Comparative study of Dual-Phase -590 steel on formability at superplastic region and room temperature

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Abstract. A steel alloy DP590 is commonly used for automobile applications because of its outstanding mechanical characteristics. One crucial limitation of this steel forming is that it has limited malleability and ductility. In this study, we compared the experimental forming limit diagram (FLD) for DP590 at RT and 800°C using stretching. An experiment with a strain rate of 0.01/s is carried out with samples cut in four different directions (0°,30°,60°& 90°) as seen from the rolling direction. Rolling direction specimens have been found to be among the stronger samples. FLD can be applied as a method for studying temperature differences in formability characteristics of DP590. Scanning electron microscopy was used for the analysis deformation pattern. Based on these results, it shows that the material has become significantly more formable.

Keywords. Dual-Phase -590 steel, Hot forming, Room temperature(RT), scanning electron microscope(SEM), forming limit diagram (FLD), limiting dome height (LDH)

1 Introduction

Modern-day metals, such as steel, are among the most desirable materials. It is used in many industries such as automotive, aerospace, infrastructure, shipbuilding, and more [1,2]. A material with attributes such as strength, ductility, and lightweight, is becoming more and more sought after to increase the efficiency of mechanical systems. In steels having these characteristics, advanced high-strength steels (AHSSs) are used [3]. A steel's structure determines these types of steel, which may be classified according to twinning-induced plasticity, transformation-induced plasticity, dual-phase (DP) or martensitic[4]. DP steel, as its name implies, consists of two phases, namely martensite and ferrite. The ferritic and martensitic phases are responsible for the steel's ductility and strength [5].

Over the last few years, researchers have focused much more on DP steel's deformation capabilities. Previous studies concluded as the martensite content increases in DP steel, its strength increases as well [6]. The ferritic phase also contributes to the material's ductility. Specifically, it depends entirely on the particles which make up the ferritic phase. Furthermore, the ultrafine ferritic phase increases the strength of the material as well as prevents it from deforming [7]. It is also possible to increase the material's overall strength by pre-straining [8].

Manufacturing industries make extensive use of processes such as cutting and forming sheet metals, particularly to replace traditional assembly processes like welding[9–11]. Significant geometries can be easily manufactured using advanced forming techniques. In such conditions, researchers discovered that elevated temperatures enhance the malleability and ductility of the material, making it easier to form the materials.[12–15] One of the most significant benefits of forming at elevated temperatures is the ability to easily deform and form complex shapes [16]. However, there are also some disadvantages, including high tooling costs and procedures that must be followed when performing such operations. Sheet metal formability can be assessed using formability limit diagrams (FLDs).

Any forming process defines the maximum form that can be applied to a material. Based on the strain path distributions of different specimens, FLD breaks down into three categories, is tension-tension, plane strain, and tension-compression. Various conventional FLDs for steel, aluminium, and magnesium alloys have been derived. furthermore, it has been used to predict failure, arising from the forming process.[17–20] Goodwin,[21] Keeler,[22] and Hecker[23] developed a systematic analysis of limiting strains in metallic materials. In the past, many researchers reported using Nakazima et al.[24]'s method of plotting an FLD for the simple setup and specimens.

A steel alloy such as DP590 is cheap, readily available, and an alloy of conventional metals. Due to its application in the automotive industry, extensive research has been conducted. There are, however, very few studies that have been conducted that have used anisotropic parameters in conjunction with ductile fracture criteria to predict fracture strains at elevated temperatures. Therefore, the author attempted experiments to determine DP590's fracture strain at various temperatures. Furthermore, in

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the study, the authors develop and compare experimental FLDs and limiting dome heights (LDHs) within a set of processing parameters.

2. Experimental study

2.1. Work material and sample preparation

DP590 steel sheets with a thickness of 1 mm were used in the present study. It has alloying elements such that Si (0.26%),Cr (0.45%), C (0.075%), Mo (0.30%),Mn (2.29%), Fe (balance) etc. Tensile specimens were made according to ASTM E08/E8 M-11 shown in figure1. To determine the anisotropic parameters, it was cut at 0°, 30°,60° and 90° based on the rolling direction. As shown in Figure 2, this work was performed on a servo-electric hot-forming setup. Tensile test temperatures were RT and 800°C with deformations of 0.01 /s each. After repeating all three experiments three times, the present work evaluated and reported the average properties of the material.

