The Effect of Thermal Treatment on Mechanical Property of Alloy 690 Tubes

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1. Introduction

Alloy 690 is used widely as pressurized water reactors steam generator tubes. It has great mechanical strength, corrosion properties and formability at high temperature. High temperature and pressure steam (60atm, 279°C) is generated by heat exchanger when the first coolant (175atm, 310°C) meets the second (227°C) coolant at the steam generator. During the long- term operation, the steam generator tubes were degraded under this condition. Stress corrosion crack(SCC) is one of the most serious problems of alloy 690. It is closely related to the amount of Cr in the grain boundary. This paper describes the effect of heat-treatment conditions on mechanical properties and microstructure.

2. Experimental Setup

2.1 Materials

Three types of alloy 690 were used in this paper. Fig.1 shows the configuration of ring specimen. The chemical composition is given in Table I. P55 and N55 are manufactured using mother pipe with outer diameter of 55mm, and N63 are manufactured using mother pipe with outer diameter of 63mm. N63 and N55 have the same chemical composition.

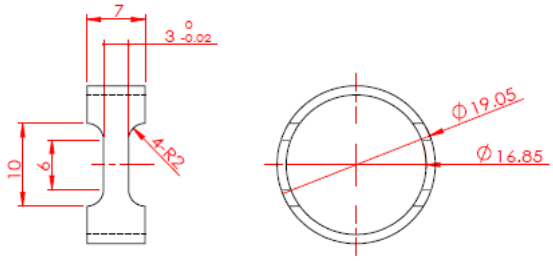


Fig. 1. Configuration of ring specimen

Table I: The Chemical Composition of Alloy 690 (wt%)

Sample I.D.	Ni	Cr	Fe	C	Si
P55	59.7	29.4	9.53	0.013	0.21
N63, 55	58.53	30.19	10.05	0.023	0.33

2.2 Microstructure analysis

Some process was done by KEPCO Nuclear Fuel before the thermal treatment. :

(1) First pilgering with mother pipe
(2) Intermediate Mill Annealing (1070 °C, 3min)
(3) Second pilgering
(4) Final Mill Annealing (1070 °C, 3min)

The Intermediate and final mill annealing was performed in hydrogen atmosphere to remove oxygen.

The thermal treatment applied for 12 hours at 705, 716, 727, 738, and 749°C in the vacuum furnace. The more Cr carbides were precipitated at the grain boundaries at higher temperature. It was reported that Cr carbides have an effect on the IGSCC and tensile strength.

In order to observe the Cr carbides in the grain boundary, cross section of the tube was polished with SiC paper. After that, it was polished down to 0.25um by using diamond paste. To observe the grain boundaries and Cr carbides, the alloy 690 was etched in 1~2% bromine-methanol solution and cleaned in methanol to 3min for 3 times. Afterwards, the cut sections were examined by an optical microscopy to observe Cr carbides.

2.3 Tensile test

Mechanical testing machine (Instron 3366) was employed to measure Ultimate Tensile Strength(UTS) and Elongation(EL). Fig. 2 shows tensile test jig. The tensile tests were performed at room temperature and testing at a strain rate of 0.08 min^{-1}.

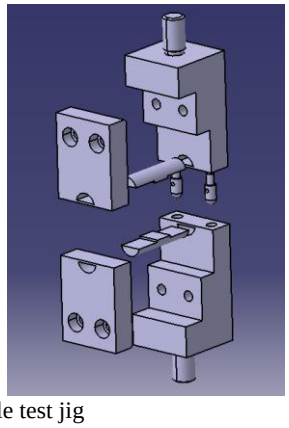
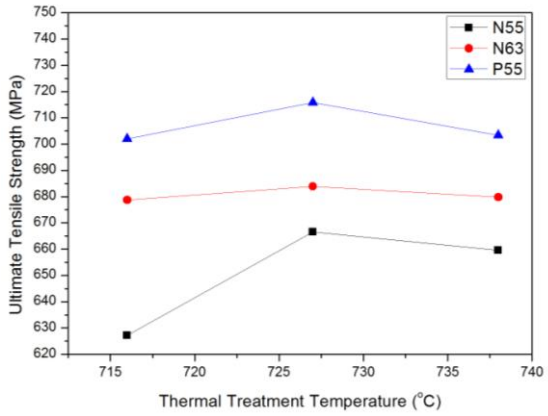


