Determining the formability of AA5052 sheets in annealed and H32 condition

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Abstract

Forming Limit Diagram (FLD) is an easy and efficient way of determining the safe region for formability in sheet metals. In this work formability of AA5052 H32 sheets of thickness 1 mm is studied by developing a FLD. Since traditional generation of FLDs requires sophisticated equipment, an attempt has been made to generate FLDs using tensile testing and Erichsen cupping tests. Reduced section tensile samples were prepared with varying notch radius of 10 mm and 12 mm for the test. Tensile testing was carried out on a Universal Testing Machine (UTM) with a maximum capacity of 120 kN. Erichsen cupping tests were carried out on rectangular specimens with length of 90 mm and widths of 60, 40, 25 and 10 mm respectively. The process (tensile and Erichsen testing) was repeated for this alloy in the annealed conditions with annealing temperature of 345°C. FLDs were plotted for both as-received and annealed conditions. The annealed samples show a better formability compared to as received samples.

Keywords: Forming Limit Diagram, Erichsen test, Annealing, Formability

1. Introduction

Many materials fracture before appreciable deformation. This phenomenon has limited the use of materials in many applications. Determining the amount of deformation a material can withstand before failure is very much needed for its effective use. Aluminium alloys find a range of application in many fields like aerospace, automobiles, household appliances. Also aluminium alloys finds applications in lightweight structures. Therefore determining the formability of aluminium alloys is gaining importance in the present scenario.

Forming Limit Diagram (FLD) is a graphical method for determining the limit strains in a material subjected to deformation. A number of test are available to determine the limit strains in a material [1], [2]. Limit strains are the strains which a material can withstand just before fracture. Thus FLD plays a crucial role in the design of many forming processes. Moshksar et al [3] studied the FLD for Al305 sheets of thickness 1 mm. FLD was plotted for inplane and outplane conditions. He concluded that in outplane FLD the amount of strain was higher. Through the test he determined the formability regimes for Al305 sheets. Naka et al [4] studied the effect of parameters like temperature and forming speed on FLD of Al-Mg alloy. He concluded that FLD depends on forming speed at high temperatures only. Also strain rate plays a major role in increasing formability regimes of FLD at high temperatures. A number of studies have been made on determination of formability of the alloys [1], [5]–[8] and also on FLDs [2], [3], [9]–[13].

In the present study AA5052 H32 sheets with thickness 1 mm was used for the tests. Forming Limit Diagram was plotted using tensile test and Erichsen cupping test data. FLDs were plotted for both as received and annealed conditions. The main aim of the present work is to determine a safe formable region for the alloy under consideration.
2. Experimental details

2.1. Material and Equipment: AA5052 H32 sheet of thickness 1mm was used in this experiment. The main elements in the alloy apart from Al are Mg (2.7 %), Fe (0.21 %) and Cr (0.20 %)

FLD was plotted by conducting two tests. Negative minor strain of FLD was determined by using uniaxial tensile test. Tensile testing was done on a Universal Testing Machine (UTM). Maximum capacity of the UTM was 120 kN. The cross head speed used was 2.5 mm/min. Deep drawing experiments were done with the help of Erichsen cup testing machine. Samples were deformed up to tearing by using a hemispherical punch (20mm diameter) and a die in Erichsen Cupping machine.

2.2. Test Procedure: Negative minor strain region of FLS was determined by using uniaxial tensile test. For this tensile sample with gauge length of 70 mm and notch radius of 10 mm and 12 mm were cut from AA5052 H32 sheets of thickness 1 mm using CNC machining. Tensile samples are cut 45 degree to the rolling direction.

Positive major strain region of FLD was determined using Erichsen Cupping test. A set of specimens with a fixed length and different widths were prepared. Rectangular specimens with varying widths of 60 mm, 40 mm, 25 mm and 10 mm were also cut from AA5052 H32 sheets of 1 mm thickness using CNC machining. Nature of strain changes from balanced biaxial tension to uniaxial tension by varying width from 60 mm to 10 mm respectively. Punch used for Erichsen cup test has a diameter of 20 mm. All the samples were subjected to cupping till onset of tearing.

Circles of diameter 2.5mm were engraved on all the specimens by using laser etching. The tests were conducted on all the samples up to fracture. After deformation the circles got stretched into ellipses with major axis and minor axis indicating deformation. The two diameters were measured on three distinct regions namely safe region, necked region and fractured region. Major and minor diameters of the ellipses were photographed using a stereomicroscope and measured using Image J software. Major strain ($\varepsilon_1$) and minor strain ($\varepsilon_2$) were measured at two distinct regions namely safe region and teared region. Graphs were plotted with major strain ($=\ln$(major dia./original dia.)) versus minor strain ($=\ln$(minor dia./original dia.)). A groove appears in the deformed region indicating localized necking. In order to improve formability the experiments were repeated after annealing the samples at 345 °C. FLD was plotted for both as received and annealed conditions.

