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ORIGINAL ARTICLE

Formability and fracture studies of austenitic stainless steel 316 at different temperatures

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Abstract Deep drawing is one of the most important sheet metal forming processes in automotive, aerospace and nuclear industries. In this process, the sheet metal blank is formed into a cup shape by an application of punch into the die. The present work is aimed at studying the formability and the nature of fracture for one of the important materials in industrial applications, austenitic stainless steel 316 at different temperatures. Circular blanks were deep drawn at room temperature, 150 and 300 °C using a 20 Ton hydraulic press coupled with a furnace and found that formability of the austenitic stainless steel 316 increased as the temperature was increased. This material underwent dynamic strain aging between 350 and 550 °C. Fractured surface of the broken tensile test specimen at different regions were studied and analyzed using scanning electron microscope. It was observed that the nature of the fracture was brittle in dynamic strain aging region.

1. Introduction

In the modern industry, the deep drawing process is used extensively. This is a complex forming process which involves tension (cup wall), bending (punch and die corners) and compression (cup flange). Both high tensile strength and better ductility in compression are required for the deep drawing material (Jiang et al., 1995). During a deep drawing operation, the work piece is subjected to different types of stresses. There are radial stresses in flange due to the blank being pulled into the die cavity and compressive stress normal to the sheet which is due to the blank-holder pressure. The radial tensile stresses lead to compressive hoop stresses because of the reduction in the circumferential direction. The flange of the blank attempts to wrinkle due to hoop stresses, however the blank-holder should prevent this from happening. Cup wall is primarily experiencing a longitudinal tensile stress, as the punch transmits the drawing force through the walls of the cup and through the flange as it is drawn into the die cavity. There is also a tensile hoop stress caused by the cup being held tightly over the punch. The punch force is limited to the maximum tensile load that can be carried by the wall of the cup and this in turn limits the depth of the flange that can be drawn (Black et al., 1996).

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The plastic forming of sheet metals is the production of a certain material under the right conditions, such as suitable stress rate and low pressure without wrinkles. Mamalis et al. (1997) has investigated the deep drawing of cylindrical boxes with the effect of forming characteristics of the material simulation. Mattiasson (2000) has studied the simulation of tin metal forming in the industry. Although the deep drawing process for high strength/low formability metals has an extensive industrial application but drawing at room temperature, has serious difficulties because of the large amount of deformations and high flow stresses of the materials (Bolt et al., 2001). Drawing at elevated temperatures decreases the flow stresses, relieve residual stresses and increases the formability of the materials hence deformations become easier (Swadesh Kumar Singh et al., 2010a,b). Since elevated temperature results in decreased flow stresses and increased formability in the sheet, it allows deeper drawing and more stretching to form products (Van den Boogaard et al., 2001).

Stainless steels can be employed in many industrial applications due to its high strength. These materials are essentially nonmagnetic in the annealed condition and can be hardened only by cold working. They usually possess excellent cryogenic properties and good high-temperature strength and oxidation resistance. Austenitic stainless steels offer excellent corrosion resistance in organic, acid, industrial and marine environments. The non-magnetic properties combined with exceptionally high toughness at all temperatures make these steels an excellent selection for many marine, nuclear and space applications. Various investigations have recently been carried out to understand the properties of these materials at higher temperatures. These properties are essential to carry out Finite Eelement (FE) studies while drawing the material in warm conditions. Artificial Neural Network (ANN) models are also developed to calculate these properties at unknown temperatures (Amit Kumar Gupta et al., 2012; Swadesh Kumar Singh et al., 2010).

Despite the large application range of stainless steel in the industry there is still a lack of knowledge about its formability and fracture in particular for the austenitic stainless steel (ASS) 316. These facts have led to a thorough study to understand the formability behavior of this material and its nature of fracture. The determination of these conditions implies not only the usual mechanical characterization but also the performance during the deep drawing process. The limiting drawing ratio (LDR) is defined as the ratio of the maximum blank diameter to the cup diameter which can produce without failure or fracture of the cup. The LDR is commonly used to provide a measure of the formability of sheet metal (Gupta and Chakravartty, 2000; Ramadoss and Rajadurai, 2009; Singh Swadesh Kumar, 2008; Avitzur, 1983).

Characteristics of Dynamic Strain Aging (DSA) were observed in ASS316 in a temperature range of 350–550 °C (Benallala et al., 2006). Serrated flow behavior, sharp yield points, negative strain-rate sensitivity are the few characteristics of DSA. These are due to the diffusion of solute atoms to mobile dislocations which leads to the variations of strength, ductility and strain hardening parameters with temperature (Benallal et al., 2003). In the present investigation, deep drawing of different diameters of circular blanks was used to find the LDR of drawn cups at different temperatures. Nature of fracture surfaces below the DSA region and in the DSA region is studied by scanning electron microscopic images.

Table 1 Chemical composition of ASS 316.

Fe	Cr	Ni	Mo	Si	Mn	Cu	Co	C
67.69	16.63	10.85	2.42	1.28	0.38	0.21	0.21	0.018

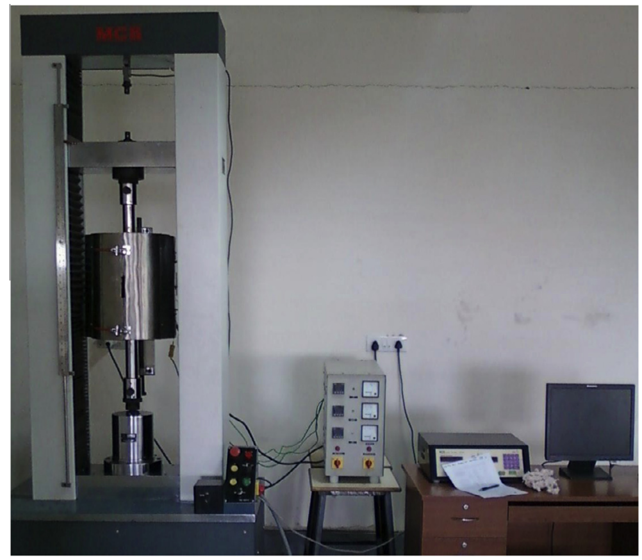

Figure 1 UTM for tensile testing at differenct temperatures.

Table 2 Mechanical properties of ASS 316 at various temperatures.

Temperature	Youngs modulus (in GPa)	Yield strength (in MPa)	Strain hardening index (n)	Hardening co-efficient (K) (in MPa)
Room temp (°C)	205	191.34	0.3819	1106
150	194.4	175.63	0.3981	984.9
300	149.5	169.3	0.4002	872.5
450	147.2	163.7	0.4703	988.7
600	126.2	141.8	0.452	849.3

Figure 2 Experimental test rig.