

2. AUTOMOTIVE METALS

A. Warm Forming of Aluminum II (AMD 307¹)

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Contract No.: FC26-02OR22910

Objective

- This project previously demonstrated the potential of warm-forming (WF) technology to significantly improve the formability of aluminum. The Phase I demonstration was done in “prototype” mode and demonstrated the expanded depth of draw that is possible with WF. The objective of Phase II is to develop and demonstrate a production process for the WF of aluminum for automotive body structures and measure the economic feasibility of the WF process for a production environment.

Approach

- Develop individual elements of the WF process in a laboratory environment including alloy characterization, lubricant development, forming simulation and process thermal modeling.
- Develop full-size demonstration of WF process and run tests in a production-like environment. Process will include blank preheating, lubricant application, WF press and die with modified thermal profile controls, and lubricant removal.
- Create a technical cost model that can generate cost comparisons between a warm-formed aluminum door inner and a same or similar door inner manufactured using conventional forming processes in steel and aluminum.
- Significant improvements in the formability of aluminum are expected to be achieved through development of enabling WF process advancements including:
 - Establishing the degree of improvement in formability of production-grade, commercial aluminum alloys.
 - Developing a cleanable lubricant suitable for use in a WF process.
 - Optimizing the temperature distribution of the die for improved thermal control and formability.
 - Evaluating rapid preheating systems for blanks.
 - Applying CAE simulation tools (finite element analysis) to modify the die to attain a production-quality part.
 - Optimizing a process and layout design.
 - Applying the results of the cost model to optimize process design.
 - To demonstrate the manufacturing and economic feasibility for a new production process such as the WF process, the definition of the process flow is paramount, as well as the development and application of a technical cost model that allows comparison of a product made in the WF process with a comparable component fabricated from aluminum or steel using current stamping technology.

Accomplishments

- Successfully demonstrated the formability improvements that can be obtained by forming Al sheet at elevated temperatures.
- The purpose-built die ultimately designed and used in the Phase II study enabled a uniform and stable thermal condition. This also minimized distortion in the tool so that the binders remained relatively flat throughout the forming trials.
- Showed that commercial AA5182-O and AZ31B-O alloys could be formed at die temperatures above 300C to a full 125 mm depth.
- A forming window was defined which is bracketed at extremes in preheat temperature and high binder pressure by splitting, and at low binder pressure by wrinkling.
- The new WF lubricant performed very well in the current trials and should be viable for a high volume WF process.
- Formability increased with increasing die temperature; however, increasing blank preheat temperature above 350C did not necessarily improve formability.
- The binder load required to successfully make Mg parts was lower than that required for steel.

Future Direction

- This project is complete.
- A follow-on project focused on warm forming of magnesium sheet is beginning and will be reported on in the annual report for fiscal year 2007.

1.1 Objectives

Approved for incorporation into the USAMP/ AMD project portfolio in 2001 with completion in December 2006, the objectives of the AMD 307 Phase II project, Warm Forming of Aluminum II, were to develop and demonstrate:

- A full scale WF process for the forming of Al sheet for automotive body structures, and
- Determine the financial viability of the WF process for a production environment using a technical cost model.

1.2 Phase II Technical Approach

The previous WF study was sponsored by PNGV and completed in 2000 as part of the Automotive Lightweighting Materials program. That Phase I study demonstrated the concept feasibility of WF technology to significantly improve the formability of Al using a specially-processed 5000 series Al alloy containing Mn and Mg. The Phase I study used a Conventional stamping die retrofitted with heaters thought to be sufficient for use in WF (Figure 1).

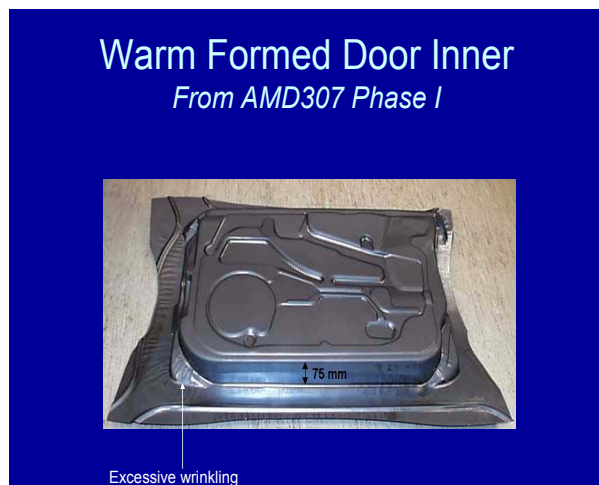


Figure 1. Warm formed door inner made in Phase I die showing excessive wrinkling and sheet distortion.

