International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 2 Issue 8, August - 2013

Experimental investigation of Dynamic strain aging regime in Austenitic Stainless Steel 316

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Abstract: Serrations in the stress-strain curve caused by the Portevin–Le Chatelier effect are the most visible effect of dynamic strain aging (DSA),other effects are marked by negative strain rate sensitivity. These DSA always appears during the plastic deformation process of metallic materials under certain temperatures and strain rates. Present work is aimed to investigate the DSA region for austenitic stainless steel 316 in the temperature range up to 650°C at a constant strain rates of $1x10^{-2}$, $1x10^{-3}$ and $1x10^{-4}$ sec^{-1}. Characteristics indicators of serrated plastic flow were observed in the temperature range of 400 to 600°C. Strain rate sensitivity of the material is found to be negative in this region. It was observed from the experiments that DSA is occurred at lower strain rate and intermediate temperatures.

Key words: Dynamic Strain Aging, Serration, Strain rate sensitivity,

1. Introduction

Discontinuous plastic flow in metals referred to as dynamic strain aging (DSA). It has been reported and various physical models and micro-mechanisms have been proposed in an attempt to explain this phenomenon [1]. The occurrence of DSA during plastic deformation is a well-known phenomenon in metallic materials [2]. It is attributed to the interaction of solute atoms with moving dislocationsand is generally observed when the deformation temperatureis high enough to permit short range diffusionof solute atoms to dislocation cores. This strong elastic interaction result in a temporary arrest of thedislocation in the slip plane.These DSA always appears during the plastic deformation process of metallic materials under certain temperatures and strain rates. It was found in recent years that the influence of DSA phenomenon on the mechanical behavior of materials should not be ignored. Most of the literature shows that the tensile strength and fatigue strength of the material are increased by DSA andductility, rupture toughness were also influenced [3, 4].

Typical macroscopic features of DSA include serrated flow behavior, sharp yield points, maxima in the work hardening temperature plot, negative strain-rate sensitivity. Both interstitial and substitution elements are responsiblefor such effects in an appropriate range of strain-rateand temperature.Mobile dislocations move by successive jerks between ‘forest’ obstacles, i.e. other dislocations piercing their slip plane. Solute atoms diffuse to and age mobile dislocations while they are temporarily arrested at these obstacles. This mechanism leads to negative strain rate sensitivity (SRS) of the flow stress in a range of strain rates where the two types of defects have comparable mobility. No material particle deforms at a plastic strain rate from within this interval. If the imposed strain rate falls into this range, plastic flow is heterogeneous, with plastic strain rate highly localized in narrow bands, either static or propagating in a continuous or discontinuous manner [5].

In austenitic stainless steels serrated flow can occur in the large temperature range. These serrated flow may be observed for certain solute atom concentrations and at some specific strain rates. The temperature range of serrated flow indicates a thermally activated behavior. Tensile tests of an austenitic stainless steel have shown [6] that serrated yielding is observed within a certain range of strain rates and temperatures, where the dynamic strain hardening is high. Both the activation volume and the activation energy for plastic deformation are a function of temperature, and increase with an increase in test temperature. The austenitic stainless steel as the structural components in petrochemical industry, power plants and nuclear reactors is usually served under a load with long period of time at a high temperature region, and it is influenced by DSA during deformation [7].

The present work tried to study the DSA phenomenon in austenitic stainless steel 316. The serrated flow behavior of the material is one of the evident features of DSA phenomenon and this region is also characterized by negative strain rate sensitivity. Found the temperature range and strain rate at which serrations are observed in the flow stress diagram. Measured the strain rate sensitivity index in this range, which is evident of DSA. This non-classic mechanism takes place at higher temperatures and causes more drastic changes in ductility.

2. Experimental procedure

Material used in this study was ASS 316 sheet of 1.0 mm thick. Chemical composition of ASS316 sheet metal blank is listed in Table 1. This alloy contains 2.42% molybdenum which enhances the corrosion resistance. This steel is more resistant to general corrosion, pitting and crevice corrosion than the conventional chromium-nickel austenitic stainless steels such as Alloy 304. Resistance to corrosion in the presence of chloride or other halide ions is enhanced by higher chromium (Cr) and molybdenum (Mo) content. This alloy also offers higher creep, stress-to-rupture and tensile strength at elevated temperatures. It is primarily austenitic phase and small quantities of ferrite may be present. Due to the presence of these phases it has excellent toughness besides high strength. These combinations of properties provide the excellent formability to the material.

