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Effects of Heat Treatment on Microstructure and Mechanical Properties of Alloy 690

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1. Introduction

Since Alloy 690 is excellent in its stability at high temperature, formability, corrosion resistance and high temperature mechanical characteristics as austenitic solid solution alloy, whose main alloy element is Ni-Cr-Fe, it is mostly used as structure materials for the engines of aircrafts and chemical containers. Also, It is especially used as materials for steam generator heat pipe of nuclear plant due to its excellent corrosion resistance. Among steam generator components, heat pipe is the part where the high temperature and pressure steam (60atm, 279^{o}C) is generated by heat exchange caused when the first coolant, high temperature and high pressure (175atm, 310^{o}C), and the second coolant with low temperature (227^{o}C) meet. Since the heat pipe of steam generator is where the primary system and the secondary system directly meets, damage to the heat pipe can enormously affect the stability of nuclear plant. Therefore, the heat pipe material should be greatly corrosion resistant and its mechanical characteristics at room temperature and high temperature should be excellent. However, as a result of long-term operation of nuclear plant which creates Grain Boundary Cr carbide discontinuously, defects, such as stress corrosion crack (SCC) and intergranular stress corrosion crack (IGSCC), have been reported [1-2]. This paper reviewed the effect of heat-treatment condition on a property of matter and micro-structure by analyzing micro-structure through optical and scanning electron microscope.

2. Experimental

2.1 Specimen Preparation

The specimens used in the experiment consist of alloy 690 tube type, which is used for nuclear power plant’s U tube steam generator. We used Alloy 690 tube for steam generation manufactured by Doosan Heavy Industries & Construction Co., Ltd. in this experiment. The diameter is 19mm and thickness is 0.98mm. We used specimen that was cut by wire in some mm of gage length. Table 1 is Chemical Compositions of Alloy 690.

Table I: Chemical Compositions of Alloy 690 (wt%)

Fe	Ni	Cr	C	Mn	Si	Co	Ti
10.60	59.0	29.50	0.02	0.30	0.24	0.01	0.25

2.2 Experiment Procedure

By using Rapid Thermal Processing System (LABSYS RTP-1200, NEXTRON), we water quenched the specimen after proceeding solution heat treatment for 20 minutes to 5 specimen for every 100^{o}C from 800^{o}C to 1150^{o}C in order to find the solubility of carbide depending on the temperature under Ar gas condition. The purpose of it was to find melting temperature of intergranular Cr carbide to Ni alloy. To find distribution of carbide, after 20 minutes of solution heat treatment from 1150^{o}C, we controlled the cooling rate at 1^{o}C /min, 5^{o}C /min, 10^{o}C /min to 800^{o}C which is the medium temperature. Then, we took 100 minutes for aging treatment from 800^{o}C and proceeded water quenching.

In order to observe the distribution and shape of grain boundary and carbide of Alloy 690, we polished heat-treated cut surface of Alloy 690 by using SiC cloth pad. Afterwards, we precision finished it to 0.25um on cloth pad. We etched it with 1~2% bromine-methanol solution (Bromine 1-2ml+methanol 98~99ml) to observe micro-structure. For activating and cleaning the surface of specimen, we put it in HCl for one minute and cleaned it with methanol. We also etched it for 1~2 seconds and cleaned with methanol. Afterwards, we observed it by using Scanning Electron Microscope (SEM).

To understand the effect of creation and distribution of carbide of grain boundary under the condition of heat treatment on mechanical characteristics, we observed fracture surface with SEM after conducting tensile test at room temperature with the strain rate of 0.12mm/min by using Instron model 3366.

3. Results and Discussion

Fig. 1 is a picture of micro-structure of Alloy 690 quenched after 20 minutes of solution heat treatment at the range of 800~1150^{o}C. It shows the carbides that were extracted to grain boundary gets dissolved into matrix as temperature rises, and most carbide gets dissolved at 1150^{o}C.

