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The Portevin-Le Chatelier Type for 316L(N) SS at Low Deformation Rate

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Keywords: Austenitic stainless steel 316L(N), Portevin Le-Chatelier, Work hardening

Abstract. This study determined the serrated yielding type for 316L(N) SS due to the Portevin-Le Chatelier effect under particular temperature conditions with the range of 24 to 655 °C at 10^{-5}/s of plastic deformation rate. The 316L(N) SS was loaded by tensile test apparatus equipped with a three-zone furnace. The cylindrical specimen was put at the centre of the furnace. Since the test was conducted at various temperatures, a thermocouple was attached to the surface of the specimen. After the test, the engineering stress-strain curve was plotted, and the serrated yielding was observed. The results showed that the type A, B, D, and E were identified for a particular temperature. Type B was identified at the low-temperature region, and type A was identified at the high-temperature region. In addition, the work hardening rate curve was plotted to describe the plastic deformation characteristic.

Introduction

Strain rate sensitivity is one of the critical parameters that must be considered to determine the creep deformation mechanism [1]. The wide range of strain rates can lead to the change of flow stress. The three-stage in the creep curve occurred due to the alteration of strain rate value. An incremental change of strain rate occurred during the first stage, where the work hardening developed. A constant strain rate occurred at the second stage, where the recovery and hardening process was relatively balanced. The last stage is the rupture process, where the strain rate incrementally increase. It has been reported that at a particular strain rate value, the heterogeneous plastic deformation or also known as the Portevin Le-Chatelier effect, can lead to a loss in ductility and produce a rippled surface [2,3]. Macroscopically, the heterogeneous plastic deformation has been modelled by a well-known model, namely dynamic strain ageing (DSA). The DSA can be simply modelled when the solute atom experienced an ageing process [3-5]. The ageing process occurred since the mobile dislocation was impeded by an obstacle such as Forrest and pipe dislocation [4,5].

The serrated yielding phenomenon has been investigated for several metal alloys such as aluminum alloy, stainless steel, and nickel-based super-alloys [2,4-8]. The 316L(N) SS as one type of austenitic stainless steel is still an essential component for the power plant [5, 9-11]. This type of steel has several unique properties, exceptionally compatible with the liquid sodium coolant and stable at elevated temperatures. Several studies have been conducted to investigate the characteristic of 316L(N) SS under tension load for particular temperature and strain rate conditions [11]. Furthermore, it has been reported that uncommon due to serrated yielding was found for particular strain rate and temperature. Since this steel grade is still in use, more information about the serrated yielding for a wide range of temperature and strain rates is still required.

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by Ekaputra I Made Wicaksana

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In this study, the 316L(N) SS was investigated at elevated temperature and 10^{-5}/s of deformation rate. The tension test was conducted in the temperature ranges of 24 °C - 655 °C. By plotting the engineering stress-strain curve, the serrated yielding was observed and identified. In addition, to investigate the strain rate effect on the plastic deformation process, the work hardening curve was plotted and discussed.

Experimental Procedure

In this study, the naming of "L(N)" is defined that this steel grade has a particular amount of Nitrogen (0.1 wt.%) and Carbon (< 0.03 wt.%). This 316L(N) SS has 0.020C–1.05Mn–0.0027P–0.005S–17.1Cr–2.4Mo–12.2Ni–0.08N (wt.%). The ingot was normalized before being formed into a cylindrical form. Specimen size and dimensions followed the manufactured into a cylindrical specimen ASTM E8 [12]. The cylindrical specimen has a circular diameter of 6±0.01 mm and a gauge length of 30±0.01 mm. The specimen was intended to have a smaller diameter around the centre to produce a fracture at the centre position. All specimens were cut in the rolling direction and polished with #2000 of sandpaper grit. The specimen size and dimension were shown in Fig. 1.

The strain rate was controlled by setting the constant crosshead velocity of 10^{-5}/s. Since the tensile test was conducted at elevated temperatures, the test followed the ASTM E21 [13]. The three-zone heating furnace was applied for the test at elevated temperature. The cylindrical specimen was put at the centre of the furnace and attached with a thermocouple on the specimen surface. Before loading the specimen, the furnace was heated until reaching the destination temperature with the range within ± 3 °C. A universal testing machine with a capacity of 50 kN was applied for the tensile test. Since no extensometer was not be used, the specimen elongation was measured based on the displacement of the crosshead movement.

Results and Discussion

The tensile test result for 316L(N) SS with the range of 24 to 655 °C at 10^{-5}/s was represented by the engineering stress-strain curve in Fig. 2. It can be seen that the curve trend is decreasing with an increase in temperatures. The ultimate tensile strength and yield strength decrease significantly above room temperature. The recovery takes control with the higher temperatures. It is also seen that the curves are located at the narrow band for the temperature range of 190 °C - 655 °C. It has been reported that the narrow band indicated the serrated yielding occurrence [5]. The serrated yielding can also be seen at the non-linear curve (plastic area) in the engineering stress-strain curve where work hardening has occurred. From literature, the serrated yielding does typically not found at room temperature [5,11]. However, the serrated yielding is found for 316L(N) SS at 24 °C with 10^{-5}/s of strain rate.

