Warm forming of stainless steels

Part II: Simulations and experiments

Editor's Note: This article is Part II in a two-part series on warm forming stainless steel. Part II discusses simulation and experimental studies conducted by the ERC/NSM on formability of stainless steel at elevated temperatures. Part I, which appeared in July, discussed the rationale for and previous work on warm forming of stainless steels.

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Previous studies conducted on forming of stainless steels concluded that a Type 304 austenitic stainless steel exhibits a remarkable improvement in drawability when it is formed at elevated temperatures (about 100 to 200 degrees Celsius).

The most common index of drawability for round cups is the limiting draw ratio (LDR). The LDR is defined as the largest draw ratio of the blank-to-cup diameter that can be drawn successfully without wrinkles and tears.[1]

ERC/NSM, in cooperation with AIDA Engineering, Dayton, Ohio, and a stainless steel part manufacturer, conducted experiments using round cup tooling to determine the influence of temperature on the LDR.

Experimental Setup

Figure 1 shows the schematic and dimensions of the warm forming tooling for deep drawing a 40-millimeter round cup. The die and the blank holder were heated through cartridge heaters, while the punch was cooled by water circulation. The tooling was mounted on a 110-ton servomotor-driven press at AIDA Dayton Technologies, Dayton.

The servomotor-driven press allows infinite freedom in programming the velocity characteristics of the press ram for a given stroke. This capability is very useful for optimizing the warm deep-drawing process.

The press ram can be programmed for slow velocity during forming to reduce the strain rate and improve formability, and a fast return stroke to reduce the cycle time of the warm forming operation. A dwell stage can be programmed into the press ram's motion curve to allow time for heating the blank before deep drawing starts.

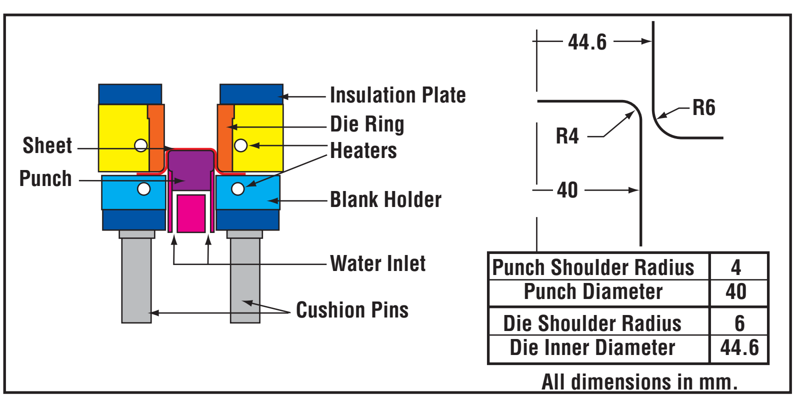

Figure 1

The die and the blank holder were heated through cartridge heaters, while the punch was cooled by water circulation for deep drawing a 40-millimeter round cup.

Experiments

Type 304 stainless steel sheet material was used for the investigation. Blanks 0.87 mm (0.034 inch) thick were selected in four diameters, representing four draw ratios (see Figure 2).

VAC-PAK® HT-620, a heat-resistant, high-elongation cast film produced from a Teflon® resin, was selected as the lubricant. Standard thickness of the lubricant film was about 0.076 mm (0.003 in.).

Test Procedure for LDR Determination. The servo mechanical press was programmed to clamp the sample between the heated dies for 90 seconds (dwell stage), during which time the sample was heated. The press ram then proceeded at a constant velocity of 2.5 mm per second to form the sheet against the stationary punch (forming stage).

The following procedure was used to determine the maximum draw ratio (LDR) at each value of die temperature:

1. For a given temperature, the smallest blank diameter was selected for deep drawing. If the cup was drawn successfully, a larger-diameter blank was selected for the next draw.

2. This procedure continued until a fractured cup was obtained. The last successfully drawn cup determined the LDR of the material, at the tested temperature value.

Material: SS 304
Thickness: 0.87 mm (0.034 in.)

Diameter (mm)	Draw Ratio
84	2.1
92	2.3
96	2.4
100	2.5

Figure 2

Blanks measuring 0.87 mm (0.034 inch) thick were selected in four diameters, representing four draw ratios.

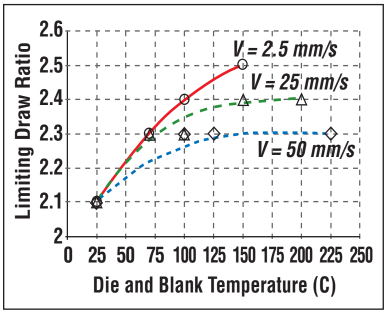

Figure 3

Drawability limits of the material were investigated at higher forming velocities that were closer to production conditions (2.5 mm per second, 25 mm per second, and 50 mm per second).

LDRs at different temperature values were determined with this test procedure. When wrinkling was observed, the blank holder force was increased to suppress wrinkles, and experiments were repeated. If the cup fractured, the blank holder force was decreased to allow easy material flow from the flange while still preventing wrinkling in the flange.

Experimental Results

Effect of Die Temperature on LDR. Consistency of results was confirmed by testing multiple samples at different die temperatures at a forming velocity of 2.5 mm per second.

The results show that the LDR increased with increasing die temperature, between 25 and 150 degrees C, at which point the formability investigation was concluded. At this die temperature, a cup with a 2.5 draw ratio was successfully drawn.

Cups formed at different temperatures were cut, and the thickness distributions along the rolling direction and transverse direction were measured. The greatest thinning always occurred at the punch corner location, and this thinning increased with increasing LDR.

Effect of Forming Velocity on LDR. Drawability limits of the material were investigated at higher forming velocities that were closer to production conditions [2.5 mm per second, 25 mm per second, and 50 mm per second (see Figure 3)].

Drawability was better (larger LDR) at elevated temperatures than at room temperature. However, this formability improvement dropped significantly at higher forming velocities. At a die temperature of 150 degrees C, LDR dropped from 2.5 (for forming velocity of 2.5 mm per second) to 2.3 (for forming velocity of 50 mm per second).

This drop in LDR can be attributed to reduced contact time between the cooled punch and the warm sheet at higher forming velocities. As an example, for the forming velocity of 2.5 mm per second, a cup was formed in about 18 seconds, while it took less than 0.9 second when the forming velocity was 50 mm per second.

With such a short contact time, the cooling effect of the punch on the cup wall temperature was reduced drastically. The forming operation was close to isothermal conditions. Thus, at high forming velocities, the benefits of the warm forming technique were diminished.

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Note

1. W.F. Hosford and R.M. Caldwell, Metal Forming: Mechanics and Metallurgy, *2nd ed. (Englewood Cliffs, N.J.: Prentice Hall, 1993), p. 287.*