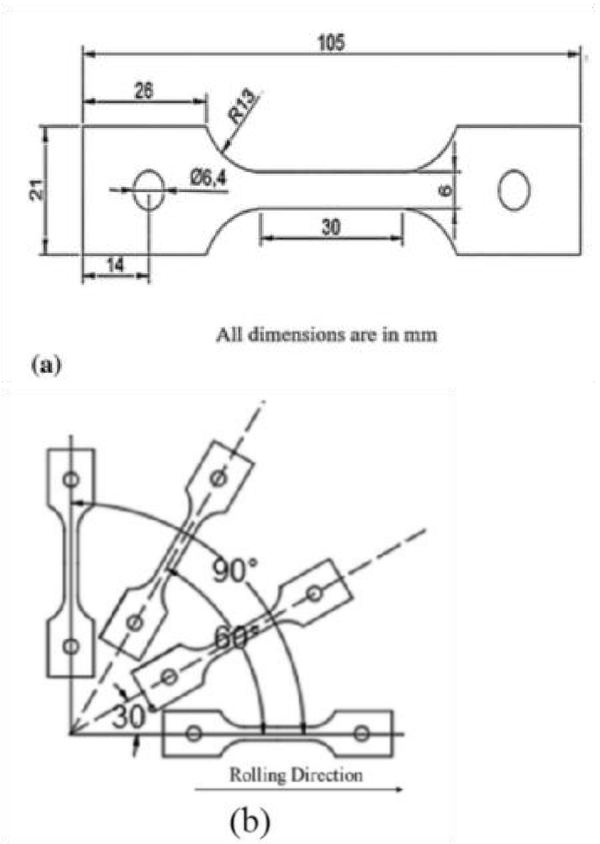

Fig. 1 (a) Tensile test specimen dimensions of ASTM E8/E8M-11 sub-size (b) schematic four different sheet orientation

2.2. Stretching at room and superplastic temperatures

Experiments were conducted on a hydraulic press of 40 tons shown in Figure 2(a). Performing stretching tests at a higher temperature are done with an induction heated hydraulic press. K-type thermocouples were used to measure the temperature during the test. To measure strains in stretch-formed specimens, they were laser-etched using a 2.5 mm diameter circular grid. Following the directions in standard (ASTM E2218-15), the specimens were laser-etched. A schematic diagram showing the sizes of the Nakazima specimens used in the FLD analysis appears in Figure 2(b). At a constant punch speed of 0.01/s and BHP of 25 bars, the stretch form test was performed at RT and 800°C to gain an understanding of how temperature impacts the ability of the material to form. To measure the strains, a stereomicroscope with a high-resolution was using an image analyzer.

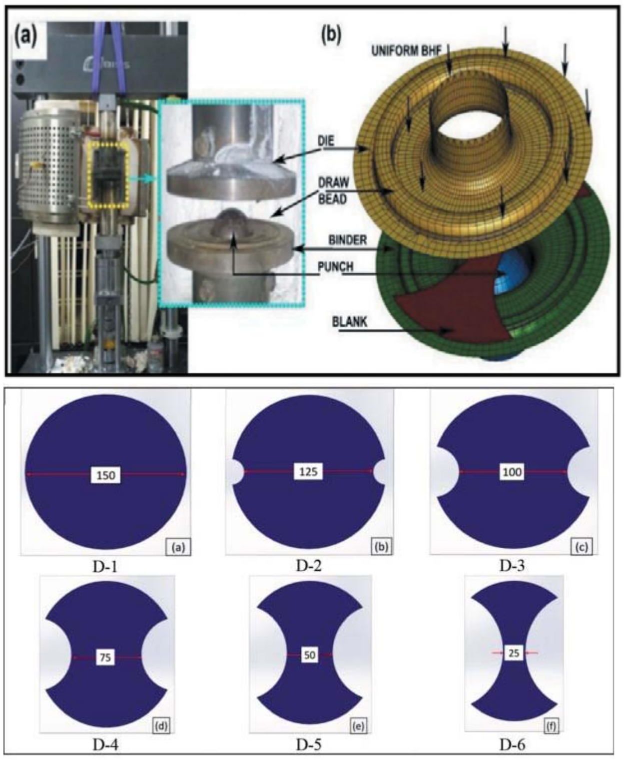

Fig. 2. (a) A servo-electric hot-forming test rig with a dual split furnace. (b) different sizes of nakazima samples

