IOP Conference Series: Materials Science and Engineering

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To cite this article: Yu Borisova *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1014** 012005

IOP Conf. Series: Materials Science and Engineering 1014 (2021) 012005 doi:10.1088/1757-899X/1014/1/012005

Portevin-Le Chatelier effect in austenitic steel Fe-18%Cr-8%Ni

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Abstract. The study of the mechanical behavior of the austenitic Fe-18% Cr-8% Ni steel was carried out in the temperature range of 530°C - 680°C at a strain rate of 1×10^{-3} s^{-1}, as well as at a temperature of 620°C and strain rates of 1×10^{-2} s^{-1} - 1×10^{-4} s^{-1}. At these conditions, the PLC effect was observed. Type A serrations were observed in the temperature range 530 - 680°C. A decrease in the strain rate at a temperature of 620°C leads to a change in the type of serrations from type A to type B.

1. Introduction

High-strength austenitic steels are the subject of research and development in many countries due to the growing demand for special steels for the production of high-quality equipment [1]. Austenitic stainless steels are used in the designs of boilers for new generation coal-fired power units operating at supercritical steam parameters (with a steam temperature above 620°C and a pressure over 25 MPa) [2]. These steels are widely used as structural materials due to their excellent oxidation resistance and high creep strength. In particular, metastable austenitic steels such as Fe-18% Cr-8% Ni type stainless steel exhibit excellent tensile properties in a wide temperature range [3].

However, at high operating temperatures, austenitic stainless steels are susceptible to dynamic strain aging (DSA) associated with interactions between dissolved atoms and mobile dislocations during plastic deformation [4]. This effect leads to the appearance of undesirable roughness on the surface of the products. This phenomenon depends on temperature and strain rate. DSA can have a large impact on mechanical properties such as strength and ductility [5]. The aim of this work is to study the manifestation of the Portevin-Le Chatelier (PLC) effect in the Fe-18% Cr-8% Ni austenitic steel.

2. Material and methods

The studied Fe-18% Cr-8% Ni austenitic stainless steel was produced by chill casting. Steel ingots were forged at a temperature of 1180°C. Then, the steel was subjected to solution treatment at 1150°C, for one hour followed by quenching into water.

The microstructure investigation was performed by scanning electron microscopy (SEM) with automated indexing of electron back-scattering diffraction (EBSD) patterns using a Quanta Nova NanoSEM scanning microscope and transmission electron microscopy (TEM) using a Jeol JEM-2100 microscope. Flat dog-bone-shaped tensile specimens with a 16 mm gauge length and a cross-section of 1.5×3 mm^2 were used. Tensile tests in the temperature range from 500°C to 680°C and a strain rate of 1×10^{-3} s^{-1} and at a temperature of 620°C and strain rates from 1×10^{-5} s^{-1} to 1×10^{-1} s^{-1} were performed by using an INSTRON 5882 universal testing machine.

3. Results and discussion

The studied steel after heat treatment is characterized by completely annealed austenitic grains with an average size of ~ 14 μm (figure 1). Numerous annealing twins can be seen within grain interiors. The fraction of high-angle boundaries and the average grain misorientation angle were determined by EBSD analysis. The fraction of high-angle boundaries is 97.3%, while the fraction of special or twin-type boundaries Σ3 is 56.3%. The average misorientation angle is 50.7°. The dislocation density inside the grains is about 2.7×10^{12} m^{-2}. TEM studies showed the presence of second phase particles which have been identified as primary Nb(C,N) particles. These particles are distributed homogeneously and have an average size of about 174 nm.

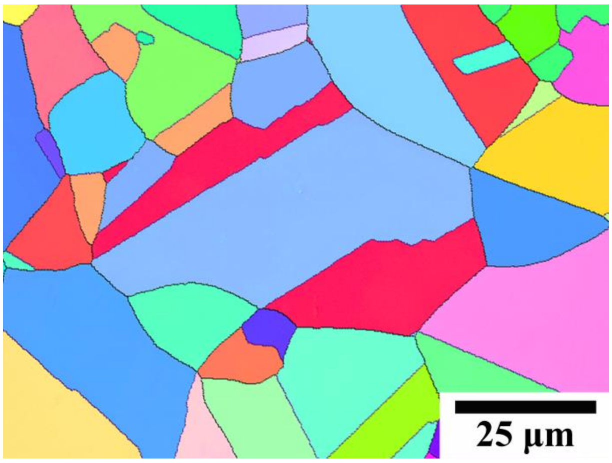

Figure 1. Microstructure of the Fe-18% Cr-8% Ni steel after solution treatment.

The uniaxial tensile tests of the studied steel performed at a strain rate of 1×10^{-3} s^{-1} showed that the deformation of the specimens at 530 – 680°C was accompanied by an unstable plastic flow, with serrations on the strain-stress curves (figure 2 (a)). This phenomenon in austenitic stainless steels is generally associated with the PLC effect due to DSA [6].

In the temperature interval of 590 - 680°C, only type A serrations were observed on the deformation curves, which are characterized by a sharp increase in stress followed by a drop to or below the general level of the flow stress. It is known that type A serration is a consequence of plane sliding, which is expressed by the propagation of deformation bands over long distances, and is associated with the interaction of mobile dislocations and interstitial atoms, such as nitrogen and carbon [7]. It should be noted that the frequency of the flow stress surges increases with increasing test temperature, while their amplitude decreases.

Since the operating temperature of these steels is ~ 620°C, the evaluation of the effect of the strain rate on the shape of deformation curves was evaluated at a given temperature. The manifestation of the PLC effect was observed in the range of strain rates from 1×10^{-2} s^{-1} to 1×10^{-4} s^{-1}. Type A serration was observed at a higher strain rate, while type B serration at low strain rates. Type B serration is associated with the slip of dislocations in deformation bands.

