Warm forming of stainless steels

Part I: Rationale and previous studies

Editor's Note: This article is Part I of a two-part series on warm forming stainless steel. Part I discusses the need for warm forming of stainless steel and the results of previous work on the material. Part II, which will appear in August, will discuss simulation and experimental studies conducted by the ERC/NSM on the formability of stainless steel at elevated temperatures.

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Stainless steels are alloy steels with iron as the primary constituent and chromium, nickel, and manganese as principal alloying elements. They are called "stainless" because a chromium- or nickel-oxide film forms on the sheet surface, effectively protecting the steel against corrosion.

In addition to automotive, construction, and transportation industries, stainless steels have a variety of applications in the food, chemical, and pharmaceutical industries. Some common products made from stainless steel are sinks, wash basins, kitchen vessels, and cutlery.

Depending on the metallurgical structure of iron in the stainless steel, these alloys can be classified into three general groups:

1. Martensitic—These steels have good toughness and are used in manufacturing turbine and compressor blades and corrosion-resistant castings.

2. Ferritic—These steels can be cold-formed easily and are used for deep-drawn parts such as vessels for the chemical and food industries.

3. Austenitic—These steels usually show the best corrosion resistance of the three groups. The 3xx series is an example of austenitic stainless steel with good corrosion resistance, formability, and welding properties.[1]

The Need for Warm Forming

Among austenitic stainless steels, type 304 is superior in formability and is the most commonly used. However, the austenitic phase is unstable and gets transformed into martensite during forming. This transformation of austenite to martensite is a function of strain, strain rate (punch velocity), and temperature.

Martensite enhances the strain hardening, thus delaying the onset of necking in sheet metal. While delayed necking is desirable for high formability and drawability, the martensitic phase raises forming loads, reduces formability, and decreases corrosion resistance.

For further deformation after the first forming operation, annealing is required. However, each intermediate annealing operation slows down production and increases costs. To eliminate or reduce the intermediate annealing operations and avoid martensitic transformation, researchers have explored warm forming of stainless steels.

Studies on Stainless Steel Warm Forming

Previous studies by Shinagawa and Takuda indicate that warm forming

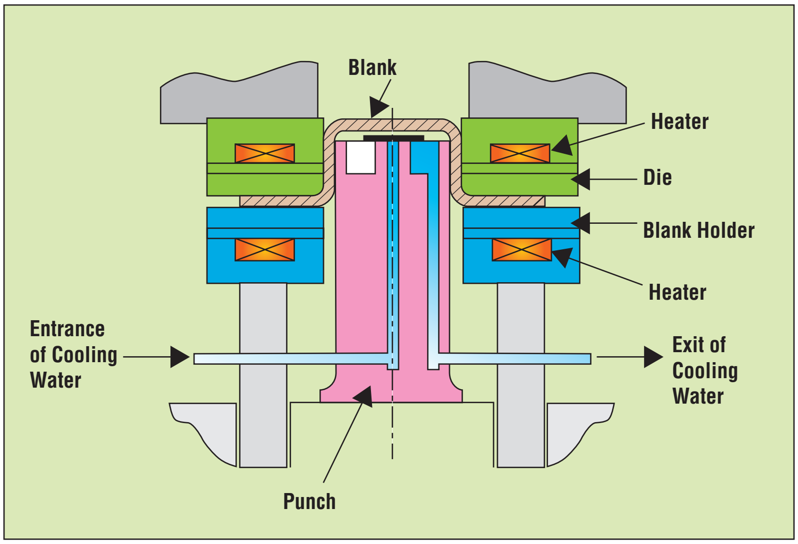

Figure 1

This diagram shows the experimental setup for warm forming cylindrical cups made of types 304 and 316 stainless steels.