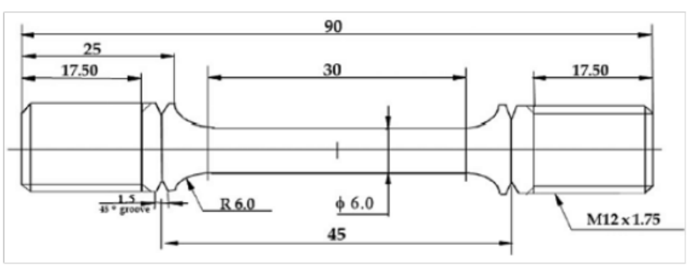


Fig. 1. Specimen size and dimesion for the tensile test.

Fig. 3 shows the magnification of the plastic curve for each temperature condition. It is seen that the different type of serrated yielding is formed. The type of serrated yielding is summarized in Table 1. Type B is observed at the range of 24 °C - 290 °C. Type B is indicated by the load oscillation about the centre of the stress-strain curve. Following the classical DSA theory, the oscillation occurred since the ageing time of the solute atom was short [14]. Therefore, the mobile dislocation moved with high diffusivity. Type A is observed at the range of 335 °C - 440 °C. Type A is indicated by the sudden increase of load followed by load drop to the centre of the stress-strain curve. Type A is almost the same as type B, with the lower diffusivity of mobile dislocation due to the longer ageing time. The combination of type A+E is observed at the range of 510 °C - 545 °C. Type E typically appears at higher stress and higher temperature after type A. Type D is observed at 610 °C. Type D indicates the plateaus on the stress-strain curve. The combination of type A+B is observed at 655 °C.

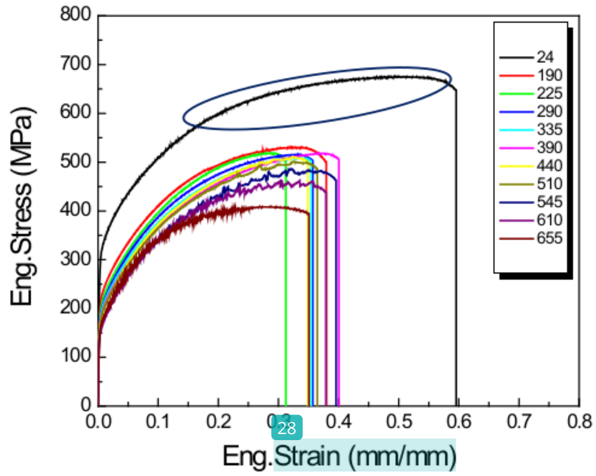
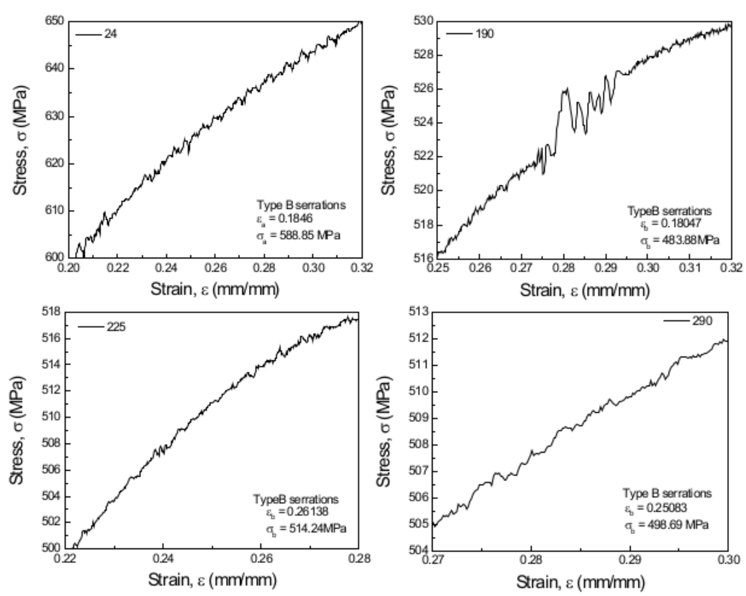


Fig. 2. Engineering stress-strain curve of 316L(N) SS.



