Effect of strain rates on the forming properties of DP Steel at high-temperature

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Abstract. Dual Phase steel grade, with its remarkable combination of features including formability and resistance to high temperatures, has been a revolutionary alloy in modern industry. It is a useful material that may be applied to many different tasks. It presents us with the task of examining its characteristics in response to changes in critical parameters such as temperature and loading rate during stretching operations. Understanding the formability behavior of DP steel sheets, which have a thickness of 1 mm, at various increased temperatures and strain rates was the main goal of the investigation. We investigated and examined the tensile characteristics at 650 and 750 degrees Celsius in the first investigation. On the other hand, because of flow stresses in the material at higher temperatures, elongation has decreased in value as deformation rates have increased. In addition, we plotted the FLDs experimentally and examined the formation behavior while performing the Nakazima Test on specimens with a thickness of 1 mm. Furthermore, a limiting dome height (LDH) study was conducted on a laboratory scale. In terms of temperature, the LDH was shown to be higher at 750 and at 0.001/s

1 Introduction

Various applications of DP steel including nuclear sciences, extremely corrosive material industries, the pharmaceutical business, and many more, demand materials with outstanding qualities at elevated temperatures. The materials that are appropriate for these businesses are extremely limited. For use in these domains, DP steel is among the best options. In specific temperature and strain rate ranges, these steels display an unusual phenomenon called Dynamic Strain Aging, or alternatively called the Protein-Le Chatelier (PLC) effect [1-3]. The primary factor that could be causing this behaviour is the material's mobility of solute atoms. These atoms can accumulate to a point where they can flow as a dislocation while the material is moving and then separate into its core when it must stop in front of an obstruction. In the stress-strain plot mentioned above, there may be odd, serrated-like observations [4-5].

Formability is difficult to describe and measure since it is a complex process in and of itself. It depends on a number of factors, the main ones being the material's characteristics and the complex reactions among metals at the tool-blank contact. The formability can be described in different varieties , FLD is the most precise since it shows how much sheet metal can deform before a material experiences plastic instability [6-8]. The initial tail symptoms of localized necking are bound to occur during the forming.The maximum and lowest strains that can be endured before a failure occur depend on the capacity of material [9-14].

A curve that connects the major and minor strains, the forming limit diagram enables us to compare strain distribution. The form of a FLD offers several benefits since it makes it easier to locate the areas where the sheet metal will fail and stay safe when under forming strain. Swadesh et al. [15] showed increases in forming features up to the DSA regime after analysing the forming behavior and fracture cause at 150 and 300 C. However, there was no discernible improvement in the DSA zone, and there was a reported decrease in ductility in the region above DSA. FLD at high temperatures using both theoretical and experimental methods.

This work's primary goal is to look into the DP steel behaviour at high temperatures and various strain rates. The mechanical features of DP steel were characterised and analysed in the first section of our work. In the second section, FLDs were drawn to analyse DP steel's forming characteristics at various strain rates in relation to temperature.

2 Experimental procedure

2.1. Materials and methods

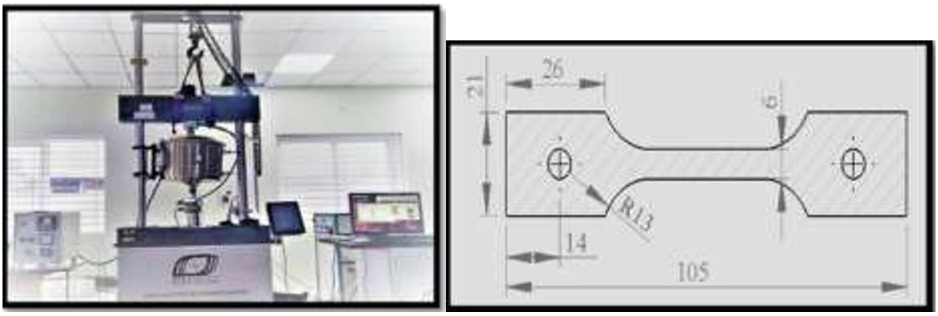
The DP Steel is the sample material used in this analysis and composition shown in table 1. The specimens of one mm thick DP Steel sheet were used. The samples were created in accordance with ASTM E8/E8M-11 guidelines. The specimens were cut in three orientations on the sheet perpendicular, diagonal, and parallel to the direction of rolling.

Table 1: As-received composition of DP590 steel sheets

Element	C	Mn	Si	Cr	Mo	Al	Fe
In wt %	0.114	1.786	0.386	0.025	0.03	0.035	Rest

2.2. Tensile testing of DP steel

The testing machine was a UTM and specimen Shown in Fig. 1.The specimen was exposed to elevated temperatures (650°C and 750°C) with variable strain rates on varied orientations. The mechanical property change of DP steel was investigated in relation to varying temperatures and strain rates. Additionally, a thorough comparative analysis was conducted across various orientations. Table 2 displays the computed material characteristics for the DP steel alloy at 650 and 750 degrees Celsius.



(a) (b)

Fig. 1. (a) Computer controlled UTM machine (b) ASTM-E8M standard specimen

2.3. Warm forming of DP Steel

Table 2 contains the results of testing the blank material's chemical makeup. This alloy's high molybdenum and chromium content prevents it from corroding when exposed to halide ions. Because nickel serves as a stabilising factor in the alloy, the fundamental phase, which is austenitic, is preserved. The material is seen to have good forming properties because of its distinct phases. A stretching die arrangement and a single pair of specimens produced at 650°C Were part of the hot stretching experimental setup, which is seen in Figure 2.

