Effect of process parameters and metallographic studies of ASS-304 Stainless Steel at various temperatures under warm deep drawing

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Abstract

Warm forming of high strength sheet metal alloys are in great demand and its application has importance in defense and nuclear industries. In the present investigation the austenitic stainless steel (ASS)-304 blanks are deep drawn under warm conditions using 20Ton hydraulic press and observed that at lower punch speed when the cup is drawn at elevated temperatures the formability is improved. Numbers of deep draw experiments are conducted under warm conditions to study the microstructure at elevated temperatures for punch corner region cups at variable speeds. In this investigation, changes in the microstructure are observed for deep drawn cups at ambient and elevated temperatures.

1. Introduction

In real world sheet metal accounts for more than half the total steel consumed. The austenitic stainless steels are high nickel and chromium steels are very limited in engineering applications because of lower yield point (Martienssen et al., 2005). A large amount of this is consumed in transportation i.e. automobiles. Austenitic Stainless Steel-304 (ASS-304) sheets are being extensively used in the field of defense and nuclear science due to its excellent corrosion resistance in seawater environment. It also has a low carbon content due to which the wear and friction properties are improved and a lower susceptibility to inter granular corrosion.

The relationship between microstructure and tensile behavior for the multiple rolling from low to high temperature for ASS-304 is observed (Yanushkevich et al., 2011). Deep drawing is one of the most important sheet
metal forming operation. In deep drawing (cup drawing or radial drawing) the thin sheet metal (blanks) is used to form into cylindrical components by pressing the central portion of the blank into the die cavity using tool (punch) to draw the sheet metal into desired shape without wrinkles. Important process parameters like Blank holding force, punch speed and displacement, mechanical properties, lubrication, die and punch corner radius, metallography are useful for drawing defect free component (Ravi Kumar et al., 2002 and Singh et al., 2010) Recent researchers are tending towards for the development of new and improved alloy materials which are more important along with understanding the formability of improved material at elevated temperature are more essential. As the deep drawing proceeds in warm forming, the deformed grains recrystallize into smaller grains. The typical microstructure after cold deep drawing is thus elongated grains that are flattened in the same direction of drawing in some cases; very heavily worked metals can have a grain size and shape that is impossible to measure. Lee et al., (2007) investigated the warm formability of Mg alloy and suggested that strain rate and formability was used to predict the failure occurred in square drawn cups and similar results are showed by Lee et al (2007) through FEM analysis from 200°C to 400°C. Serkan.T et al (2008) investigated on (Al–Mg) alloys and observed that at room temperature the surface quality of the final products of this alloy material is not good, hence after the tests in warm conditions the formability of these alloys is increased at temperature range from 200 to 300 °C and better surface quality of the final product has been achieved. Patrick et al (2004) investigated that below the recrystallize temperature under warm conditions by using an elevated temperature the complex shapes can be drawn easily for better quality. Recently Singh et al (Singh et al., 2010) investigated that under warm conditions the formability of extra deep drawing (EDD) steel at elevated temperature and found out that there was rapid increase in the formability of EDD steel when the temperature of the material increases. ASS-304 has huge industrial usage due to its corrosive resistance in acid and marine state, high strength, non-magnetic and possesses very good cryogenic and high temperature resistance properties and all this poses to very good material for usage in high temperature like in defense and heat exchangers industries. Jayahari et al., (2013) has investigated the drawability and observed that for ASS-304 at low heating temperature i.e. at 150°C it has better formability than at higher temperature. Amit et al(2012) studied the properties of this austenitic stainless steel-304 series material at elevated temperature and also developed ANN model to find out the mechanical properties at elevated temperature. In spite of all this still some gap is there for better usage of ASS-304 at elevated temperature. So, ASS-304 material is investigated at elevated temperature for improvement in formability and metallographic studies.