3. Results and discussions

3.1 Tensile behaviour

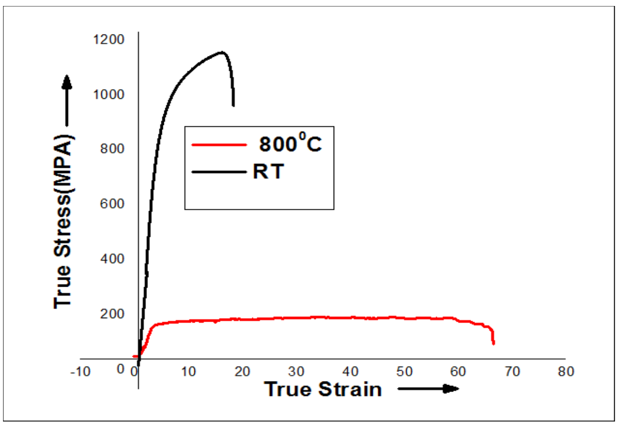

Fig. 3 True Stress - True Strain graph at RT & 800°C

In this section, we study the effects of test temperature, strain rate, and sheet orientation on DP590 steel flow stress behaviour. According to Figure 3, the tensile flow behaviour of DP590 steel for 0.01/s is affected by test temperatures (RT and 800°C). A significant effect of rising temperature on flow stress and yield stress was observed in table1. As the temperature rises, the yield stress decreases. This is primarily caused by the softening effect, particularly at higher temperatures. The behaviour of most metals at the superplastic region is similar to uniaxial tensile deformation. In high temperatures, the shrinkage of the yield stress is primarily caused by the activation of the dislocation motion, which makes plastic deformation easier [19].

Table 1: DP 590 steel mechanical properties at RT & 800°C

Temperature(⁰C)	RT	800
Strain Rate(/s)	0.01	0.01
Orientation(°)	0,30,60,90	0,30,60,90
UTS(Mpa)	966.74±3	121.24±7
YTS(Mpa)	758±21.	85.08±5
% Elongation	18.41±4	68.82±13
n	0.174	0.093
K	1483	391

3.2 Forming Limit Diagram (FLD)

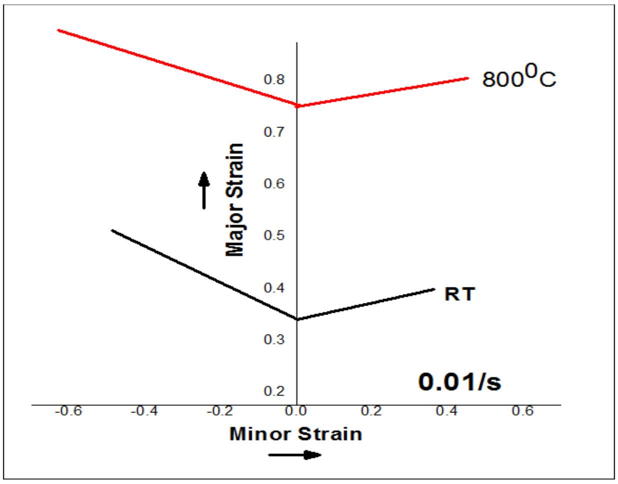

Fig4. Comparison of FLDs at RT & 800°C for 0.01/s

It is important to know forming and fracture limits of the material before performing forming operations on it. To determine the limiting strain, samples of different shapes are deformed at 800°C, as shown in Figure 4. To avoid failure from the bead region, circular and nakazima specimens were used. It has been observed that stretching specimens have not significantly resulted in necking, especially at RT. Stereomicroscopes with high magnification and an imaging analysis technique were used to estimate the stresses in the fractured and unbroken regions of the cup specimen. The necking region of the FLD at RT also displayed very few straining points, including those in the T–C zone. The plane strain region and T–T region were necked with an increase in temperature from RT to 800°C. The FLD (shown by solid coloured lines) was calculated by considering the specimen's highest safe strain at two temperatures. Moreover, if specimens were subjected to plane strains, fracture would occur with no changes to strain direction (i.e. ε2 is very small) compared to other specimens. As the temperature is increased, FLDs tend to move upwards, and Figure 5(b) presents a comparative analysis of FLDs at 800°C. With an increase in forming temperature from RT to 800°C, the forming limit of material increased by approximately 76%.