Table1: Chemical composition of ASS 316

Fe	Cr	Ni	Mo	Si	Mn	Cu	Co	C
67.7	16.6	10.8	2.4	1.3	0.38	0.21	0.21	0.018

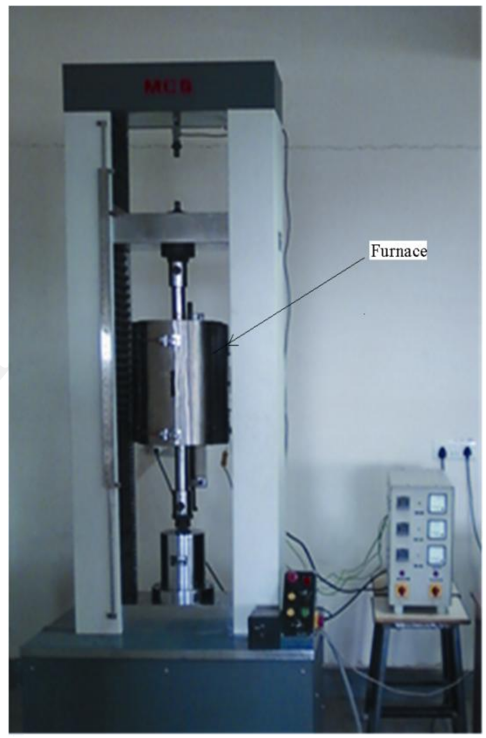

Fig.1:Universal testing machine

Tensile testing was conducted on Universal testing machine made by MCS as shown in Fig 1. It is electronic screw driven machines with precision screw, column construction and completely control by computer. It has variable speed drive. For conducting the test at higher temperature, this machine is attached with a special type split furnace. It hasa uniform distribution of heating coils, which are arranged in three zones to achieve temperature up to 1000° C with ± 1°C accuracy. Temperature control and measurement is done by thermocouple. Tests were conducted in air by maintaining constant strain rate of $1x10^{-2}$, $1x10^{-3}$ and $1x10^{-4}$ sec^{-1}in the temperature region from 50 to 650°C. Flat tensile specimen blanks were cut from the flat sheets. The tensile specimens having 30 mm gauge length and 6.4 mm gauge width according to ASTM standard E8M (Sheet type sub-size specimen) were cut from the blanks. Evaluate the tensile properties by draw the flow stress curve to find the temperature range where the serration occurs in the curve.

3. Results and discussion

After conducting the tensile test as per ASTM standard true stress vs true strain graphs are constructed to find the serration. Serrations in the stress–strain curve was observed at lower strain rate, they are absent at higher strain rates. For the entire set of tests, serrations were observed only over a limited range of strain-rate and temperature, as summarized in Table 2. DSA serrations on the stress–strain curves are well-defined at the testing of lower strain rate and temperatures of 400°C to 600°C, while at the lower temperature they are absent in the whole range of the strain rates. Fig. 2 provides a graphical summary of the results of tensile test carried at lower strain rate $1x10^{-4}$ sec^{-1}. It is clearly seen that the serrated flow appears at 400 to 600°C temperature at this strain rate.

The strain-rate sensitivity index (m) is considered to be the one of the parameter that can characterize DSA phenomena. The flow stress equation that describes plastic behavior is usually written as an equation (1) [8]where 'σ' is the flow stress, 'K' is a materialconstant, '$\dot{\varepsilon}$'is the strain rate and 'm' is the strain-rate sensitivity index of the flow stress. The m-value is a function of the forming parameters, such as the strain rate and the temperature. The most convenient method of measuring m is a uniaxial tensile test at a particular constant temperature and at different strain rates. The simplest method is reflected in the relationship between the flow stress (σ) and the strain rate ($\dot{\varepsilon}$).

