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Effect of Short Range Ordering on Lattice Variation in Garter Spring (X-750) in CANDU

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1. Introduction

The primary side of the CANDU reactor consists of a feeder pipe and a pressure tube. A calandria tube surrounds the pressure tube. The space between these two sections forms the annulus gas system. A dry carbon dioxide flows to detect the leak of coolant from the pressure tube [1, 2].

If the pressure tube sags under its own weight and the weight of the nuclear fuel, the two tubes can come into contact. In order to prevent this contact, a garter spring is installed on the outside of the pressure tube. The garter spring is made of X-750, a Ni-base alloy. It is reported that the garter spring has shown intergranular (IG) cracking. It has been suggested that this cause is due to He bubble formed by fast neutron irradiation [3].

A primary water stress corrosion cracking (PWSCC) based on ordering reaction has been proposed [4]. This explains PWSCC of Alloy 600 without corrosion. The lattice contraction provides an additional stress by ordering reaction. This concepts can be applied the IG cracking in X-750.

Whether the short-range ordering (SRO) phenomenon in X-750 occurs and how it influences on the lattice variation are investigated in this study.

2. Experimental

Table 1 shows the chemical composition of the X-750 material used in this study. The rod-shaped X-750 was hot rolled to form a plate. This material was water quenched (WQ) and furnace cooled (FC) at 1100°C. The 20% cold rolled material (CR)l has a condition of air cooled after hot rolled.

The WQ, FC, CR materials were subjected to ordering treatment at 475 for 4, 24, 100, 500, and 2,180 hours, and then observed the lattice change with the ordering time using Cu Ka XRD.

DSC analysis was applied for WQ, FC, CR, aged at 475°C for 2,180 hours. The activation energy (Q) for the ordering reaction was determined using the relationship between heating rate and peak temperature [5, 6].

Table 1. Chemical composition of X-750.

	Ni	Cr	Fe	Ti	Al	Nb
wt%	73.1	15.3	8.0	2.5	0.64	0.73

3. Results and Discussions

Fig. 1 shows the specific heat variation with temperature of X-750 materials treated in various conditions. It could be confirmed that X-750 which was cold worked or water cooled showed exothermic reaction. Water-cooled X-750 exhibits exothermic reactions at about 600°C and 700°C. On the other hand, the cold rolled materials show exothermic reactions at 150, 300, 450 and 680°C.

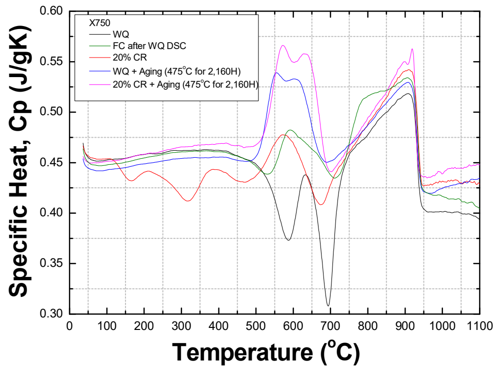

Fig. 1. Specific heat (Cp) variation of X-750 in various conditions.

This is a direct evidence of SRO reaction in X-750. This exothermic reaction is a result of exothermic reaction with the reduction of entropy remaining in the water cooling process or cold processing. Therefore, DSC analysis showed that the X-750 SRO reaction occurs.

Table 2 shows the activation energy for the exothermic reaction that occurs in water-cooled specimens. The activation energy of the exothermic reaction at 600°C in the WQ specimen was about 303 kJ / mol. This seems to be for the diffusion of Cr at the Ni base.

Table 2. Calculation of Q for 1st peak for ordering in WQ X-750.

Heating Rate [K/min]	**Peak 1 [°C]**	**absolute [K]**	**1/T (K^{-1})**	**alpha/T2**
5	**581**	**854.15**	**0.001171**	**6.85333E-06**
10	**588.6**	**861.75**	**0.00116**	**1.3466E-05**
20	**604.1**	**877.25**	**0.00114**	**2.59886E-05**
40	**621**	**894.15**	**0.001118**	**5.0031E-05**
1100°C WQ			**Q=**	**-303 (kJ/mol)**

Fig. 2 shows the activation energy measured on water-cooled specimens. The activation energy for the 1st peak at about 600°C was -303kJ/mol and that for 2nd at about 700°C was 217kJ/mol.