2. Experimentation

2.1 ASS-304 Material and formability parameters

The chemical composition of AISI type 304 stainless steel alloy sheets was analyzed by a spectrometer are shown in Table 1. The tensile properties for the material were determined by uniaxial tensile tests on a 5T-electronically controlled Universal Testing Machine-UTM Fig.1 at elevated temperature result analysis are shown in Table 2.

Table 1: Typical chemical composition of ASS-304 stainless steel

| MATERIAL | COMPOSITION |
|----------|-------------|
| C        | 0.0025      |
| Mn       | 1.14        |
| Si       | 0.410       |
| Mo       | 0.360       |
| Co       | 0.210       |
| Cr       | 18.40       |
| Ni       | 8.19        |
| Cu       | 0.18        |
| Fe       | 70.78       |
| Others   | 0.305       |
Universal Testing Machine-UTM tensile data at elevated temperature is used for formability analysis and also during warm forming operations.

2.1. Variable Process parameters in deep drawing

The Warm forming experiments are conducted on experimental test rig Fig.2 which is so designed for deep drawing operations at elevated temperatures along with furnace installed on a 20 ton hydraulic press. The temperatures are recorded by using parameter which is a non-contact temperature detecting instrument. A data acquisition system which is connected to the press obtains input parameters like punch travel, load applied on the blank, blank holding pressure by the press. Then the punch was lowered and when it reached to the required temperature, and drawing operation was performed. Molycote was used as the lubrication for the reduction of friction between the die, blank and punch assembly. It contains Molybdenum base material which is highly effective at elevated temperature. The setup temperature was controlled and prevented from overheating by means of water circulation from the cooling tower.

ASS-304 blanks of 1mm thickness were cut into circular shapes on a wire cut EDM machine and deep drawing was carried out on constant blank diameters (60mm) at variable punch speed and blank holding pressure. Since there is tendency in the materials to change dimensions at higher temperatures, Ni based Super alloy and Die steel (D3) is used in designing and manufacturing of die, blank holder and punch. An induction furnace is used to heat the blank and also the lower die.

In this investigation two important process parameters like blank holding force and speed of the punch were studied to understand their effect on the sheets. Padmanabhan et al (2008) investigated that to restrict wrinkling on

| Temp°C | Strain Hardening(n) | Strength Coefficient(K) |
|--------|---------------------|-------------------------|
| RT     | 0.3226              | 999                     |
| 50°C   | 0.3910              | 840                     |
| 100°C  | 0.3651              | 999                     |
| 150°C  | 0.3379              | 1032                    |
| 200°C  | 0.3226              | 1077                    |
| 300°C  | 0.3000              | 1089                    |
the cup minimum blank holder force is applied during forming operation. It is proved that the blank holder force scheme reduces the thinning of the deep drawn part. The initially variable blank holding pressure is used, and constant punch speed is maintained. In deep drawing blank holding pressure used to be taken 1 to 2% of the yield stress. The material in the investigations has yield stress of 197 MPa. So, variable blank holding pressures at constant punch speed 15mm/sec are 10 bar, 15bar, 20bar and 25bar. At different Blank Holding Pressure the drawn cups are shown in Fig: 3. Blank was drawn well under 15, 20 bar blank holding pressure, but fractured at 10, 25 bar pressure. At very low 10 bar pressure, results in the severe wrinkle in the flange portion, which was prevented the material to go through the die and the punch clearance this leads tear the cup bottom while pass into the die. Whereas 25 bar presser holds the blank and does not allow the material to flow into the die cavity which results in fracture at punch corner.

![Fig.2. 20T Hydraulic press test rig](image1)

![Fig: 3 ASS-304 Deep drawn cups at different Blank Holding Pressure in bar (a) 25 (b) 20 (c) 15 (d) 10 at constant speed.](image2)

By applying high or low blank holding pressure cup was fractured. At intermediate pressure 20, 15 bar cups are drawn but at 15 bar on the cup walls little wrinkles were observed. At 20bar cup was drawn to a good shape without wrinkles. For the ASS 304 at room temperature 20bar is the best Blank holding pressure.

