Low Temperature Effects on the Tensile Properties of STS 304 Stainless Steel

Do-Sik Kim, B. O. Yoo, S. J. Baik, Y. S. Choo, K. P. Hong
Korea Atomic Energy Research Institute, Irradiated Materials Examination Facility, 150, Yusong-Ku, Dukjin-Dong, Taejeon, 305-353, kimds@kaeri.re.kr

1. Introduction

Accurate mechanical property data at low temperatures are essential for design of economical, efficient, and safe structures for low temperature operation. AISI Type 300-series stainless steels are the most widely used structural alloys for cryogenic applications, because they exhibit high strength and ductility as well as low thermal expansion. In this study, the tensile tests of the cold-worked STS 304 stainless steel plate were conducted in the temperature range of 111K (-162°C) to 293K (20°C). The effects of low temperature on tensile properties were estimated experimentally.

2. Experimental Procedure

2.1 Material and Apparatus

The material used in this study was a 2mm thick plate of cold worked STS 304 stainless steel produced by POSCO in Korea. Tensile tests were conducted on a 100kN computer controlled servo-hydraulic testing system with a cryogenic testing apparatus illustrated in Figure 1. All the tests began after the temperature had stabilized at 111K (-162°C), 153K (-120°C), 193K (-80°C) and 293K (20°C) and the extensometer output was constant. A thermocouple was positioned at the center portion on the tensile specimen. Fractographic observation of the fracture surfaces of the tensile specimen was carried out using a scanning electron microscope (SEM).

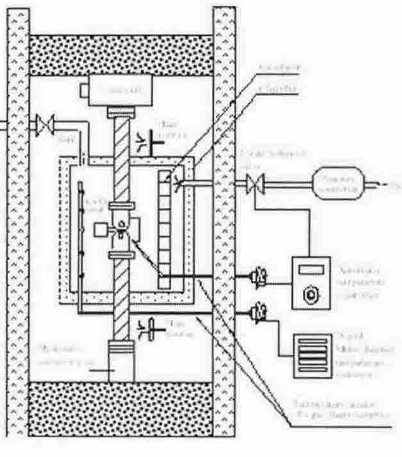


Figure 1. Schematic diagram of the low temperature experimental apparatus.

2.2 Tensile test

Flat tensile specimens with a 2mm thickness, a 12.5mm width and a 50mm length in gage section were fabricated in accordance with ASTM E8M-01, and oriented in the longitudinal (rolling) direction. All tests were performed at a constant crosshead rate of 0.5mm/min in displacement control. Three identical specimens were tested at the same test temperature and the results are averaged.

3. Results and Discussion

3.1 Stress-Strain behavior

Figure 2 shows the effects of temperature on the stress-strain behavior of the STS 304 stainless steel plate. As the temperature decreases, the stress-strain curves change from a smooth parabolic to sigmoidal behavior. The observed variation in the stress-strain curve shape was consistent with that observed by previous researchers for Fe-18Cr-8Ni alloys [1] and AISI Type 304 stainless steel [2].

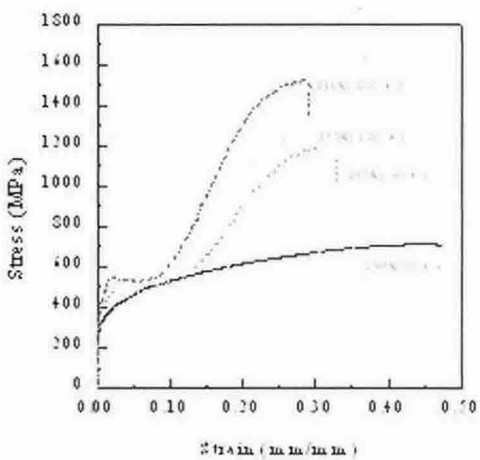


Figure 2. Stress-Strain Curves.

The temperature dependence of tensile strength, 0.2% yield strength and total elongation is shown in Figure 3. The tensile strength at 111K is about twice as high as that at 293K, and the 0.2% yield strength does not change noticeably as the temperature decreases. The total elongation, which is commonly used as a measure of ductility, significantly decreases at 193K by nearly 50% of that at 293K, and then it decreases slightly at 193K to 111K. Figure 4 shows typical SEM fractographs of the fracture surface of tensile specimens. This figure indicates that fracture surfaces for both the specimens fractured at 293K and 111K are dominated by dimples produced by microvoid coalescence, and the dimple size is slightly smaller for the specimen fractured at 111K.