Fig. Fig. 3 compares the diffraction lines of the (200) plane of the specimens which were subjected to the water-cooled specimens at 475°C for ordering treatment. The diffraction angle is higher with increasing ordering time. This means that the lattice shrinkage occurred according to the ordering process.

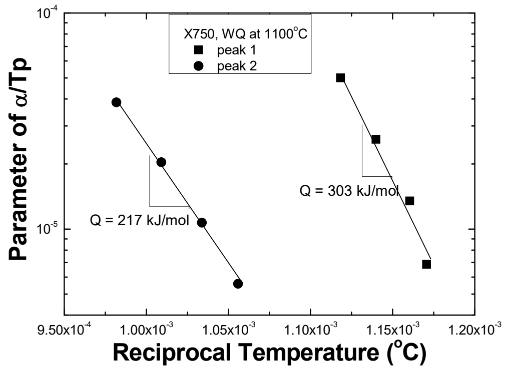

Fig. 2. The plot of Q for the 1st and 2nd peak in WQ X-750.

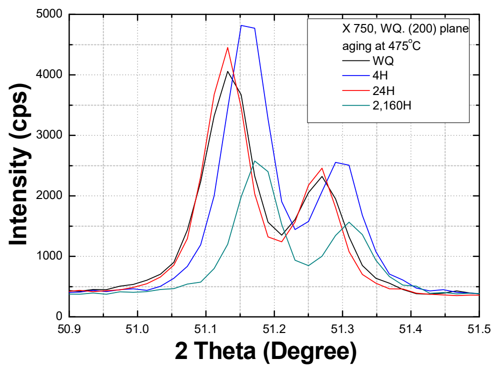

Fig. 3. Variation of diffraction angle of WQ x-750 with ordering time.

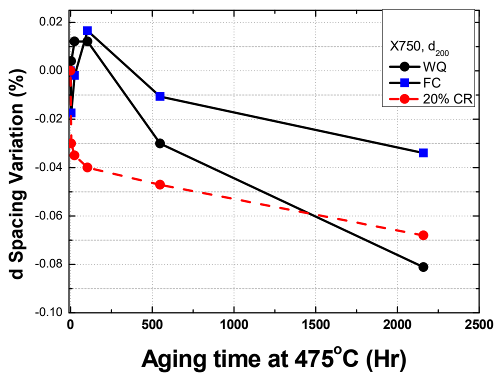

Fig. 4. Variation of yield strength at 310°C in Zr-2.5%Nb pressure tube material with aging conditions up to 3,000 hours.

Fig. 4 shows the contraction ratio of the (200) plane according to the ordering time in WQ, Fc, CR X-750. Cold worked material shows lattice contraction during ordering treatment. The magnitude of contraction reaches 0.04% within 100 hours, whereas the contraction of FC specimens is smaller than 0.04% even in the 2,180 hours treatment.

The magnitude of lattice contraction is related to the entropy remained. The WQ and CR specimen show a large exothermic reaction as shown in Fig. 1. On the other hand, the FC specimen does not show an exothermic reaction.

4. Conclusions

1. The activation energies in WQ specimen for 1st peak and 2nd peak in WQ X-750 alloy are 217 and 213 kJ/mole, respectively. The exothermic energy is 13 J/g.
2. The activation energies for disordering reaction for 1st peak and 2nd peak in WQ aged X-750 alloy are 247 and 202 kJ/mole, respectively.
3. The activation energies for disordering for 1st peak and 2nd peak in CR aged X-750 alloy are 245 and 239 kJ/mole, respectively.
4. The magnitude of lattice contraction at 475°C aging is about 0.03-0.08% according to prior condition before ordering treatment.
5. The origin of 1st peak seems to be due to SRO of Ni_2Cr and that of 2nd peak is due to SRO of NiAl and/or NiTi, respectively.

Acknowledgments

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