Formation of the residual stress due to the thermal treatment in Alloy 690 tubes

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1. Introduction

It is known that the steam generator tubes made of Alloy 600 have suffered primary coolant leakage accidents due to stress corrosion cracking (SCC). The one of main reasons for the susceptibility to SCC is understood to be chromium (Cr) depletion in the grain boundary. Therefore, the precipitation of carbide is controlled by heat treatment in the final manufacturing stage. In order to investigate the formation reason of residual stress in the steam generator tube systematically, the tube specimens were cooled both at inside and at outside tube after heat treatment and the residual stress formed during water quenching was measured by strain gage using sectioning method.

2. Experimental

The tube specimens for the investigation of the effects of water quenching were prepared, as Fig. 1. The inside cooling specimens were extended by welding to provide the cooling water path inside tube at 1050°C, whereas the outside cooling specimens were closed by welding to prevent quenching inside. These specimens were heated at 1050°C and maintained for 15 min, and then water quenched.

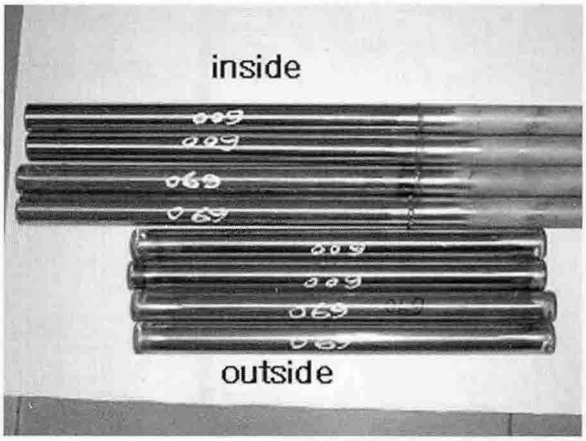

Fig.1. The tube specimens for the inside and the outside water quenching experiments.

The strain gages were attached in both inside and outside of quenched specimens. Then, the variation of strain before and after cutting and splitting was measured, and the residual stress formed during water quenching process was calculated using this change in strain.

3. Results

It is appeared that the inside quenching tube was widened after spilt, as shown in Fig. 2. This means that the residual stresses at inside and outside tube are compressive and tensile in the inside cooling tube, respectively.

On the other hand, it is appeared that the outside quenching tube was closed after spilt. This suggests that the residual stress for the outside quenching specimen shows tensile and compressive at inside and outside tube, respectively.

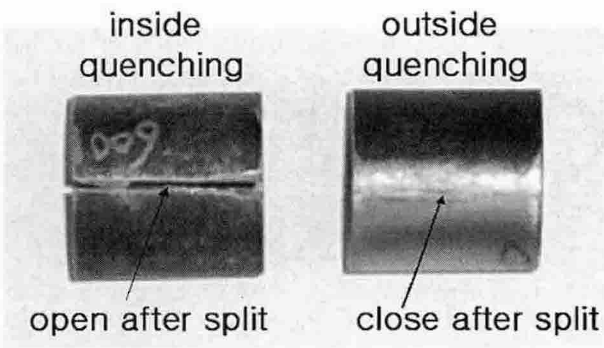

Fig. 2. The change in shape due to residual stress formed by water quenching process in the inside and in the outside quenching tube.

These are compared in Fig. 3. It is clear that the quenching side determines the sign of the residual stress. Therefore, the quenching side is changed, and then the sign of the circumferential residual stress is reversed. The maximum residual stresses in the circumferential direction appeared to be ~150MPa in the outside quenching specimen.

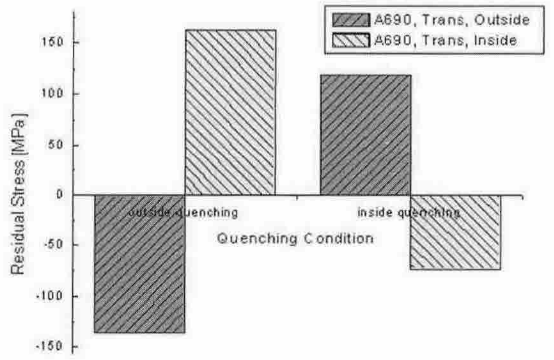

Fig. 3. The comparisons of the magnitude and sign of the hoop residual stress formed by water quenching process in the inside and the outside quenching in the Alloy 690 tubes.

In general, the steam generator tube becomes widened after splitting. This behavior is similar to the inside quenching tube, as above. This configuration of residual stress seems to be due to the fact that the cooling effect at inside tube is much larger during the water quenching after mill annealing processes, because the area for the cooling water at inside tube is much greater than that of outside tube because of their stacking geometry, as shown in Fig. 4.

One of the reasons why residual stress is formed during water quenching process seems to be related to the thermal expansion and the high concentration of the vacancy at mill annealing temperature. The tubes might be expanded by heating, however, the water quenching process would not provide the spontaneous or slow cooling period. Therefore, the quenching side should be longer in length after quenching, compared to the slowly cooling side. Thus, the cooling side should be compressed by the contraction of the reverse side, and vice versa. Why the circumferential residual stress is high seems to be originated to the curved shape in the circumferential direction, compared to the axial direction of the tube.

The magnitude of the residual stress will be varied by the cooling speed. Therefore, the furnace cooling and the air cooling may develop lesser residual stress than water quenching.

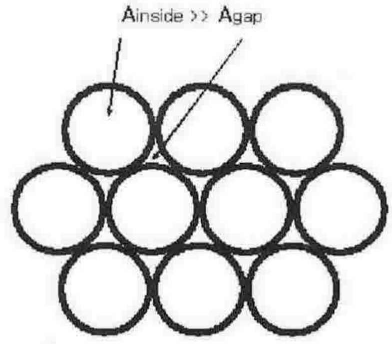

Fig. 4. The conceptual diagram showing the dominant cooling effect at inside during water quenching in the bundle stacking.

4. Conclusions

The inside quenching tube was widened after spilt, and the residual stress at inside and outside tube appeared to be compressive and tensile, respectively. The sign of the residual stress appeared reversely according to the cooling side, and the magnitude of the maximum residual stress was appeared to be ~150MPa. This means that the general behavior of the steam generator tube which becomes widened after split seems to be originated to be the residual stress formed during water quenching. The reason for this behavior seems to be due to the fact that the cooling effect at inside is more significant than that at outside because the tube are surrounded during heat treatment as a bundle.

REFERENCES

[1] Reed-Hill, Physical Metallurgy Principles, Litton Educational Publishing, 1973, 2nd ed.

[2] C. O. Rudd and M. E. Jacobs, EPRI TR-102355, 1993.