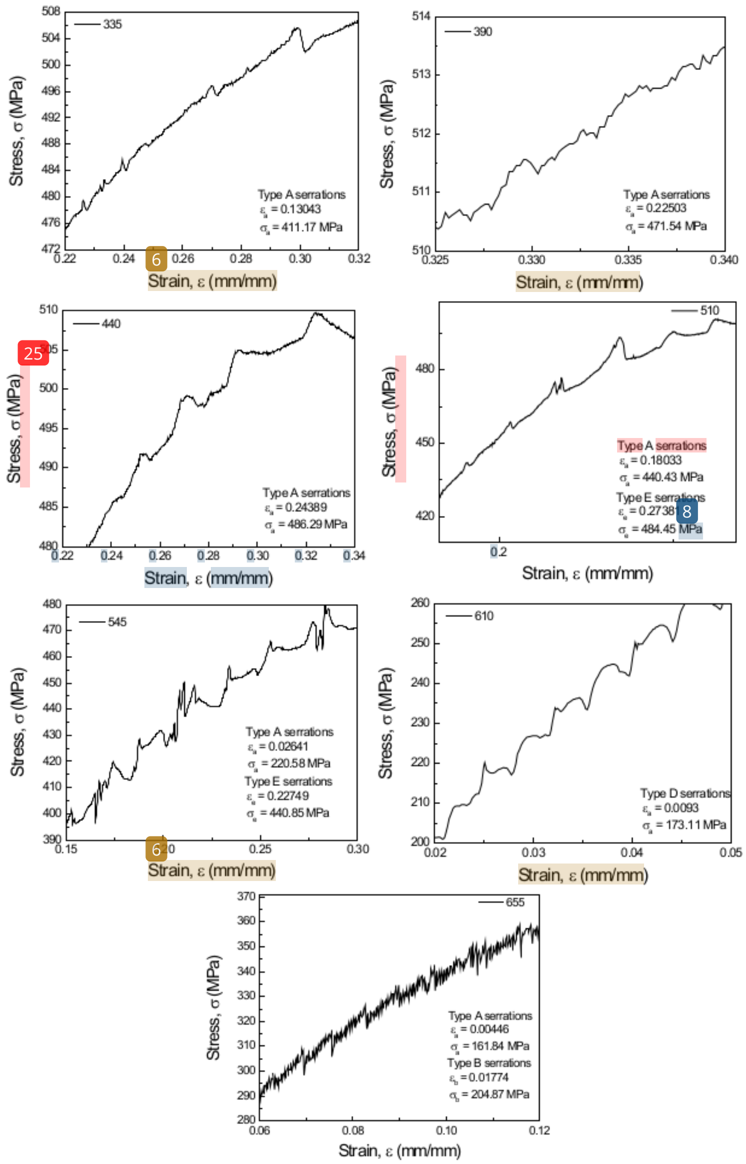


Fig. 3. Type of serration yield for each temperature condition.

Table 1. Identification of serrated yielding type for 316L(N)SS.

	24	190	225	290	335	390	440	510	545	610	655
A	-	-	-	-	O	O	O	O	O	-	O
B	O	O	O	O	-	-	-	-	-	-	O
C	-	-	-	-	-	-	-	-	-	-	-
D	-	-	-	-	-	-	-	-	-	O	-
E	-	-	-	-	-	-	-	O	O	-	-

The curve of work hardening rate of 316L(N) SS under various temperatures at 10^{-5}/s is represented in Fig. 4. In this study, the work hardening rate for 316L(N) SS confirmed the previous study obtained by Samuel [15]. The work hardening rate, θ, is determined by calculating the derivative of true stress, σ_t, to the true strain, ε_t [14]. the three stages of work hardening rate was seen

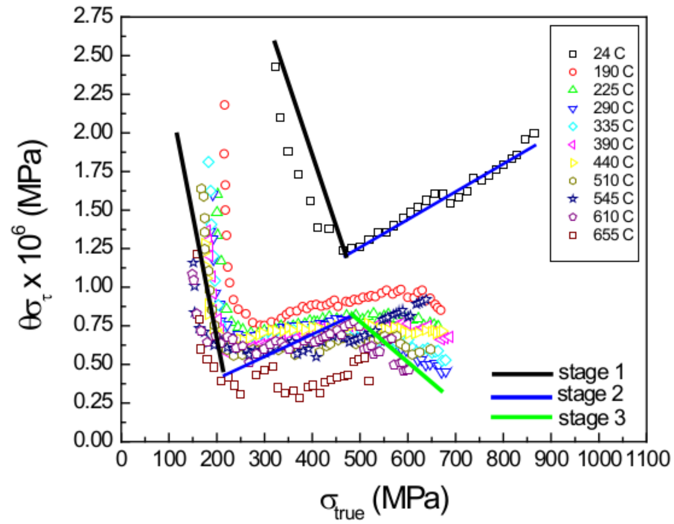


Fig. 4. Work hardening rate for 316L(N) SS at 10^{-5}/s.

by plotting $\theta\sigma_t$ vs σ_t. The first stage was initially indicated by a rapid decrease in $\theta\sigma_t$ followed by a gradual increase in $\theta\sigma_t$. The first stage is also called a transient stage, interpreted as plastic strain increases due to increasing mobile dislocation density after passing the elastic limit. The second stage was related to the hardening process where the slip was activated and resulted in heterogeneous dislocation. Finally, the third stage was identified as the recovery process.

Summary

In this preliminary study revealed that the serrated yielding type for 316L(N) SS was dominated by types A and B under various temperatures at 10^{-5}/s. The remaining type of serrated yielding was also observed as type D and E. Following the engineering stress-strain curve, the work hardening rate showed that the recovery process was not found at room temperature. While above the room temperature, the recovery process occurred after the hardening process.

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