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Effects of Short Range Ordering on High Temperature Deformation Behavior in SS316L

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1. Introduction

It is confirmed that the ordering reaction occurs through a differential scanning calorimeter (DSC) in Alloy 600 [1, 2]. Similarly, it is understood that a short range ordering (SRO) occurs in 316L stainless steels through a DSC analysis. The ordering reaction can be checked by DSC using an ordered and a disordered specimen. The specific heat variations with temperature are shown in Fig. 1. The exothermic reaction appears at 500-550°C and at 470-520°C in SA and 40% cold rolled specimen, respectively, whereas the ordering treated SS316L shows an endothermic reaction at 500-600°C. The exothermic and endothermic reactions are due to the formation of SRO and the disordering of SRO respectively. This fact is consistent with the previous investigation in Ni-Cr-Fe alloys [3, 4].

It is understood that the SRO causes a lattice variation in various Ni-Cr-Fe alloys. It can be inferred that the lattice variation due to the SRO comes from the variation of atomistic arrangement. Thus, the SRO induces variation of slip planes and varies slip process during deformation in 316L stainless steel

In this study, the high temperature mechanical tests were carried out up to 750℃. The reason why the formation of serration and the plateau of UTS in 316L stainless steel is interpreted by the effect of ordering reaction.

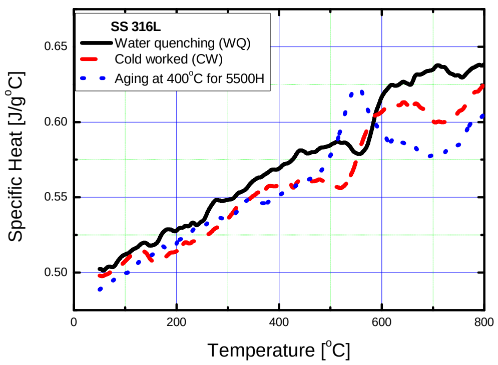

Fig. 1. The specific heat variation (Cp) in SA (solution anneal), 40% cold rolled, and ordering treated SS316L stainless steels.

2. Experimental

A round type tensile specimen with a thread in the grip region was machined using a 316L plate with 50 mm thickness. The chemical composition of 316L stainless steel is shown in Table 1. Tensile tests were carried out at RT to 750℃. The strain rate is 3.3x10^{-5}/s. The uniform and total elongations are determined using stain-stress curves.

The deformed regions of the tensile specimens at various temperatures have been examined by a transmission electron microscope (TEM) and neutron diffraction. The lattice variation during tensile tests was calculated by the center gravity of the diffraction peaks using a relationship of ($d_{deformed}$ - $d_{as\text{-}received}$)/$d_{as\text{-}received}$. The full width half maximum (FWHM) variation is analyzed similarly.

Table 1. Chemical composition of SS316L (wt. %).

elements	Cr	Ni	Mo	Mn	Si	C
Composition [%]	17.29	12.19	2.06	1.19	0.69	0.008
Spec.[%]	16.0~ 18.0	12.0~ 15.0	2.0~ 3.0	2.0	1.0	0.03

3. Results and Discussions

Fig. 2 shows strain-stress curves with temperature in 316L stainless steel. The results show that the elongation decreases with temperature until 300℃. The serration is observed at 283-580℃. This is relatively wide range.

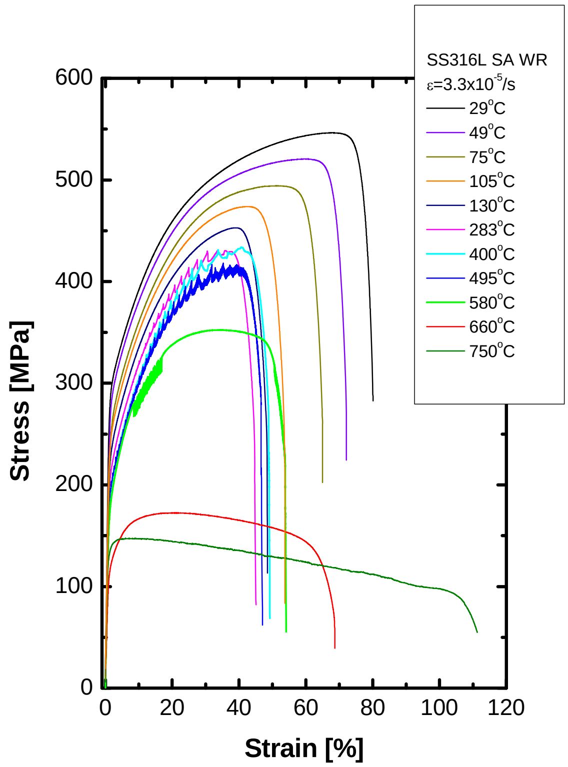

Fig. 2. Comparisons of stain-stress curve in 316L stainless steel at strain rate of 3.3x10^{-5}/s.

