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Dimensional Change due to Short Range Ordering in 316L Stainless Steel

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1. Introduction

It is confirmed that the ordering reaction occurs in Alloy 600 through a differential scanning calorimeter (DSC) [1, 2]. On the other hand, it is rarely understood that a short range ordering (SRO) occurs in almost all stainless steels. The ordering can be checked by differential scanning calorimeter (DSC) using specimens with an ordered and a disordered state. An evidence for the ordering reaction in SS316L is 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.

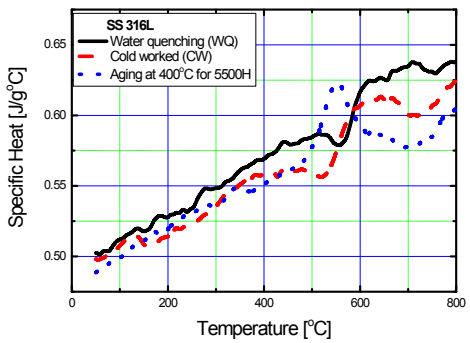

Fig. 1. The specific heat variation (Cp) in SA (solution anneal), 40% cold rolled, and ordering treated SS316L stainless steels.

It is known that the SRO causes a lattice variation [3, 4]. The SRO formation causes a lattice contraction and the disordering of SRO induces a lattice expansion. It is expected that this lattice variation varies the dimensional change in the structures made of SS316L.

It is worthy to confirm whether the dimensional change occurs due to the ordering and disordering in the SS316L stainless steel.

2. Experimental

Solution annealed and 40% cold rolled 316L stainless steel (40% CR SS316L) plates were used. The chemical composition is shown in Table 1. The dimensional change is examined by a high temperature neutron diffraction (high resolution neutron diffraction, HRPD) and dilatometer. The specimen is rotated during neutron diffraction measurements. It is possible to measure the anisotropic lattice variation, since the HRPD provides an individual peak variation. The in-situ high temperature neutron measurement was carried out up to 900°C. The dilatometer measurement was done up to 1000°C.

The diffraction peaks shift to lower angle with increasing temperature due to thermal expansion. The lattice expansion is calculated by a relationship of $(d_{\text{high temperature}} - d_{\text{as-received}})/d_{\text{as-received}}$. It was possible to determine the thermal expansion coefficient according to crystallographic planes using neutron diffraction, whereas the dilatometer measurement provides a bulk thermal expansion behavior.

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 the d_{111} and d_{200} lattice variation with temperature during heating and cooling processes in 40% cold rolled 316L. The thermal expansion curves show a difference between heating and cooling. The thermal expansion during heating is smaller at below 600°C. This is due to the SRO formation during heating. The dimensional difference in d_{111} is shown in Table 2.

The initial SS316L is a disordered state, since the cold rolling produces and increases the number of disordering bonds. These bonds tend to form SRO bonds when the thermal energy is supplied during heating. This means that the dimension of structure made of SS316L changes and the structure is changing after thermal cycle to disordering temperature.

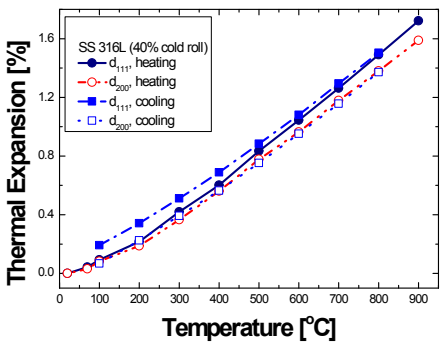

Fig. 2. Comparisons of d_{111} and d_{200} variation during heating and cooling processes in 40% CR SS 316L.

Table. 2. Dimensional difference measured by HRPD.