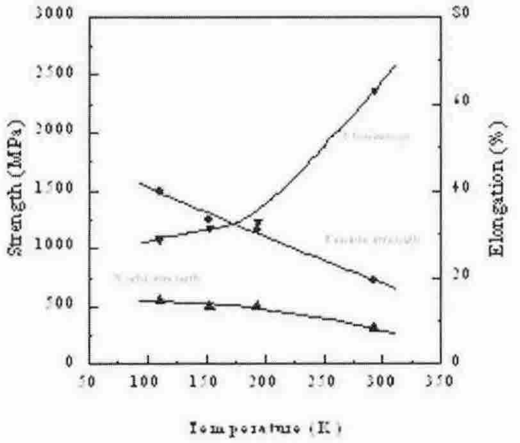
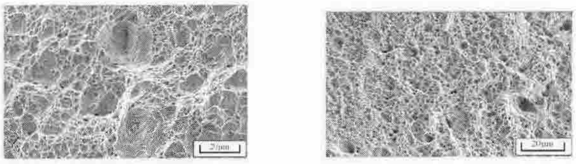


Figure 3. Temperature Dependence of Yield Strength, Tensile Strength and Total Elongation



(a) 293K (b) 111K

Figure 4. Fracture Surfaces of Tensile Specimens Tested at 293K and 111K.

3.3 Strain Hardening

Figure 5 shows a log-log plot of true stress versus true plastic strain. The strain hardening exponent (n) is 0.33 at room temperature (293K), while n is relatively high ranging from 1.24 to 1.36 over the low temperature range of 193K to 111K where significant strain-induced martensitic transformation occurs.

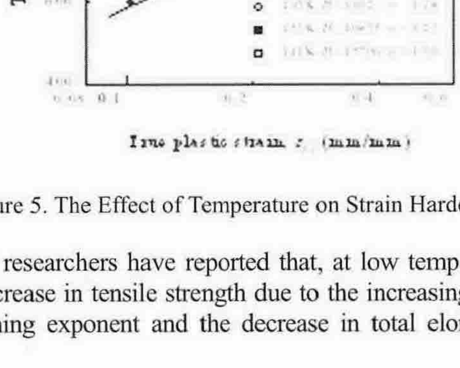


Figure 5. The Effect of Temperature on Strain Hardening

Many researchers have reported that, at low temperature, the increase in tensile strength due to the increasing strain hardening exponent and the decrease in total elongation correlates with the strain-induced transformation of unstable austenite to martensite [1,2,3,4]. At a given strain, the extent of transformation increases with a decrease in temperature. And the strain dependence of the martensite transformation rate increases with decreasing temperature [2]. Therefore, it could be found that the decrease in elongation and the increase in tensile strength as the temperature decreases in STS 304 stainless steel reflect the increased contribution of strain-induced martensite.

4. Conclusion

The cold-worked STS 304 stainless steel plate was tested to investigate the temperature dependence of the tensile properties in the temperature range of 293K to 111K. The main conclusions drawn from the experimental data are as follows:

1. The tensile strength significantly increased with a decrease in temperature, and the 0.2% yield strength was relatively insensitive to temperature. The total elongation at 193K abruptly decreased by nearly 50% of that at 293K, and it decreased slightly at 193K to 111K.
2. The strain hardening exponents in the low temperature range were about four times as high as that at room temperature. The variations in tensile properties with temperature could be caused by the fact that the strain dependence of the martensite transformation rate increased with a decrease in temperature.

REFERENCES

[1] R. P. Reed and R. L. Tobler, Deformation of Metastable Austenitic Steels at Low Temperatures, Advances in Cryogenic Engineering and Materials, Vol. 28, pp. 49-56, 1982.

[2] G. L. Huang, D. K. Matlock and G. Krauss, Martensite Formation, Strain Rate Sensitivity and Deformation Behavior of Type 304 Stainless Steel Sheet, Metallurgical Transactions A , Vol. 20(A), pp. 1239-1246, 1989

[3] C. J. Guntner and R. P. Reed, The Effect of Experimental Variables Including the Martensitic Transformation on the Low-Temperature Mechanical Properties of Austenitic Stainless Steel. Transactions of the ASM, Vol. 55, pp. 399-419, 1962.

[4] R. L. Tobler and R. P. Reed, Tensile and Fracture Properties of Manganese-Modified AISI 304 Type Stainless Steel, Advances in Cryogenic Engineering and Materials, Vol. 28(6), pp. 83-92, 1982.