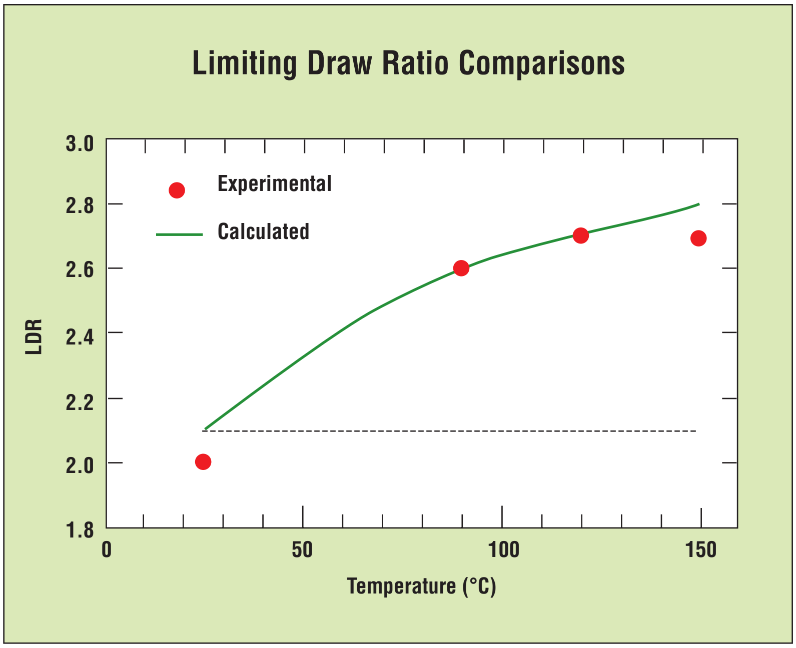

Figure 2a

LDRs obtained at different temperatures from experiments and simulation for type 304 stainless steel displayed good correlation.

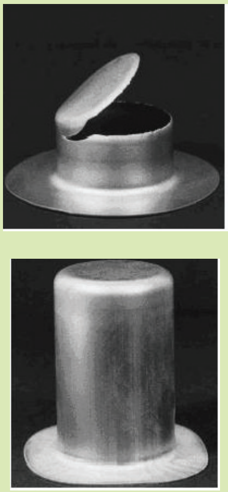

Figure 2b, 2c

Warm forming at room temperature causes the cup to fracture at an LDR of 2.2. However, warm forming at 120 degrees C allows the cup to be drawn much deeper at an LDR of 2.7. [4]

of stainless steel sheet reduces martensite formation when forming at elevated temperatures.[2,3] These researchers performed drawing tests of cylindrical cups made of types 304 and 316 stainless steel. **Figure 1** shows the experimental setup used by Takuda.

Tests were carried out at room temperature and at 90, 120, and 150 degrees Celsius. In the warm deep-drawing tests, the die and blank holder were heated by the built-in heater in the tools, while the punch was cooled by water circulation under 10 degrees C. The limiting draw ratio (LDR) values were obtained for the three different forming temperatures to measure the drawability of the sheet material.

The properties of sheet metal are determined by its microstructure, which is a function of strain, strain rate, and temperature. Takuda conducted finite element (FE) simulations by modeling the flow stress of sheet metal as a function of martensite content. The LDR obtained from experiments and FE simulations showed good correlation (see **Figure 2**). Shinagawa obtained similar results.

Both Shinagawa and Takuda observed that the LDR becomes remarkably higher in warm deep drawing compared with drawing at room temperature. Takuda recorded a maximum LDR of 2.7 at 150 degrees C for a punch velocity of 2.5 millimeters per second, and Shinagawa obtained a maximum of 3.1 at 200 degrees C for a punch velocity of 1 mm per second. The higher the LDR, the deeper the cup could be drawn.

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Notes

1. *Sidney H. Avner,* Introduction to Physical Metallurgy *(New York: McGraw Hill, 1964).*

2. *K. Shinagawa, K. Mori, and K. Osakada, "Finite Element Simulation of Deep Drawing of Stainless Steel Sheet With Deformation-Induced Transformation,"* Journal of Materials Processing Technology, *Vol. 27 (1991), pp. 301-310.*

3. *H. Takuda, K. Mori, T. Masachika, E. Yamazaki, and Y. Watanabe, "Finite Element Analysis of the Formability of an Austenitic Stainless Steel Sheet in Warm Deep Drawing,"* Journal of Materials Processing and Technology, *Vol. 143-144 (2003), pp. 242-248.*

4. *Ibid.*