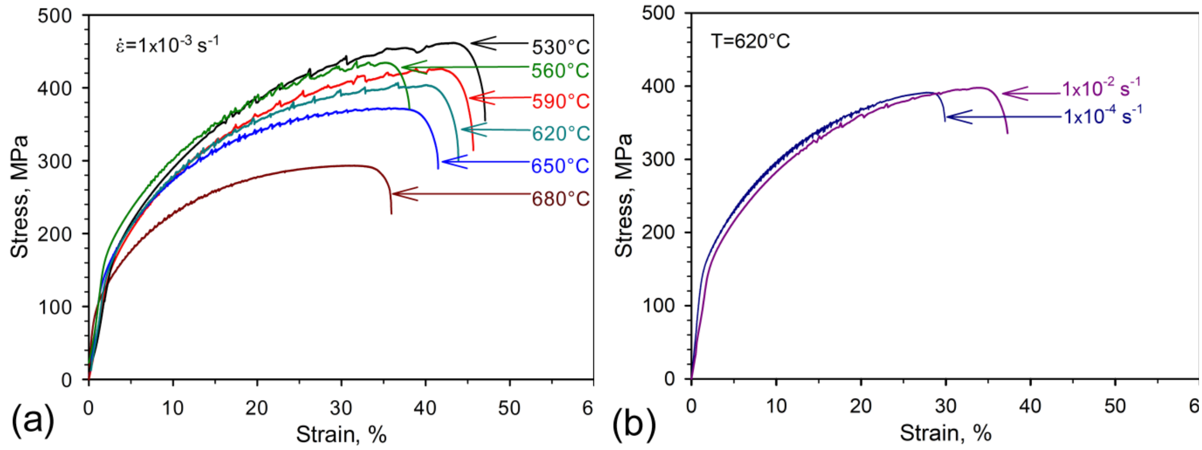

Figure 2. Deformation curves obtained at a strain rate of ~1×10^{-3} s^{-1} and temperatures of 530–680°C (a) and at 620°C in the strain rate interval from 1×10^{-2} s^{-1} to 1×10^{-4} s^{-1} (b).

The appearance of an unstable plastic flow takes place only after reaching a certain value of the critical strain [8]. The dependence of the estimated critical strain on temperature and strain rate is shown in figure 3. The critical strain values tend to decrease with increasing temperature, demonstrating "normal" behavior (figure 3 (a)). At a temperature of 620°C, an “inverse” critical strain dependence was observed (figure 3 (b)). It is suggested that such dependence is associated with the effect of strain rate/temperature on the dislocation movement and the cyclic segregation of atoms [8]. Both dependences in figures 3(a) and 3(b) are typical for the DSA process.

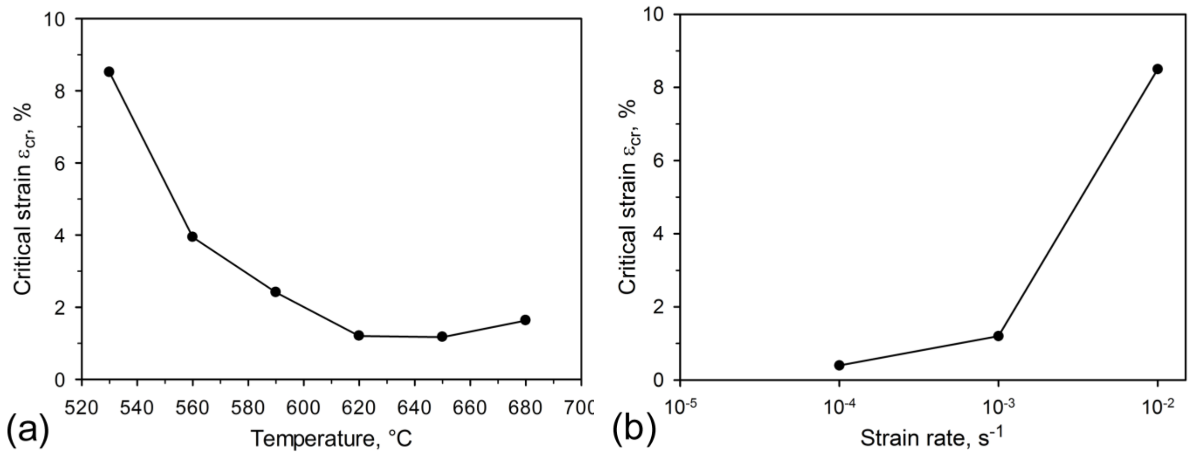

Figure 3. The critical strain as a function of the temperature (a) and strain rate (b).

4. Conclusions

The main conclusions based on the present study could be summarized as follows:

1. The temperature and strain rate intervals of the occurrence of the PLC effect in the Fe-18% Cr-8% Ni steel have been determined as 530 - 680°C at a strain rate of 1×10^{-3} s^{-1} and 1×10^{-2} s^{-1} to 1×10^{-4} s^{-1} at a temperature of 620°C.

2. Type A serrations were observed on the stress- strain curves at temperatures of 530-680°C and a strain rate of 1×10^{-3} s^{-1}. Type B serrations were observed at a temperature of 620°C and a strain rate of 1×10^{-4} s^{-1}.

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3. The increase in temperature and decrease in the strain rate leads to an increase in the frequency of serrations and a decrease in their amplitude.

4. The critical strain for the appearance of the unstable plastic flow gradually decreases with decreasing strain rate or increasing temperature.

Acknowledgement

The reported study was funded by RFBR and NSFC according to the research project № 20-58-53053. The main results were obtained by using the equipment of the Joint Research Center, «Technology and Materials», Belgorod State University.

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