Fig. 2. Sheet Metal Forming setup & One set of specimens used for plotting the FLD

3 Result and discussions

The figure below displays the stress-strain curves that were calculated from the tensile tests conducted at two increased temperatures under quasi-static strain rate conditions (0.001 s1 & 0.1 s1). It was observed that when the temperature rose from 650 to 750 degrees Celsius, the overall elongation improved. At higher temperatures, however, a notable decrease in the overall flow stress was observed with a rise in both temperature and deformation speed. Because of the material's increased stacking fault energy (SFE), which increases flowability at higher temperatures, flow stresses dropped as temperature rose.

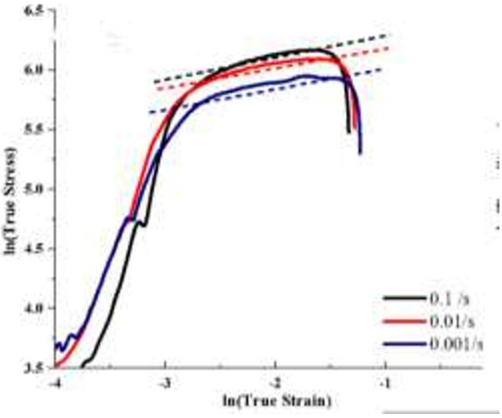


Fig. 3. representation of Stress- Strain graphs at 750°C at different strain rates

Table 2: DP590 steel- Mechanical properties

Temperature	YS (MPa)	UTS (MPa)	% Elongation
650	**355.93**	**452.67**	**27.53**
750	**143.67**	**165.67**	**48.79**
YS – Yield Strength, UTS – Ultimate Tensile Strength			

It was discovered that the greatest improvement in overall deformation occurred at 750°C with the lowest strain rate of 0.001 s1. Furthermore, compared to the 650 Shown in Fig. 4, the overall deformation was observed to be better at 750 °C. The stretch created samples' Limiting Dome Height (LDH) is determined at 650C and 750°C under various strain rates of 0.001 s1, 0.01 s1, and 0.1 s1. It is the dome height that is measured immediately prior to a fracture and is useful in determining how well different materials can stretch and drive under varied working circumstances.

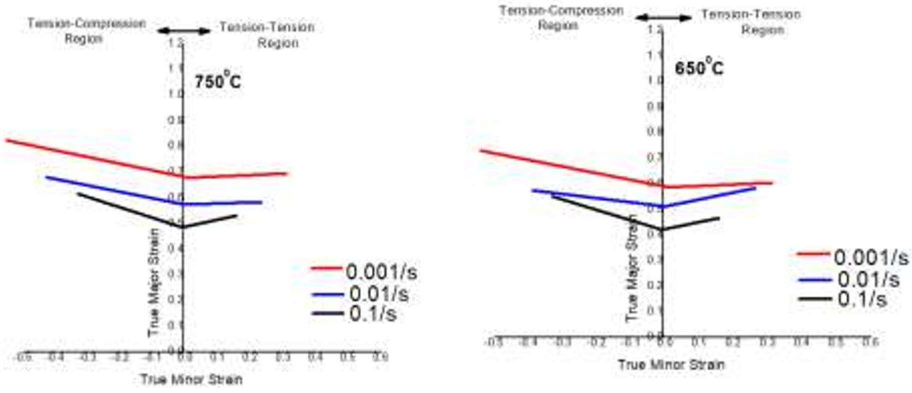


Fig. 4. Comparison of FLD in three different deformations at 650 C and 750 C respectively.

Fig. 5 illustrates the compression of LDH with various specimen widths. It is discovered that LDH is inversely proportional to strain rate and directly proportional to the testing temperature. Because of the larger strain hardening exponent at 650°C, the LDH is noticeably lower than the LDH at 750 °C. As temperature rises, formability will also rise. Additionally, it is seen that when strain rate increases, the LDH value in relation to sample width is decreed in Figure 5. Therefore, components with the highest possible strength and formability can be manufactured by carefully choosing the forming temperature and strain rate.

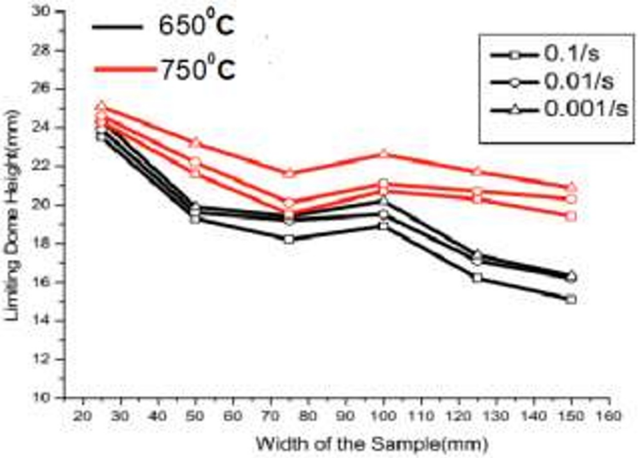


Fig. 5. Limiting Dome Height of Cup at 650 C & 750 C

4 Conclusions

The results of the experimental analysis lead to the following deductions.

- The tensile behaviour and forming features of a particular material at increased temperatures are greatly impacted by variations in strain rate.
- It was evident from the forming limit diagrams that formability would increase in proportion to a drop in strain rate value.

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