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A PWSCC mechanism in Alloy 600

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1. Introduction

Comprehensive facts for a primary water stress corrosion cracking (PWSCC) of Alloy 600 can be summarized as follows:
1) PWSCC occurs along a high angle grain boundary always.
2) PWSCC is reproducible by a slow strain rate test (SSRT).
3) PWSCC occurs in a cold worked region in Alloy 600 and in a dissimilar weld metal of the 82/182 type, frequently.
4) The critical stress for a PWSCC can be assumed to be over 250 MPa since a plastic deformation at a crack tip is necessary for a continued propagation of a crack.

However, the applied design stress for a component made of Alloy 600 during an operation is relatively low, compared to a critical stress for the PWSCC. Thus, it has been assumed there had been a high residual stress where a PWSCC occurred at present.

It is understood that a stress is a driving force for all stress corrosion cracking (SCC) processes. Thus, the nature of a thermal activation process in a PWSCC should be related to a stress producing phenomenon.

Therefore, the PWSCC in Alloy 600 is explained by an introduction of an additional stress source due to a contraction of a lattice by an ordering reaction in this paper. Although the PWSCC phenomenon have been explained by an action of an unknown stress before, the PWSCC phenomenon will be explained by a self induced stress source due to ordering, here.

2. Basis of a new PWSCC mechanism

1) SCC occurs due to a combined process of three elements, these are a stress, and the characteristics of a material, and the environment. It is agreed that an oxidation and/or an anodic dissolution of a material is a necessary, and not a sufficient condition for a SCC. Therefore, the stress is a driving force for SCC. Ironically, how the stress is produced and involved in the SCC process is not proposed and explained yet.
2) Because a PWSCC is a thermal activated process and a stress is a driving force for a SCC, a new explanation for a PWSCC should reflect that a thermally activated process is related to a stress and/or a stress source.
3) This effect is able to explain both an initiation and a propagation process in a SCC. It is important that how the micro cracks form in the initiation stage and how the driving force for a SCC are supplied during the propagation period.
4) This thermal activation process helps to form the micro cracks by a material itself with an atomistic scale in GB during the initiation stage.
5) The propagation stage in a SCC contains a long enough crack. The applied stress intensifies the level of a stress at a crack tip region and forms a plastic zone. Once the stress concentration phenomenon forming a plastic zone occurs, this sustains the whole SCC processes continuously or intermittently. Therefore, this thermal activation process produces an additional stress source in a plastic zone during the propagation stage.
6) It is proposed that the nature of the thermal activation process for a PWSCC in a new model is an ordering reaction forming short range order (SRO) phases in Alloy 600 and in various Ni-base alloys including weld metals.
7) The ordering reaction induces a lattice contraction; this contraction produces an additional stress locally depending on the degree of contraction and on the lattice planes. Therefore, the activation energy for a PWSCC is the same as that for an ordering reaction.
8) It is thought that a total judgment for a mutual interaction between the ordering reaction and plastic deformation based on the experimental observation is needed in order to arrive and to complete this model.

2. Results and Discussions

Whether an ordering reaction exists in Alloy 600 is proved through a differential scanning calorimetric (DSC) analysis and reported in the literatures [1, 2]. The apparent activation energy for the ordering reaction is determined to be 46 kcal/mol (190 kJ/mol). The results are summarized in Fig. 1.

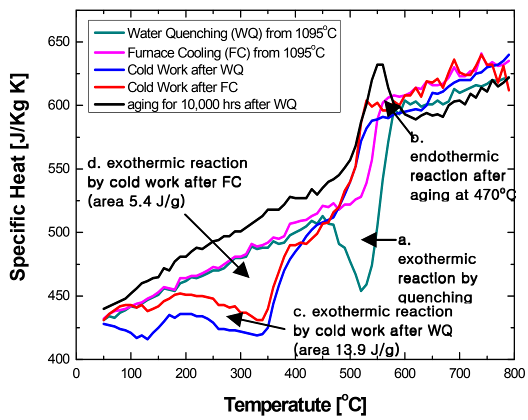

Fig. 1. The specific heat variations in the variously treated Alloy 600 materials [1,2].

The ordering reaction in Alloy 600 causes a lattice contraction anisotropically, as shown in Fig. 2. The magnitude of the lattice contraction in WQ Alloy 600 is saturated over 2000 hours at 400°C.

The ordering reaction occurs in two ways. The first one is by a pure thermal activation process without a stress, as shown in Fig. 2. Let's call this process a thermal ordering. However, the other is by a strain induced process with a plastic deformation. This kind of reaction occurs relatively quickly. Let's call this process a strain induced ordering.

