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# Microstructure Analysis on Alloy 600 Steam Generator Drain Nozzle of PWR

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## 1. Introduction

Primary water stress corrosion(PWSCC) of alloy 600 in a PWR has been a big concern. A PWSCC has been reported in a control rod drive mechanism (CRDM), pressurizer instrumentation nozzle, and a pressurizer heater sleeve. Recently some cracks and precipitation of boric acid were found in a steam generator (SG) drain nozzle in a Korea nuclear power plant. PWSCC cracks were reported first in the SG drain nozzle at Shearon Harris in 1988.[1] These drain nozzles had been roll expanded into the SG head and then seal welded on the inside surface of the head. The cracking was evaluated as a PWSCC like in the EdF pressurizer nozzles which were roll expanded into the shell.

The objective of the present work is to evaluate the microstructure of a alloy 600 sample removed from a Korean plant, and to find the causes of a PWSCC.

## 2. Experimental

Samples were decontaminated at the plant site and transferred to the metallography examination facility in KAERI. Specimens were prepared following to the procedures below.
Cutting -> Mounting ->Grinding -> Polishing
Then the specimens were etched in a bromine solution and a two step etching process (Ortho phosphoric acid then Nital) was applied. Etching in a bromine solution enables the carbide morphology to be clearly observed in a scanning electron microscopy(SEM), and an etching in ortho phosphoric acid reveals a grain boundary carbide. Nital etchant clearly showed a grain boundary of the alloy 600 specimens. All the samples were examined with SEM or with an optical microscopy.

## 3. Results and discussion

### 3.1 Grain boundary carbide

Fig 1 shows the microstructure of the alloy 600 nozzle specimen. Discreted carbides were found at the grain boundaries. Well developed grain boundary carbide as shown in this figure is considered to be resistant to a PWSCC[1,2].

As shown in Fig. 2, a dislocation in the thermally treated Alloy 600 seemed to be preferentially emitted from the grain boundary carbides, and thereby reduced the stress concentration around them which is attributed to an improvement of the IGSCC resistance of Ni base alloys, whereas, a tangled dislocation appeared near the grain boundary.

Solution treatment temperature of 980 $^{o}$C for the material having 0.04 % C is considered to be a little low to dissolve all the carbides.

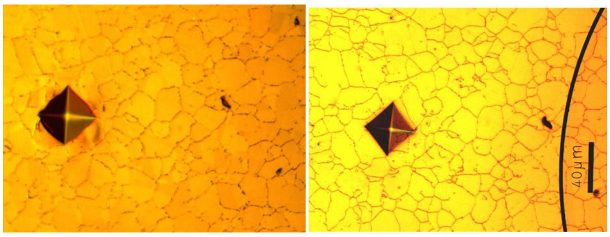


Fig. 1 (a) Microstructures of the Alloy 600 nozzle etched with phosphoric acid and Nital

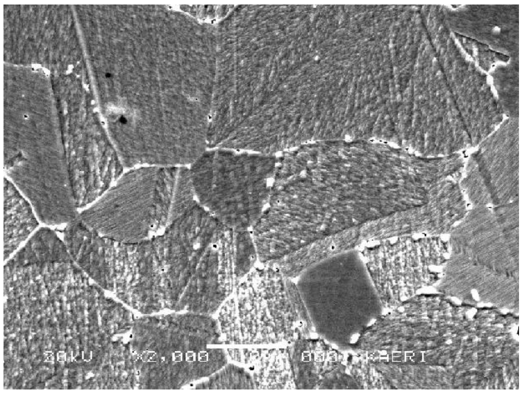

Fig. 1 (b) Microstructure of the alloy 600 nozzle specimen etched with bromine.

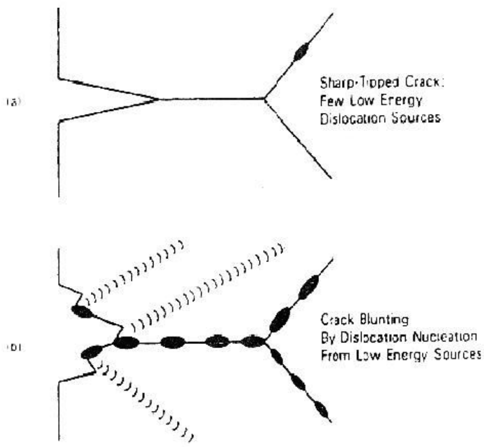


Fig. 2 Improvement of PWSCC resistance by grain boundary carbide of thermally treated alloy 600[2]

### 3.2 Grain size analysis

Based on the certificate of materials testing report(CMTR), grain size of the nozzle was 34 um in diameter as shown in Fig. 3. When we consider the grain boundary carbide structure is 'structure I", which is not susceptible to a PWSCC, the material could be considered as not susceptible to a PWSCC.

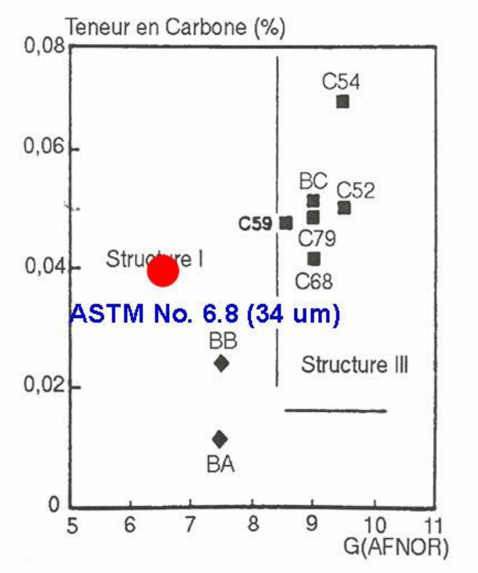


Fig. 3 Relationship between grain size and PWSCC

### 3.3 Microhardness measurement

Table 1 shows the microhardness of the test specimen. Compared with the data on CMTR, the measured hardness of 268 Hv is considered to be very high. It means that the test specimen was severely cold worked during a sample pulling out or due to other reasons.

Table 1 Correlation among hardness, cold work, and strength of alloy 600.

**Correlations between Alloy 600 Hardness. Cold work and Strength**

| Yield Strength (ksi) | Tensile strength (ksi) | Hardness Rockwell B | Hardness Vickers | Hardness Knoop | Cold Work (%) |
|---|---|---|---|---|---|
| 23 | 89 | 65 | 117 | 133 | |
| 23 | 90 | 70 | 126 | 144 | |
| 29 | 92 | 75 | 137 | 156 | |
| 34 | 95 | 80 | 151 | 173 | 3 |
| 42 | 100 | 85 | 167 | 190 | 4 |
| 52 | 105 | 90 | 188 | 215 | 8 |
| 67 | 112 | 95 | 215 | 246 | 13 |
| 90 | 125 | 100 | **248** | **283** | **20** |
| 130 | 153 | 105 | 297 | 338 | 45 |

:CMTR
:Measured at KAERI

### 4. Conclusions

(1) Based on the CMTR, the nozzle specimen was considered not to be susceptible to a PWSCC

(2) The measured hardness was considered to be very high, which means that the test specimen was severely cold worked during a sample puling out.

(3) Residual stress due to a welding process or pipe installation process could be a main cause of the PWSCC of the alloy 600 nozzle.

### REFERENCES

[1] EPRI TR-1303696, "PWSCC of Alloy 600 Materials in PWR Primary System Penetrations", July 1994

[2] S.M. Bruemmer, Corrosion, 44(11), 782 (1988)