The Phase II technical approach used was designed to first experiment and to test the capabilities of various process components in a laboratory environment before scale-up to a press-shop-type process demonstration. The technical approach was to:

- Develop and evaluate individual elements of the WF process first in a laboratory environment including alloy characterization, forming lubricants, forming simulations, and process thermal modeling.
- Develop full-size demonstration of WF process and run test trials in a press-shop environment. Process design included planning for blank preheating, lubricant application, press and die with WF thermal controls and identification of lubricant removal strategies.
- Create a technical cost model that can be used to generate cost comparisons between a warm-formed, deep-drawn Al part and a same or similar part manufactured using conventional forming processes in steel or other alloys.

Phase II Accomplishments

Significant improvements in the formability of production grade, commercial Al alloys, specifically AA5182-O, were achieved through development of WF process advancements in Phase II as discussed below:

- **Constitutive equation** was developed for AA5182-O for formability simulations that allowed design of WF pan die and definition of WF process parameters.
- **Cleanable lubricant** suitable for use in a WF process was identified through extensive laboratory-based studies of multiple lubricant formulations. Lubricant application and friction trials were conducted and the best performing lubricant, Fuchs 216 BN, was selected for WF trials.
- **Rapid conduction preheating system** for blanks was designed in Phase II that would enable cycle times of 6-10 jobs/minute. However, the project budget proved insufficient to build a full-scale preheater and material handling automation. A conventional conduction oven was made available to preheat the blanks for the WF trials and the blanks were moved manually, thereby allowing the project to remain within budget.
- **WF trials** were initially conducted in November 2005, utilizing the Phase I door inner die that was modified in Phase II to the maximum extent possible, in an attempt to achieve thermal control over die regions and components.

Knowledge gained from these first trials reaffirmed the viability of a WF process, but conclusively proved that a controlled WF process cannot be achieved using a conventional stamping die refitted with heaters, as was the door inner die shown in Figure 2.

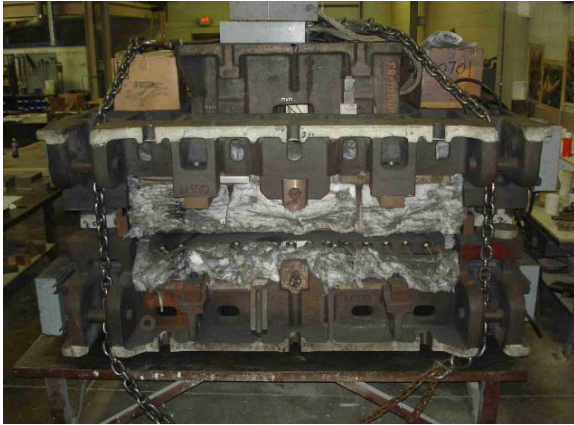


Figure 2. The conventional stamping die refitted for the WF feasibility study performed in Phase I.

- **Purpose-built WF pan die** was designed using CAE simulation tools (finite element analysis) and knowledge gained from monitoring and analyzing thermal behaviors during the door inner WF trials utilizing the modified Phase I die. This purpose-built pan die provided thermal stability and uniformity (See Figure 3).
- **WF pan die trials** conducted in October 2006 allowed optimized process parameter monitoring and control. Forming was conducted using four different thermal conditions: room temperature, entire die at 250C, binder at 300C with the punch at 250C, and entire die at 350C. Full pans, 125 mm deep, were stamped at the latter two conditions without splitting or wrinkling. Trials were performed to understand the effect of blank preheat temperature and lubricant type as well as to provide a preliminary understanding into the performance of Mg sheet.
- **Technical cost model** was developed and used to evaluate and optimize the Phase II process design and to compare process cost of WF of Al parts to similar parts fabricated in steel by conventional stamping methods. The model can be applied to future process designs.



(a)



(b)

Figure 3. (a) Photograph of the WF pan die used in Phase II study and (b) typical pan produced by the die.

Conclusions

The WF pan die trials conducted in October 2006 successfully demonstrated the formability improvements that can be obtained by forming Al sheet at elevated temperatures. Blanks were preheated externally from the die prior to forming, traditional press speeds were used, and a complex die temperature control / monitoring system was used to understand and control the thermal conditions in the tool. This enabled forming windows to be identified wherein successful WF could be performed. It also enabled comparison of lubricants and various materials. Some specific conclusions are:

1. The purpose-built die ultimately designed and used in the Phase II study enabled a uniform and stable thermal condition. This also minimized distortion in the tool so that the binders

- remained relatively flat throughout the forming trials.
2. Commercial AA5182-O and AZ31B-O alloys could be formed to a full 125 mm depth at die temperatures above 300C.
 3. A forming window was defined which is bracketed at extremes in preheat temperature and high binder pressure by splitting, and at low binder pressure by wrinkling.
 4. The new WF lubricant performed very well in the current trials and should be viable for a high volume WF process.
 5. Formability increased with increasing die temperature, however, increasing blank preheat temperature above 350C did not necessarily improve formability.
 6. The binder load required to successfully make Mg parts was lower than that required for steel.

¹ Denotes project 307 of the Automotive Metals Division (AMD) of the United States Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the “Big Three” traditionally USA-based automakers to conduct joint pre-competitive research and development.