was used to compare the amount of prestrain with annealing time and temperature. It was found that post-anneal elongation was independent of annealing time over a wide range of thermal conditions, but

generally the annealing temperature to recover work hardening for this alloy ranged from 300°C to 400°C. Since induction heating is much faster than convection, the annealing cycle may be reduced from minutes to seconds. Such a process cycle time could allow the annealing step to be integrated within the production stamping line for continuous operation with robotically transferred parts. If heating and cooling could take place within 10-15 seconds, the stamping line rate would be minimally affected. This paper describes an experimental development of the PA process for an aluminum liftgate inner panel to demonstrate that rapid, local annealing via the induction heating technique can provide sufficient improvement in stamp more complex panels.

PROCEDURE

The liftgate inner panel of a large sport utility vehicle designed for steel sheet stamping was chosen for this exercise because the shape is too complex for normal stamping with aluminum sheet. [Figure 1](#) illustrates the steel draw panel as well as the splitting fractures that occur when the panel is stamped with aluminum sheet alloy 5182-O (1.1 mm thick). In a prior development of the PA process, a convection annealing oven was used to demonstrate that this complex shape could be formed. Aluminum blanks were partially stamped, placed in the oven at 350°C for 20 minutes to recover strain and then drawn to home without splitting. This allows for direct comparison of ‘global’ convection versus ‘local’ induction heat treatment methods for the PA process.

FORMABILITY PROCEDURE

Formability simulation for the PA process follows conventional procedures to determine when and where thickness strains in a stamped panel exceed predetermined limits. In this case, simulation was used to determine the maximum punch stroke when local sheet thickness strain (or thinning) reached 20%. This punch stroke position represents the first draw and the incomplete shape of the panel at this position is referred to as the ‘preform.’ For simulation of convection annealing, the entire finite element mesh of the preform shape was re-set to the incoming material properties in order to approximate the annealing heat treatment effect. For induction annealing, properties of the mesh elements were only re-set at critical locations of high thinning. The simulation was continued for the second draw, monitoring thickness strain until either the punch stroke was complete or some region of the panel again exceeded the predetermined thickness limit. Thus, formability simulation can provide a target for maximum punch stroke during the initial draw and also identify critical regions of the preform that require the annealing heat treatment [5, 6]. Re-setting mesh elements to the properties of the incoming material may not accurately represent the state of hardening of the material or of the level of recovery and recrystallization of the microstructure, but it is a good first approximation. [Figure 2](#) demonstrates eight locations on the liftgate inner panel that require annealing in order to avoid fracture during the second draw.



Figure 1. Liftgate inner panels stamped with (a) aluminum showing splitting fractures and (b) steel product representation.



Figure 2. Locations of high thickness strain on the aluminum liftgate inner panel preform that require local annealing.

INDUCTION PROCESS PARAMETERS

Before creating coils to anneal specific areas of the liftgate panel, it was necessary to determine basic heating parameters and process settings for the induction heating technique for this aluminum sheet using a laboratory-scale die set. This die set included a 101 mm diameter, flat-topped punch and a blank holder with lock beads based on the Marciniak-Kuczynski design for measuring forming limits in sheet metal [7]. Sheet samples were bi-axially stretched with this flat dome shape to a punch depth of 10.7 mm, just prior to the start of strain localization (necking). An induction heating coil shown in [Figure 3a](#) was fabricated to heat treat the high-strained region of these dome samples as shown in [Figure 3b](#) [8].

Choosing the appropriate frequency, power supply, cycle, etc. are crucial for any induction heating application in order to efficiently couple the magnetic field of the coil with the work piece. Based on a prior study for induction heating this material, the dome samples were induction heat treated at the annealing conditions shown in [Table 1](#), which included a control sample that was not heated and a convection annealed sample for comparison. The remaining samples were induction heated to 371°C, which was verified using

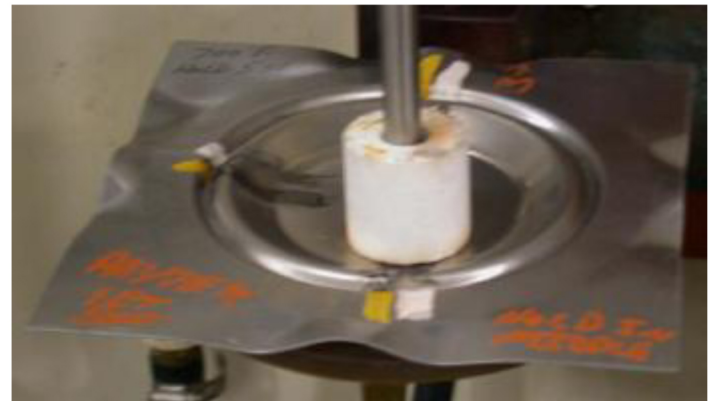


Figure 3. Induction Coil Fixture (a) and Set-up for annealing the Marciniak Test Samples (b).

Table 1. Test Matrix for Dome Samples with Induction Heating.

Heating Method	Ramp Time	Hold Time
Control – no heating	N/A	N/A
Convection Oven (350°C)	5 min	20 min
Induction (371°C)	5 sec	5 sec
Induction (371°C)	5 sec	10 sec
Induction (371°C)	5 sec	15 sec
Induction (371°C)	5 sec	20 sec
Induction (371°C)	5 sec	30 sec
Induction (371°C)	5 sec	60 sec