$$\sigma = K\dot{\varepsilon}^{m} \quad (1)$$

Table 2: Serration in flow stress curve for ASS 316 at different strain rate and temperatures

Temperature (°C) → / Strain rate (sec-1) ↓	100	200	300	350	400	500	600	650
$1x10^{-2}$,	X	X	X	X	X	✓	✓	X
$1x10^{-3}$	X	X	X	X	✓	✓	✓	X
$1x10^{-4}$	X	X	X	X	✓	✓	✓	X

The 'm' value is usually calculated from the logarithmic plot of the flowstress vs. strain rate. Fig3shows the graph at DSA temperature range covering the true strains of 0.2. The m-values were calculated from the slopes of the graph. The curves exhibit negative slope these values are presented. The negative value of 'm' for the temperature from 400 to 600 C evident the occurrence of DSA. Decreasing the strain rate sensitivity with increasing strain in the DSA regime has been reported in low carbon steel and subsequently analyzed in detail by McCormick[9]. The appearance of negative strain-rate sensitivity coincides with the appearance of serrations in the stress–strain curves, again suggesting solute induced dynamic strain aging.

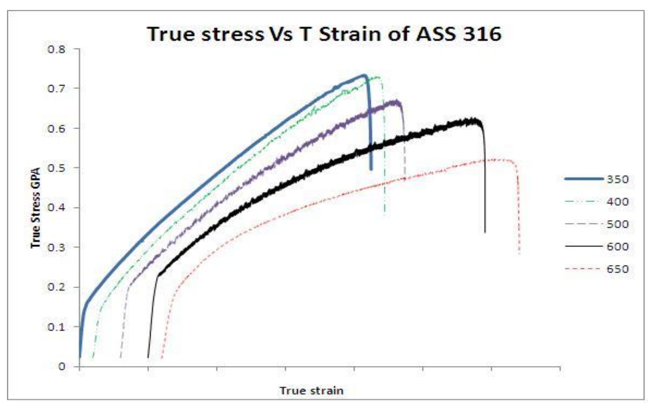

Fig. 2: Flow stress curve of ASS 316 at

The occurrence of the serration is linked to a bounded region of negative strain-rate dependence of the flow stress, which may be explained by dynamic strain aging (DSA) resulting from diffusion of solute atoms to dislocations temporarily arrested at obstacles in the slip path [10]. It clearly indicates that within the temperature range where serrated flow occurs, the strain rate sensitivity of the flow stress becomes negative. This serrated flow to originate from the pinning of dislocations by solute atoms of the alloy. These are attributing the occurrence of DSA in ASS 316.

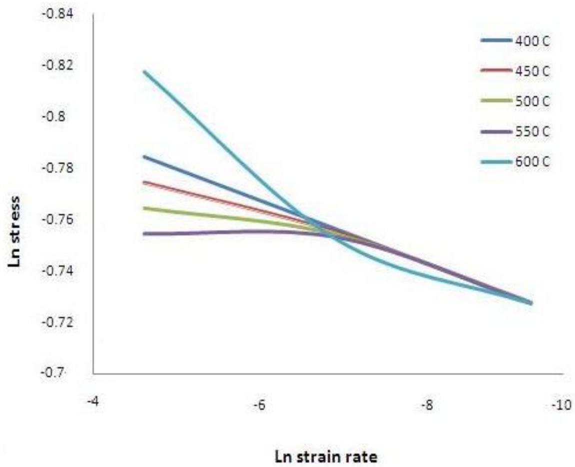

Fig. 3: True stress Vs Strain rate

4. Conclusions

In this study, DSA region of austenitic stainless steel 316 has been investigated by uniaxial tensile test. Occurrence of serrationin true stress vs true strain curve was the indicator of DSA. The serrations were observed in the temperature range of 400°C to 600°C at a strain rate of $1x10^{-4}$ sec^{-1}. As the strain rate increases, DSA region was decreased. At a strain rate of $1x10^{-2}$ sec^{-1} DSA observed at 450°C to 600°C. In this DSA region strain rate sensitivity was negative which one of the evident features of DSA is.

Acknowledgement

The financial support received for this research work from the All India Council for Technical Education(AICTE), Government of India, is gratefully acknowledged.

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