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Anisotropic lattice variation of alloy 600 by an aging at 474℃

SungSoo Kim*, H. Kim, D. Kim, S. Hwang, Y. Lim, and J. Kim

Nuclear Materials Technology Dept.
Korea Atomic Energy Research Institute,
P. O. Box 105, Yusung-Ku, Taejon 305-353, Korea

1. Introduction

Recently it has been reported that the exothermic reaction between 430~500°C in the water quenched specimen of alloy 600 originates from a formation of the short range order (SRO) through DSC (differential scanning calorimetry) study [1].

Marucco [2] has established the existence of an order–disorder transformation in Ni–Cr base alloys from the study of Ni_2Cr, Ni_3Cr, and Ni–Cr–Fe. Marucco concluded that the degree of order primarily depends on the Cr content and that the ordering kinetics become slower when the Ni:Cr atomic ratio departs from that of the composition of Ni_2Cr. The presence of Fe has a strong delaying effect on the ordering kinetics, even in small quantities and other alloying elements can also influence the transformation.

Marucco and Nath [3] have concluded that most commercial Ni–Cr based alloys including alloy 600 have an ordering reaction based on Ni_2Cr at below 550°C. Ordering is known to have the following consequences: (i) dimensional instability due to lattice parameter changes; (ii) electrical and thermal characteristics; (iii) changes in mechanical properties due to the pile-ups of dislocations; and (iv) phenomenon of negative creep or material contraction under a load.

The effects of a formation of SRO on alloy 600 have not been identified as yet. However, it is reported that an aging treatment under about 500 °C results in a lattice contraction after an aging for 40,000 hrs. The magnitude of contraction by an aging for 40,000 hrs was 10^{-4} for Ni_3Cr. It is reasonable that this lattice contraction is due to the formation of SRO or an atomic clustering.

In this study, in order to understand the aging effects for long time at 474 °C in alloy 600, neutron diffraction studies were carried out from room temperature (RT) to 650 °C. The ordering effect on the interplanar spacing and thermal expansion coefficients were reported.

2. Experimental

A mill-annealed alloy 600 rod with a diameter of 10 mm was used. A 50 mm long rod was water-quenched (WQ) from 1095°C to fully resolve the carbide to carbon in a solution. Then, the WQ rod was aged for 80,000 hrs at 474 °C in air.

This rod was examined by neutron diffraction from RT to 650 °C under a vacuum. The wavelength of the neutron beam was 1.837225 ±0.000034 A. The axial direction of the rod was aligned vertically and it was rotated with respect to the center line of the rod during a measurement.

This temperature variation covers an ordered state below 500 °C and a disordered state during a cooling, since a disordering reaction in alloy 600 occurs at about 500~580 °C.

High temperature measurements were carried at 300, 450, 500, 550, 600, 650 °C during a heating and a cooling. Diffraction results before 500 °C show the aged state, and those after the 600 °C measurement show the disordered state.

The lattice contraction was calculated by using the difference in the interplanar spacing between the ordered state by an aging and the disordered state after the measurement at above 600 °C. Thermal expansion coefficients were calculated by using interplanar spacing between RT and 300 °C both for a heating and a cooling.

3. Results and Discussion

Fig. 1 shows the shifts of the (222) and (311) peaks by a heating from RT to 650 °C and the disordering effects. The peak intensities decrease with the temperature, because the thermal vibration increases with the temperature.

Both the (222) and (311) peaks at RT show the difference between the ordered state and the disordered state after the 650 °C measurements. Only a slight peak shift was observed. This means that the difference in the interplanar spacing is very small, and this shift was identified to be a lattice contraction. This is a level of 1.5 x 10^{-4} which is a similar to ae lattice contraction from the literature [3].

Table 1 shows the anisotropic lattice contraction between the ordered state and the disordered state, because the ordered state after an aging treatment would be changed to a disordered state due to a heating above a critical temperature, Tc.

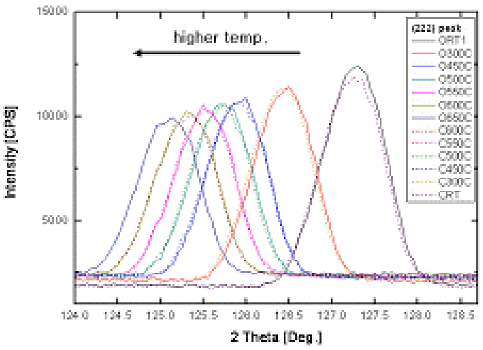
The most interesting point in Table 1 is that the lattice expansion occurs due to a disordering and the magnitude is different from one plane to another plane.

This means that an ordering by an aging contracts the lattice and a disordering expands the lattice.

Thermal expansion coefficient from RT to 300 °C shows an anisotropy. The difference of the thermal expansion coefficient between different planes in the aged state is slightly larger, whereas there is little difference in the disordered state after the measurement at 650 °C. This means that an ordering intensify the anisotropy, even though the magnitude is small.

The aging treatment below Tc for the ordering induces an atomic rearrangement, so called an ordering. The lattice contraction occurs during an ordering and a lattice expansion occurs after a disordering. It is understood that the formation of SRO or a local atomic order may change the physical properties, unexpectedly.

a) (222) peaks



b) (311) peaks

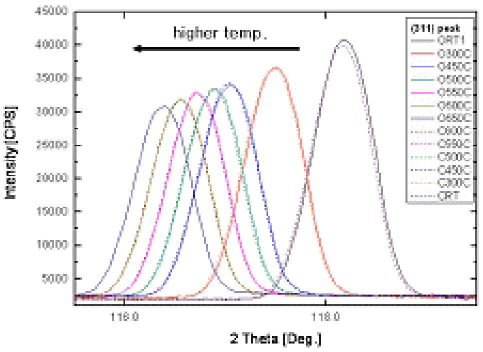


Fig. 1. (222) and (311) diffraction peaks of alloy 600 with temperature variations.

4. Summary

It is confirmed that the lattice contraction occurs by a long period aging in alloy 600 below Tc at about 500 °C. This behavior is consistent with the reported results for Ni_3Cr. The magnitude of the lattice contraction is an order of 10^{-4}. The ordering due to a formation of SRO and/or a local atomic clustering induces an anisotropic thermal expansion of the lattice. The contraction of the lattice and the anisotropic thermal expansion behavior by an ordering was relaxed by a heat treatment or a high temperature measurement above Tc, e.g. 650 °C.

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Table 1. Lattice strains for various planes between the ordered state after aging at 474 °C and disordered state after high temperature measurement at 650 °C.

planes	Strain [%]
200	0.07184417
220	0.04055602
311	0.02612348
222	0.02162181

Table 2. Thermal expansion coefficient for various planes during heating and cooling from RT and to 300 °C (between the ordered state after aging at 474 °C and the disordered state after high temperature measurement at 650 °C).

planes	Ordered state during heating from RT to 300 °C, aged for 80,000 hrs at 474 °C [°C^{-1}]	Disordered state during cooling from 300°C to RT after measurement at 650 °C [°C^{-1}]
200	1.55E-05	1.34E-05
220	1.31E-05	1.36E-05
311	1.32E-05	1.37E-05
222	1.25E-05	1.38E-05