MEASUREMENT OF RESIDUAL STRESSES IN ALLOY 600 PRESSURIZER PENETRATIONS

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ABSTRACT

Alloy 600 penetrations in several pressurized water reactors have experienced primary water stress corrosion cracking near the partial penetration J-welds between the Alloy 600 and the cladding on the inside diameter of the components. The microstructure and tensile properties indicated that the Alloy 600 was susceptible to primary water stress corrosion cracking (PWSCC) providing that a high tensile stress (applied + residual) was present.

The residual stress distributions at the inside diameter surface and at different depths below the surface were measured in Alloy 600 nozzle and heater sleeve mockups. Surface residual stresses on the nozzle mockup ranged from -350 to +830 MPa. For the heater sleeve mockup, the surface residual stresses ranged from -330 to +525 MPa. In the areas of high tensile residual stress, for the most part, the residual stresses decreased with increasing depth below the surface. For the nozzle and heater sleeve mockups, the percent cold work and yield strength as a function of depth were determined.

INTRODUCTION

Several of the pressurizer heater sleeves and nozzles in Calvert Cliffs Unit 2 (CC-2) developed primary coolant leaks during the 1989 refueling outage, as evidenced by the presence of boric acid deposits on the pressurizer around some of the Alloy 600 nozzles and heater sleeves (1). A destructive examination of leaking CC-2 nozzles and heater sleeves determined that the leakage was the result of throughwall intergranular stress corrosion cracks near the J-groove partial penetration weld between the sleeves/nozzles and the Alloy 600 pressurizer head. The microstructure and tensile properties indicated that the Alloy 600 was susceptible to primary water stress corrosion cracking (PWSCC) providing that a high tensile stress (applied + residual) and an aggressive environment were present.

The major objective of this project was to bench mark the residual stresses present in pressurizer nozzles and heater sleeves. For this paper we will discuss the residual stress results in two mockups.

MOCKUP FABRICATION

We prepared one Alloy 600 heater sleeve mockup (mockup #8) and one Alloy 600 nozzle mockup (mockup #2). To the extent possible, materials, fabrication procedures, and geometries for the nozzle and heater sleeve mockups closely duplicated those in the field (2). The Alloy 600 heater sleeve material (SB-167) was prepared from decontaminated sleeves from the CC-2 pressurizer. The heater sleeve had a yield strength of 434.4 MPa and a reamed portion (reamed area length is about 2.54 cm for the sleeve). The mockup was prepared from the reamed portion of the sleeve. The Alloy 600 nozzle (SB-166) was fabricated from 482.7 MPa bar stock. For the heater sleeve and nozzle mockup descriptions refer to Figures 1 and 2.

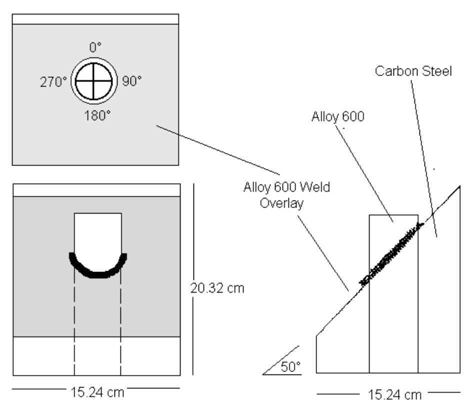

Fig 1 - Alloy 600 Heater Sleeve in the Pressurizer Head (50°).

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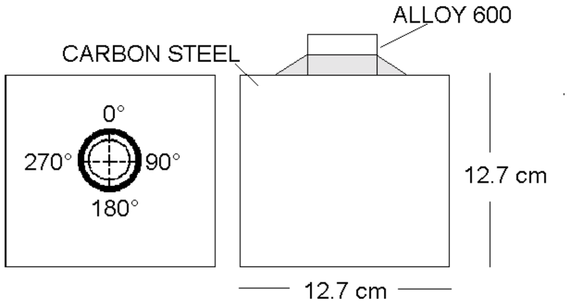

Fig 2 - Alloy 600 Nozzle in the Pressurizer Head (90°).

MEASUREMENT PROCEDURE

A combination of mechanical (strain gage) and X-ray diffraction (XRD) techniques were used to measure residual stresses resulting from the fabrication process of the Alloy 600 nozzle and heater sleeve mockups (3).

Residual stress measurements were obtained in mockup #2 and the high side (0° sector) of mockup #8. Measurements were made at the surface and at different depths below the surface for both mockups (2).

The percent cold work as a function of depth for the nozzle and heater sleeve material in mockups #2 and #8 was calculated from the diffraction peak widths based upon the empirical relationship between peak width and known levels of true plastic strain (4). The percent cold work levels are reported as scalar quantities and represent the true plastic strain required to produce the diffraction peak width measured, based upon the empirical relationship.

Because the percent cold work was defined as the amount of true plastic strain, the yield strength as a function of depth for the nozzle/heater sleeve material in mockups #2 and #8 could be estimated using the true stress-strain curves shown in Figures 3 and 4.

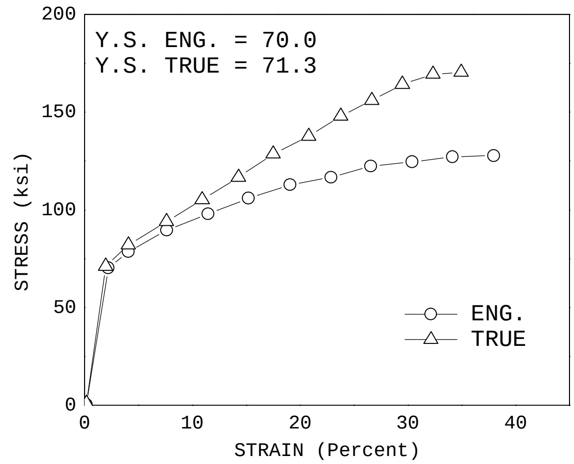

Fig 3 - Engineering and True Stress-Strain Curves For Alloy 600 Nozzle Material.

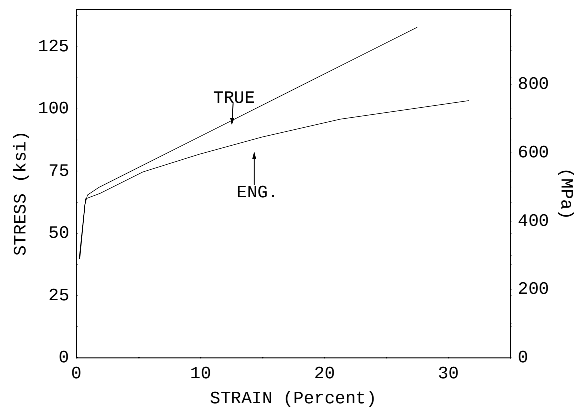

Fig 4 - Engineering and True Stress-Strain Curves for Alloy 600 Heater Sleeve Material.

RESULTS

Results from the residual stress measurements obtained in mockups #2 and #8 are presented in Figures 5 through 8. All residual stresses reported are referenced from the top of the steel encasement.

The XRD residual stress measurements for the high strength nozzle (248.2 MPa) at 90° are presented in Figures 5 and 6. For the most part, the surface residual stresses in both the axial and hoop directions