In this investigation also checked the effect of formability by varying the punch speed. Naka et al (1999) studied the effect of temperature and ram velocity on the drawing Mg alloy at higher temperature (293- 453K) and observed that drawability becomes lower with increasing forming speeds at all temperatures. Now kept the blank holding pressure constant at 20bar and change the speed of the punch at various temperatures at room temperature, 150°C and 300°C. Punch speed was changed at three different speeds of 20, 15, 10 mm/sec. Cups were drawn at these speeds are shown in Fig.4.
2.2. Metallographic studies (100X) for ASS-304 60mm Punch corner cups at variable speed and at elevated temperatures

The molded samples are etched using concentrated aquaregia and are washed with water to remove etchant traces. Dried samples are observed under metallographic microscope and their microstructures are captured. Above process is repeated for samples made from cups drawn at all temperatures. Inverted microscope range up to 1600X are used to capture the microstructure images from 100X to 800X and are uploaded to MetImageLx metallographic software to analyze the grain size and phase/volume fraction. Jayahari et al (2013) investigated and observed that the thickness distribution in the punch corner is less, so an attempt was made to observe the microstructure studies in the neck portion of cups drawn for constant blank (60mm) at room, 150°C and 300°C.
Fig. 6. Microstructure (100X) of ASS 304 -60mm cup - Neck region for variable punch speed (a) 10mm/s (b) 15mm/s (c) 20mm/s at 150°C.

Fig. 7. Microstructure (100X) of ASS 304 -60mm cup - Neck region for variable punch speed (a) 10mm/s (b) 15mm/s (c) 20mm/s at 300°C.
3. Punch load and microstructure dependence of punch speed

Fig. 8. Punch load vs displacement for ASS-304 at constant Punch speed at RT, 150°C & 300°C (a) 10mm/s (b) 15mm/s (c) 20mm/s

Table 3. Martensite Volume fraction % for ASS-304 60mm cup samples at punch corner region of the cup at various punch speed.

| Temperature | 10mm/sec | 15mm/sec | 20mm/sec |
|-------------|----------|----------|----------|
| RT          | 3.88%    | 3.94%    | 3.60%    |
| 150°C       | 3.89%    | 4.02%    | 3.52%    |
| 300°C       | 3.52%    | 3.73%    | 3.42%    |

Table 4. Grain size for ASS-304 60mm cup samples at punch corner region of the cup at various punch speed.

| Temperature | 10mm/sec | 15mm/sec | 20mm/sec |
|-------------|----------|----------|----------|
| RT          | 7.5      | 7.5      | 6.5      |
| 150°C       | 7.5      | 7.5      | 7.0      |
| 300°C       | 7.5      | 6.0      | 6.0      |

Fig. 8 presents the load displacement graph for drawing 60mm blank of ASS-304 at various temperatures and various speeds. As it can be seen from this graphs that as there is increase in temperature punch load decreases. In ASS-304 DSA (Dynamic strain gaining) appears in the material due to sudden increase in the dislocation density of the material and in this region the material behaves in an unusual way (Amit et al., 2012). In ASS-304 martensite phase may also appear due to increase in the deformation speed and also increase in temperature. As it can be seen from the Table 3 and Table 4 by increasing the punch speed % martensite at the punch corner radius is increases. Also there is decrease in grain size by increase the punch speed. These factors will tend to increase the strength of material that is the reason at 300°C and also at 20mm per sec punch speed there is slight increase in the load requirement. This is probably the reason that at 300°C and beyond (Jayahari et al., 2013) there is decrease in the formability of the material. So, this material can best form either below 300°C or at a temperature beyond DSA phenomena.
4. Conclusions

Since in ASS-304 not only the DSA appears in the material with in a temperature limit but also martensite phase appearing depending upon the temperature and also on the forming rate. So, it was observed in this study that for achieving higher formability, temperature and punch speed should be so selected that martensite formation and grain refinement should be kept minimum.

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