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Considerations for Metallographic Observation of Intergranular Attack in Steam Generator Tubes

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1. Introduction

The Intergranular corrosion (IGC) of steam generator tubes can be divided into at least three forms: intergranular stress corrosion cracking (IGSCC), intergranular attack (IGA), and intergranular penetration (IGP) [1]. In the case of IGSCC, the corrosion morphology consists of single or multiple major cracks with minor to moderate amounts of branching. IGA is one of the corrosion forms in which numerous grain boundaries are uniformly attacked over the tube surface. Finally, IGP can be described as a mixture between the other two forms.

Intergranular crazing on an area with IGA/IGP can occur by the applied stress. The extent and direction of the crazing depend on the type and direction of the applied stress to the corroded tube. In addition, it has been reported that IGA/IGP cannot be observed without proper etching techniques [2].

This paper provides the metallographic characteristics of IGA in Alloy 600 steam generator tubes. The effect of applied stress on the morphology change of IGA area is discussed.

2. Experimental Methods

Steam generator tubes of high temperature mill-annealed Alloy 600 with a nominal outer diameter of 19.05mm and a nominal wall thickness of 1.07mm were used to manufacture IGA in a laboratory.

The IGA was grown in an oxidized solution of 0.1M sodium tetrathionate at room temperature. These defects were made in the inner diameter (ID) free span of clean tubes. That is, they were not interfered with either geometry changes or sludge.

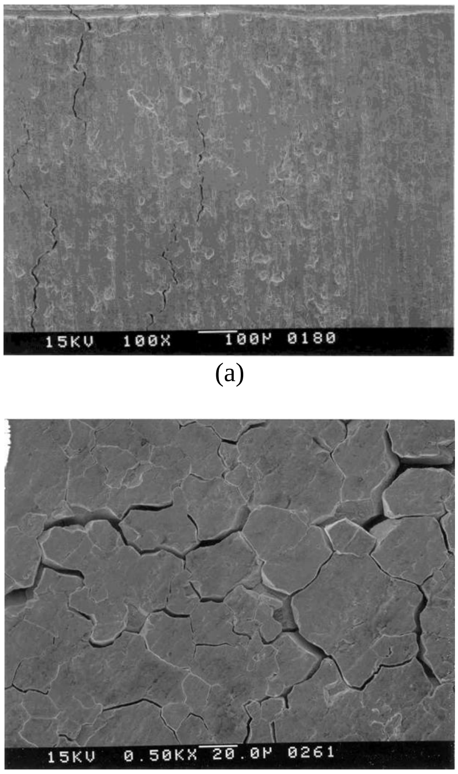
The IGA tubes were deformed by applying several types of stress, such as hoop stress, 3-axes stress, hard rolling, and indentation. The subsequent morphology changes of the IGA area were observed using scanning electron microscopy.

3. Results and Discussion

No defects were observed on the ID surface of the IGA tube without any applied stress conditions. However, some crazing did occur at the tube axial direction when applying hoop stress, as shown in Fig. 1(a). This seems to be axial cracks. Similarly, some crazing occurred at the circumferential direction of the tube by applying tension stress. When three axial stress was applied to the IGA tube, the surface was crazed into a radial crack-like morphology. Finally, the attacked grains were apparently revealed through a distorted deformation, as shown in Fig. 1(b).

The degree of IGA depends on not only the depth and width of the Cr depletion along the grain boundaries but also the corrosive environmental factors. Therefore, grain drops are not always identified on an IGA surface. Similarly, IGA can be observed on an unetched-polished cross section, while in some cases it can be viewed only using proper etching methods. Furthermore, there is another case in which IGA cannot be identified regardless of any etching techniques. In this case, the presence of IGA can be revealed by an applied deformation to the tube sample.

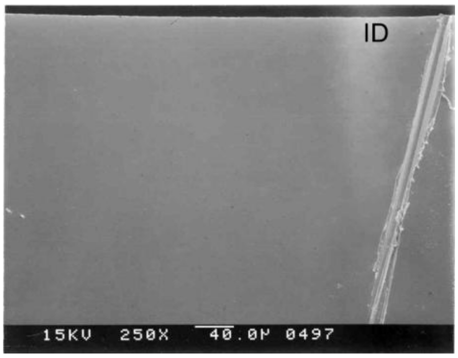
Fig. 2(a) shows a circumferential cross section of the IGA tube. There was no evidence of IGA on the as-polished metallographic sample, and even on the etched sample in a 5% nital solution. However, when the same tube was expanded by hard rolling, IGA was clearly revealed by a crazing of the IGA area, as shown in Fig. 2(b).



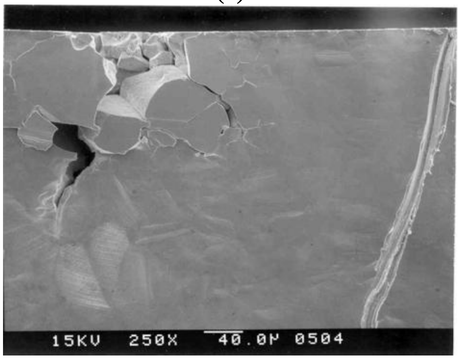
(a)

(b)

Fig. 1. Morphology change of the IGA surface by (a) hoop stress and (b) distorted deformation.

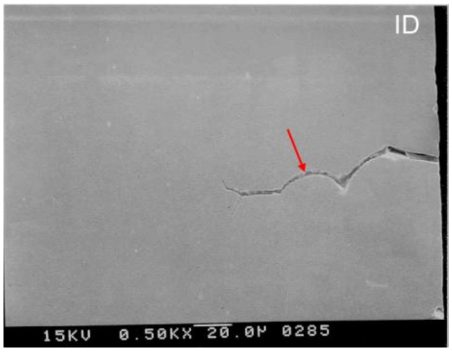


(a)

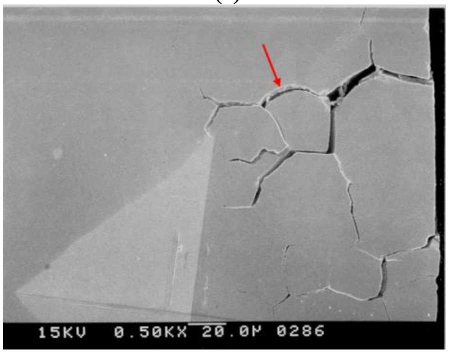


(b)

Fig. 2. Morphology change of IGA on the transverse cross section of tube by a hard roll expansion: (a) before expansion and (b) after expansion.



(a)



(b)

Fig. 3. Morphology change of IGA on the transverse cross section of tube by forcing with the Vickers indenter: (a) before indentation and (b) after indentation.

Fig 3(a) shows a circumferential cross section of an IGA tube. There is no doubt that the defect type is a single stress corrosion crack. In this case, it is reasonable to term the flaw as primary water stress corrosion cracks (PWSCC) because it was initiated from the ID surface of the tube. However when the same area was forced by a Vickers indenter at a load of 2kg, crazing along the grain boundaries occurred. This clearly indicates that this defect is IGA, not PWSCC.

4. Conclusions

In some cases, an IGA of steam generator tubes cannot be identified through etching techniques. It was found that an IGA tube was crazed along the grain boundaries into various types and directions through a deformation from applied stress. The direction and extent of the crazing depended on those of the applied stress. It was clearly shown that an IGA cannot be observed or misevaluated as an SCC. Therefore, special cautions should be paid during the destructive evaluation of the pulled-out tubes from operating steam generators.

ACKNOWLEDGMENTS

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