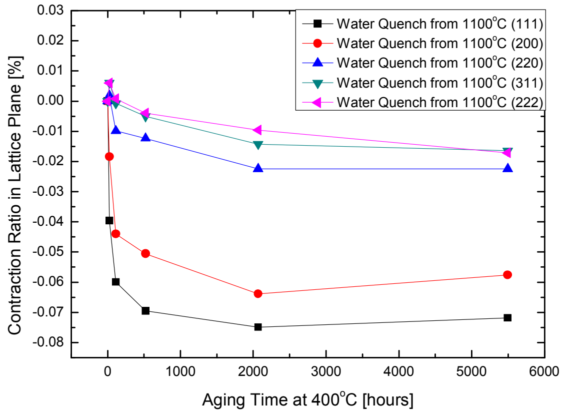

Fig. 2. The change in the lattice spacing's of the water quenched (WQ) Alloy 600 with aging time at 400°C.

The consequence of the lattice contraction is explained briefly in Fig. 3. Almost all the material is a polycrystalline. Therefore, a nano-scale crack would be formed by a lattice contraction, as the ordering reaction proceeds.

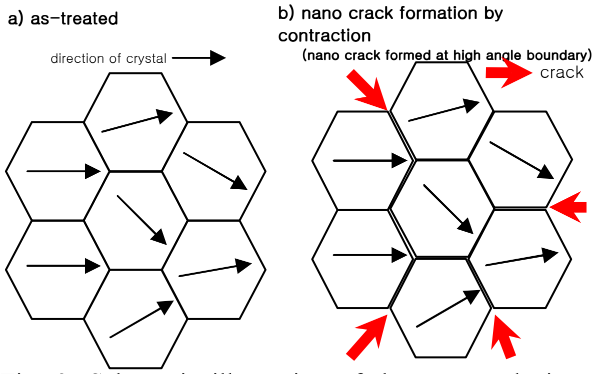

Fig. 3. Schematic illustration of the nano-scale inter-granular cracks formation due to the anisotropical contraction of a crystal.

This contraction causes an additional stress both during the initiation and in the propagation stages of the PWSCC process in Alloy 600. The stress level formed due to the lattice contraction is related to the magnitude of a contraction. Therefore, the additionally formed stress would be 50 ~ 150 MPa according to the lattice planes. This level is not low by itself. However, this level can be magnified by a certain combination of the neighboring grains. This causes a crack formation during the initiation stage of a PWSCC.

Furthermore, this stress operates again during the propagation stage of a PWSCC due to the strain induced ordering. The propagation of a PWSCC is controlled by the strain induced ordering reaction. This is why the activation energy for the order reaction is similar to that of a PWSCC propagation, 40~50 kcal/mol.

The applied stresses in a component made of Alloy 600 are usually understood to be a design stress and a residual stress. However, the ordering reaction causes an additional stress. Therefore, the overall stress can be plotted together, as shown in Fig. 4. The total stress can be over the critical stress for a PWSCC.

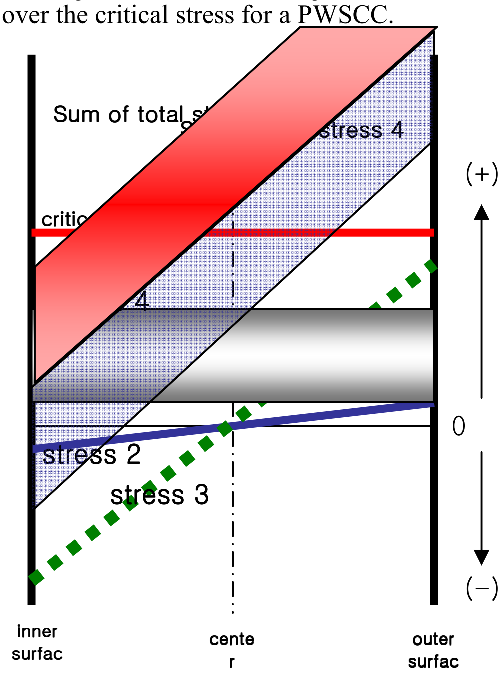

Fig. 4. A schematic illustration of the total stress across the wall thickness of an alloy 600 component.

4. Conclusions

Both the existence of an ordering reaction and an activation energy, Q=~46 kcal/mole (~190 kJ/mole), for an ordering reaction in Alloy 600 have been determined by a differential scanning calorimeter (DSC). This ordering reaction in Alloy 600 causing a lattice contraction can produce an additional stress, internally, in components made of Alloy 600 at a reactor operating temperature, which is the temperature range at which the ordering reaction occurs. The stress level by the ordering reaction would be about 50 ~ 150 MPa according to the lattice planes. These values are calculated from the magnitude of the lattice contraction measured from the neutron diffraction analysis. This stress level can be doubled by a certain combination of the orientation of the neighboring grains, which cannot be a negligible factor for a PWSCC process in Alloy 600. So an additional stress by an ordering reaction in Alloy 600 could be one of the major factors controlling a PWSCC in Alloy 600.

Acknowledgements

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