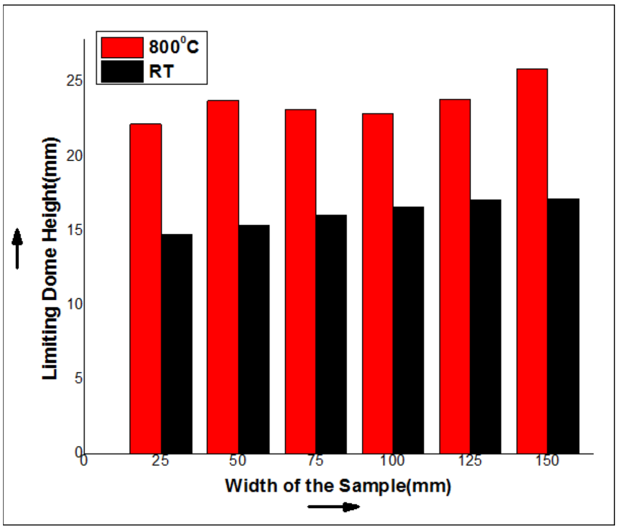

Fig. 5 LDH variation

Measurements are carried out at both RT and 800°C for cup-shaped samples. An excellent way to evaluate the stretchability and driveability of materials under varied conditions is to evaluate the dome height just before a fracture. In Figure 5, we demonstrate that LDH varies with species/width and temperature. LDH is a function of both. A significant difference is observed between LDH at room temperature and LDH of hot-formed sheets because the strain hardening exponent is higher in hot-formed sheets, which suggests that these sheets cannot be manufactured at room temperature. Hence, the proper selection of temperature allows for components to be formed efficiently and with maximum strength.

3.3 SEM

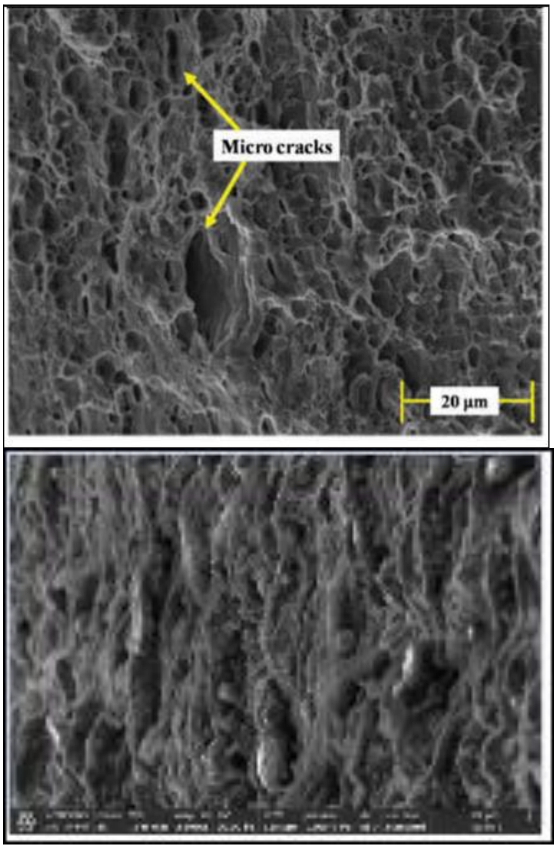

Fig 6. The SEM images show fractures in DP steel, at (a)RT (b)800 °C

Figure 6 illustrates fractographic observations made on deformed specimens at room temperature and 800°C using a scanning electron microscope. A complete deformation of the broken surface is observed with dimples, flat areas, ripping borders, and a serpentine sliding pattern. This material is ductile fractured.

Conclusions

. Here are some conclusions based on the experimental results:

- ThDP590 steel showed an increase in FLD of 76% as it went from room temperature 800°C. Therefore, high-strength materials can be formed more easily at elevated temperatures, as they undergo less deformation load when being formed into the desired shape.
- There is an inverse relationship between LDH and the width of the sample and the temperature of the experiment.
- As detected by scanning electron microscopy, it seems the fracture is primarily ductile. Fractures occur diagonally to the normal plane in all fractured specimens.

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