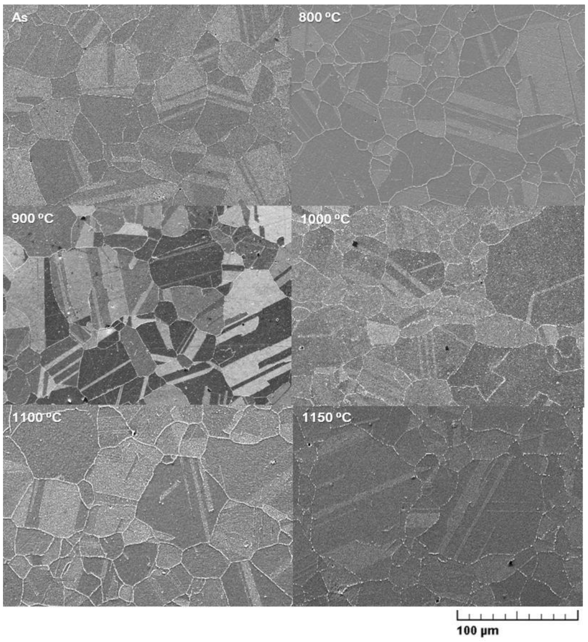

Fig. 1. SEM images of Alloy 690 quenched after 20 minutes of solution heat treatment at the range of 800~1150^{o}C

If heat-treated at certain range of temperature, we can extract carbide with specific distribution and shape to grain boundary. Fig. 2 is the picture of SEM quenched after following process: 20 minutes of solution heat treatment at 1150^{o}C, cooling to 800^{o}C, which is the medium temperature, with the cooling rate of 1^{o}C /min, 5^{o}C /min, 10^{o}C /min and 100 minutes of aging heat treatment. We could see that the grain became bigger as the cooling is slower. When cooling rate is high, the size of two alloys is approximately between 25~100um.

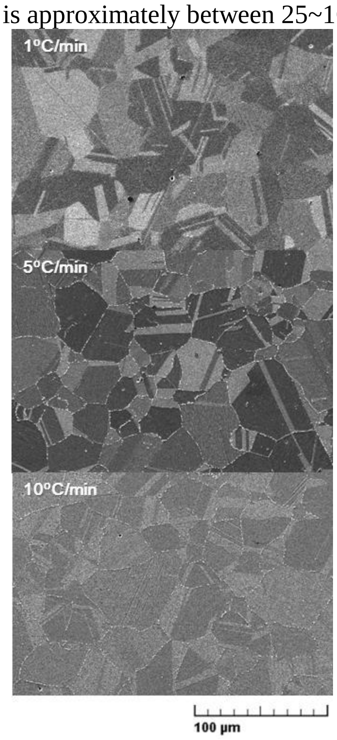

Fig. 2. SEM images of Alloy 690 quenched after 20 minutes of solution heat treatment at 1150^{o}C, cooling to 800^{o}C, which is the medium temperature, with the cooling rate of 1^{o}C /min, 5^{o}C /min, 10^{o}C /min and 100 minutes of aging heat treatment.

Fig. 3 is the result of tensile test in relation to the cooling rate. As it is fast, UTS value was high, but the effect of micro-structure, depending on cooling rate, was not large.

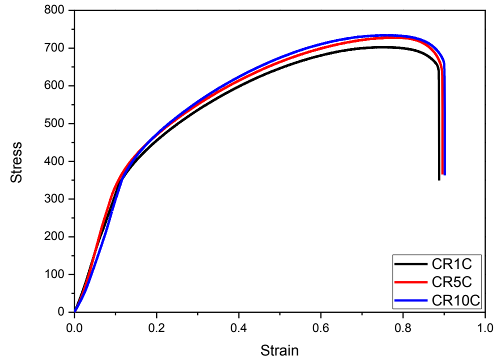

Fig. 3. Tensile test in relation to the cooling rate.

Fig. 4 is a picture of SEM fracture surface after tensile test of Alloy 690. Dimple on the fracture surface shows ductile fracture behavior. As a result of micro-structure following different cooling rate, when the cooling is slow, grain is large and depletion region was included in intergranular Cr. This characteristic shows that, in fracture appearance, ductile fracture will happen as ductility increases due to large grain and Cr depletion region.

Fig. 4. SEM images of SEM fracture surface after tensile test of Alloy 690.

3. Conclusions

We water quenched Alloy 690 after proceeding solution heat treatment for 20 minutes to 5 specimens for every 100^{o}C from 800^{o}C to 1150^{o}C. As temperature rose, solubility also rose, and solubility did not affect tensile strength much. After 20 minutes of solution heat treatment from 1150°C, we controlled the cooling rate at 1°C /min, 5°C /min, 10°C /min to 800°C which is the medium temperature, and we proceeded 100 minutes of aging treatment. As a result, we found out that as cooling rate was high, it took a shape of continuous carbide and fine grain. Meanwhile, low cooling rate resulted in discontinuous carbide shape and significant grain and Cr depletion. Also, cooling rate did not affect tensile strength much.

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