Temperature [°C]	Difference in d_{111} [%]	Difference in d_{200} [%]
100	0.099	-0.016
200	0.128	0.038
300	0.091	0.027
400	0.087	0.003
500	0.049	-0.025
600	0.037	-0.012
700	0.031	-0.022
800	0.014	-0.008

This ordering causes a lattice contraction, whereas the thermal expansion causes a lattice expansion. These two components are controversial and act oppositely. This is why the thermal expansion appears smaller during heating.

The disordering reaction occurs at above 600°C. However, the ordering occurs during cooling at below 500°C. However, the kinetics of ordering during heating is much larger than that of cooling, since the cold work provides a larger driving force for SRO formation. The lattice expansion appeared to be anisotropic according to the crystallographic planes, although all data is not shown.

Fig. 3 shows the bulk dimension variation with temperature during heating and cooling processes in 40% cold rolled 316L in dilatometer. The thermal expansion shows a difference between heating and cooling even in the dilatometer examination, again. This confirms that the dimension of SS316L changes with heating and cooling.

Fig. 4 shows the bulk dimension variation with temperature during heating and cooling processes in SA SS 316L in dilatometer test.

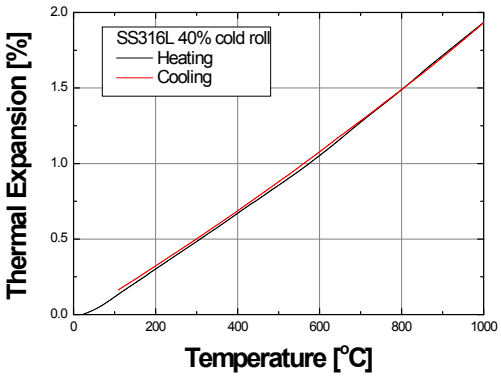

Fig. 3. Comparisons of bulk thermal expansion measured by dilatometer during heating and cooling processes in 40% CR SS316L.

The neutron diffraction shows an anisotropic thermal expansion in Fig. 2, and the dilatometer examination shows a hysteresis in thermal expansion regardless of its prior treatment conditions, in Figs 3 and 4. The normal treatment condition of SA SS316L is water quenching after SA in order to prevent carbide precipitation during cooling. This cooling process causes a disordered state, and any cold work process induces a disordering.

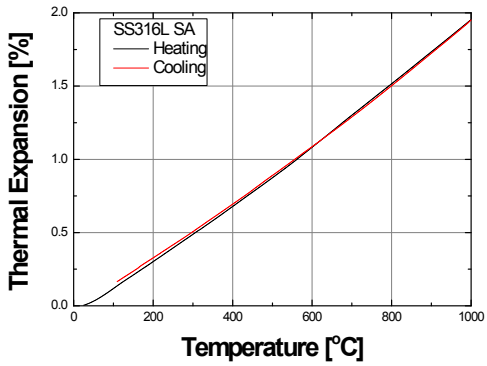

Fig. 4. Comparisons of bulk thermal expansion measured by dilatometer during heating and cooling processes in SA SS316L.

The ordered state is more stable than the disordered state below critical temperature (Tc) for ordering, thermodynamically. The disordered state tends to change to an ordered one when the thermal energy is supplied. This causes a lattice contraction and a structural change during service in nuclear reaction condition.

It is thought that the SRO formation is general phenomenon in Fe-Cr-Ni ternary alloys. Therefore, it is expected that these alloys exhibiting SRO will show a dimensional change. The ordering reaction is an unavoidable process in nuclear reactor operating condition. Therefore, the effect of lattice contraction due to ordering reaction should be considered, since the ordering reaction is a spontaneous and an unavoidable phenomenon below 500℃.

4. Conclusions

1. Both SA and 40% cold rolled 316L stainless steel shows a dimensional expansion after thermal cycle above 900℃ in 316L stainless steel.
2. The dimensional change between heating and cooling process occurs regardless of prior thermo-mechanical treatment in 316L stainless steel.
3. The origin of the dimensional change is due to the lattice contraction by SRO formation during heating and cooling processes.

Acknowledgements

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