The results of the yield, tensile, elongation, and uniform elongation are compared with the trend of specific heat in Fig. 3. The yield strength decreases with temperature monotonically. However, the UTS decreases with temperature fast below 150℃, and maintains a similar value between 150 and 500℃, and decreases rapidly again above 500℃. An elongation minimum appeared at around 300℃. The elongation increases fast above 600℃. The uniform elongation behaves reversely above 600℃. It is possible to understand that the ordering has a significant influence to the mechanical behavior of 316L stainless steel.

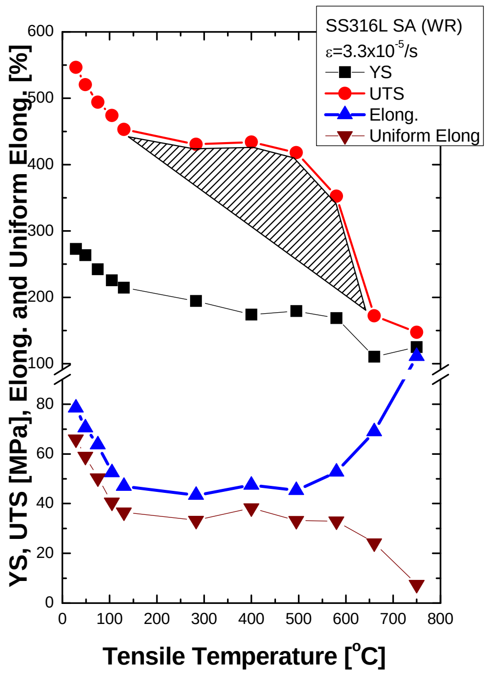

Fig. 3. Comparisons of mechanical properties with temperature in 316L stainless steel at strain rate of 3.3x10^{-5}/s.

The neutron diffraction results show anisotropic lattice contraction with tensile temperature. The d_{311} and d_{222} variation shows little contraction at RT, whereas a maximum contraction occurs at 500℃. The lattice contraction is an evidence of ordering. The ordering occurs at 280-580℃ during tensile deformation. This is called a strain induced ordering (SIO). The FWHM plateau appears similarly in same temperature region.

The plateau of UTS appears in the exothermic reaction region, as shown in Fig. 1. The deformation at 280-580℃ causes an ordering dynamically. The occurrence of serration is due to a repetition of formation of dislocation pile-up and disappearance of dislocation pile-up during deformation at 280-580℃. This behavior is very similar to that of Alloy 600 and is interpreted by SIO properly [5].

The various properties are compared together in Fig. 4. The temperature region of exothermic reaction of specific heat (Cp), UTS plateau, elongations, occurrence of serration, lattice contraction, and plateau of FWHM are identical to the box of 170-600℃. Thus, it can be understood that all these variation is due to the ordering.

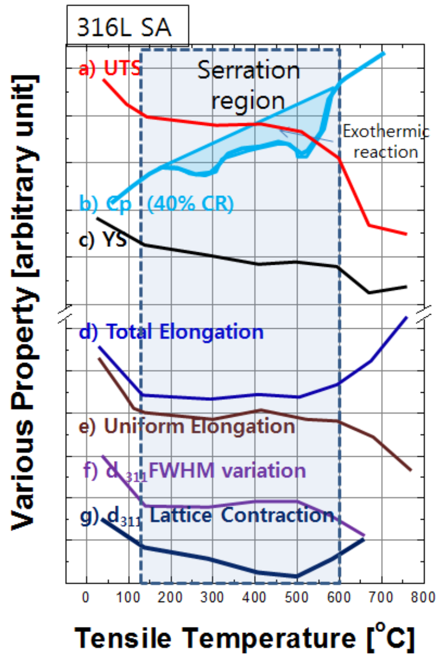

Fig. 4. Comparisons of various properties with temp.

4. Conclusions

1. A 316L stainless steel exhibits an ordering reaction below 550℃.
2. The SRO causes a lattice contraction and a plateau of FWHM during tensile deformation at 170-600 ℃ in 316L stainless steel.
3. The strain induced ordering causes a serration and UTS plateau at 170-600℃ in 316L stainless steel.

Acknowledgements

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REFERENCES

[1] S. Kim, I. Kuk, and J. Kim, Materials Science and Engineering **A279**, 142, 2000.
[2] S. Kim, J. Kim, and H. Kim, Journal of Korean Metal and Materials, **44**, 473, 2006.
[3] A. Marucco, Mater. Sci. Eng. **A189**, 267, 1994.
[4] A. Marucco, Mater. Sci. Eng. **A194**, 225, 1995.
[5] S. Kim, J. Kim, and H. Kim, Journal of Korean Metal and Materials, **50**, 703, 2012.