Fig. 2. Tensile test jig

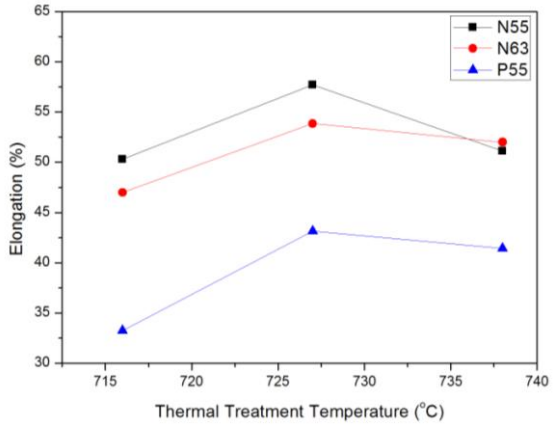
3. Results and Discussion

3.1 Effect of thermal treatment on mechanical properties

Fig 3(a) and (b) show the UTS, EL graphs of the alloy 690 specimens from the N63, 55 and P55 in the thermal treatment at 716°C, 727°C, 738°C. The thermal treatment at 727°C had the highest UTS and EL value. In addition, P55 specimens were slightly brittle than N63, 55.



(a) Ultimate tensile strength



(b) Elongation

Fig. 3. The ultimate tensile strength and elongation of specimens thermal treated at the temperature of 716°C, 727°C, 738°C.

An increase in both UTS and EL may be explained by dislocation and Cr carbides. Dislocation made from second pilgering process may be disappeared during the thermal treatment because of recovery. The thermal treated specimen under higher temperature may have less dislocation. However, the thermal treated specimen under 738°C has lower elongation than the thermal treated specimen under 727 °C because more Cr carbides were precipitated at 738 °C, as shown in Fig. 4 and 5. In addition, the thermal treated specimen under 727 °C has higher UTS than the thermal treated specimen under 738 °C because the thermal treated specimen under 727 °C has more dislocation and less Cr carbides than the thermal treated specimen under 738 °C

3.2 Effect of the thermal treatment on microstructure

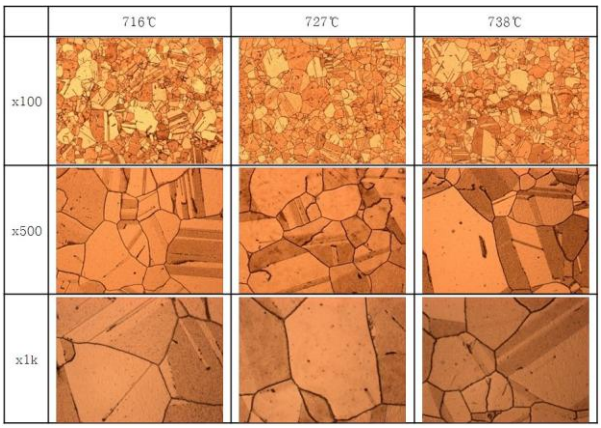


Fig. 4. Optical micrographs of specimens after the thermal treatment at the temperature of 716°C, 727°C, 738°C.

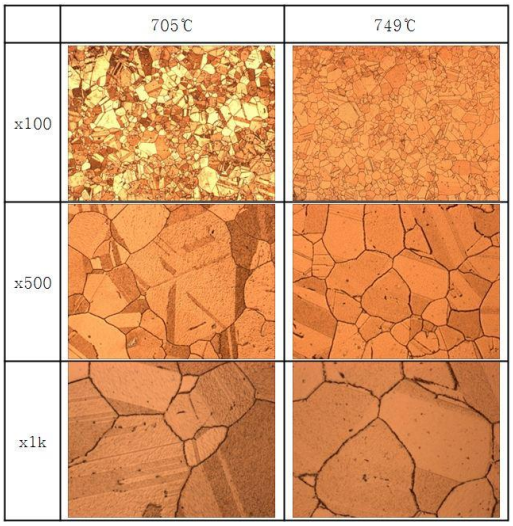


Fig. 5. Optical micrographs of specimens thermal treated at 705°C, 749°C.

The optical micrographs for the thermal treated at 705°C, 716°C, 727°C, 738°C, 749°C are shown in Fig. 4 and 5. As mentioned above, Cr carbides at grain boundaries were increased at a higher thermal treatment temperature. The grain size of ally 690 was ASTM No. 7.

4. Conclusions

The effect of thermal treatment on mechanical property of alloy 690 was investigated using tube specimens thermal treated in vacuum chamber at 705°C, 716°C, 727°C, 738°C, 749°C for 12 hours. The ultimate tensile strength and elongation was the highest at 727°C. Both the UTS and EL increased, it may be caused by dislocation and Cr carbides. And Cr carbides at grain

boundary increased at a higher thermal treatment temperature.

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