Specimen geometry used for uniaxial tension and Erichsen cupping test are shown in figure 1 and 2. Table 1 shows the shape and dimensions of specimen used for both tests.
Table 1. Dimensions of specimens used for both tests.

| Specimen type | Specimen Width, W (mm) | Specimen length, L (mm) | Notch radius , r (mm) | Length of notch, L₁ (mm) |
|---------------|-------------------------|-------------------------|-----------------------|-------------------------|
| Notched Specimen (Uniaxial tension test) | a) 50 b) 50 | a) 150 b) 150 | a) 10 b) 12 | a) 70 b) 70 |
| Rectangular Specimen (Erichsen cupping test) | a) 60 b) 40 c) 25 d) 10 | a) 90 b) 90 c) 90 d) 90 | No Notch |
3. Result and discussion

From the uniaxial deformation of the notched specimens with circular grids, we will get the limit strains. These limit strain represents the negative minor strain region of the FLD. Similarly for plotting the positive strain region of FLD Erichsen cupping test was done on rectangular specimens with circular grids.

3.1. Formability in the As Received Condition: Uniaxial deformation test was conducted on notched specimens with notch radius 10mm and 12 mm respectively. Major Strain versus Minor Strain graphs were plotted for both samples. figure3 (a) and (b) shows the limit strain values for both samples. These are the strain values just before failure.

![Figure 3](image)

**Figure 3.** Major and Minor strain values measured after Uniaxial deformation (as received) on specimens with varying notch radius (r) **(a) r=10mm** **(b) r=12mm**

Erichsen cupping test was conducted on rectangular specimens of width 60mm, 40mm, 25mm and 10mm respectively. Here also major strain versus minor strain value is plotted and the results are shown in figure4. (a-d). These are the strain values just before failure.
Considering all data points from uniaxial deformation test and Erichsen test a graph was plotted. In the graph ordinate represents major strain and abscissa represents minor strain. It is as shown in figure.5. On the negative minor strain region (second quadrant) of the graph a line was drawn demarcating safe and unsafe regions. Similarly a demarcating line was drawn on the positive minor strain region (first quadrant). Joining the two (demarcating line and curve) an FLD is drawn which indicates the limit of the formability region diagram for the material AA5052 H32 in the as received condition.

**Figure4.** Major and Minor strain values measured from Erichsen Cupping test (as received) on specimens with varying width (w) a) w=60mm b) w=40mm c) w=25mm d) w=10mm
3.1. Formability in annealed condition

As a further improvement in formability AA5052 H32 sheets were subjected to annealing at a temperature of 345°C for a holding time of 10 min. Uniaxial deformation test and Erichsen test were repeated as for the as received case and graphs were plotted. Comparing the tensile test data for annealed condition shown in figure 6 with the corresponding data’s for as received condition (figure 3) it can be concluded that ductile regime is more for the former case. The reason for this is that the material in the as received condition is cold rolled one and so severely strain hardened.

**Figure 5.** FLD (as received condition)
Erichsen cupping data of the rectangular specimens are shown in figure 7 (a-d). These are the strain values just before failure. Here also we can see that when when the width of the samples were varied the state of strain changes from biaxial to uniaxial stretching. Also from the figure 7 (a-d) it is evident that the strain values for the rectangular specimens are more which indicated better formability for the annealed samples.
FLD for the annealed condition was plotted taking into consideration all the data points from uniaxial deformation test and Erichsen test. (figure8).

Figure7. Major and Minor strain values measured from Erichsen Cupping test (annealed) on specimens with varying width (w) a) w=60mm b) w=40mm c) w=25mm d) w=10mm

Figure8. FLD (annealed condition)
For comparison both FLDs were plotted a single graph (figure 9). From the figure it can be inferred that the FLD for annealed case is above the FLD for as received one. Thus a part of unsafe region in the as received case becomes the safe region for annealed case. This indicates that the limit of formability has been increased by annealing.

**Figure 9.** Comparison of FLDs for annealed and as received conditions.

figure 10 shows the samples after deep drawing test. As the sample width decreases the failure region got shifted from center to the edges.
Conclusion

Forming Limit Diagram (FLD) for AA5052 sheets were determined using uniaxial tensile deformation and Erichsen cupping tests on grid marked specimens in the as received (H32) condition and annealed condition (345°C temperature for 10 min). As width decreases the failure was concentrated near the edges rather than in the center of the Erichsen test specimens. FLD for the annealed condition lies above the FLD for as received material which implies better formability in the annealed condition.

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