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PWSCC of Alloy 600 Components and its Countermeasures in PWRs

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1. Introduction

Primary water stress corrosion cracking(PWSCC) of alloy 600 in a PWR has been reported in the control rod drive mechanism (CRDM)[1], In original PWRs, the SCC was not considered appropriately. Beginning in the mid seventies the world's PWR plants suffered from a sequence of SCC events mostly confined to S/G tubes, initially ODSCC then PWSCC. In forged alloy 600 materials, PWSCC was first reported in the Bugey 3 vessel head penetration in September1991. All reactor vessel heads(RVH) with alloy 600 penetrations (54 VH out of 58) were replaced in France. Other PWRs experienced cracking attributed to PWSCC of major primary side welds made from Alloy 182 at the end of the year 2000. The three events concerned dissimilar metal butt welds between the main austenitic stainless steel primary circuit piping and the outlet pressure vessel nozzles of Ringhals 4 and V. C. Summer and some J-groove welds of the CRDM of the RVH at Oconee 1. [2]

In addition to the RVH, PWSCC of Alloy 182/82 has been reported at Bottom Mounted Instrumentation (BMI) nozzle J-welds, Steam Generator (SG) drain J-welds drain nozzle and SG tube sheet cladding [3]. As of the year 2006, 344 PWSCC incidents of Alloy 600/82/182 were reported in RVH, SG, Pressurizer, and other primary side pipings.

The objective of the present work is to review the PWSCC events and some countermeasures to manage the degradation.

2. Mitigation and repair techniques

Mitigation and repair techniques are categorized as material changes, isolations, weld metal changes, design changes, weld overlay, stress improvement, environment improvement, mechanical repair, part replacement etc.

2.1 Material changes

Generally, Alloy 600 has been replaced with more corrosion resistant Alloy 690. Alloy 82/182 weld metal for alloy 600 has been replaced with alloy 52/152 for alloy 690 welds. In some cases, the Alloy 600 of pressurizer nozzles for instrumentation has been changed with type 316 stainless steels. Thermally treated Alloy 690 is being considered as a new SG tubing material in the Republic of Korea, the USA, France, Japan and elsewhere.

2.2 Isolation techniques

Cold spray with a corrosion resistant coating is being considered to isolate the susceptible components from the coolant. It is a technique for depositing fine metal powder onto the susceptible metal surface using a supersonic heated gas stream at low temperatures.

Inlay is another method to keep the components from primary water. A groove is first machined on the surface for maintaining a flow passage and inspection ability after repairing. And cladding with alloy 690 weld metals, like alloy 52, is secondly performed at the groove by using temper-bead welding to avoid Post Weld Heat Treatment (PWHT).

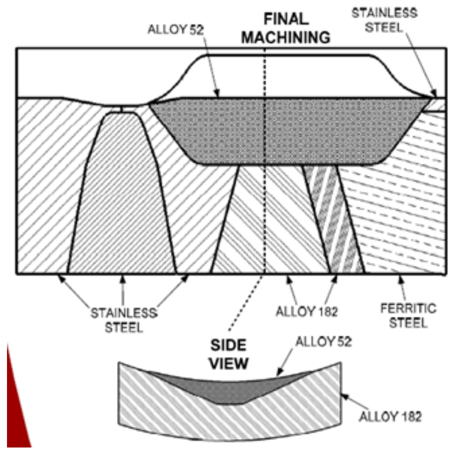

Fig. 1 Concept of weld inlay in nozzles

Weld onlay is a method to cover a component with Alloy 52M. Two Alloy 52M weld metal layers are applied continuously over the 308L and Alloy 82 first layer.

Because small bore nozzles or pipes with cracks are not easy to isolate from the coolant, some other mitigation techniques should be considered.

2.3 Weld overlay

Because of the geometry of the nozzle region and the large grained microstructure present in the welds, inspection is not easy on pressurizer nozzles. The weld overlay process is a suitable repair technique since the location can be made more amenable to NDE inspection techniques and corrosion resistant alloy 690 weld metals can be used. Weld overlays provide three main benefits, whether they are installed to stop an existing crack, or to prevent one from occurring: Structural reinforcement, Resistant material, Favorable residual stress pattern (compressive stress). This technique has been applied in South Korean nuclear power plants since 2009.

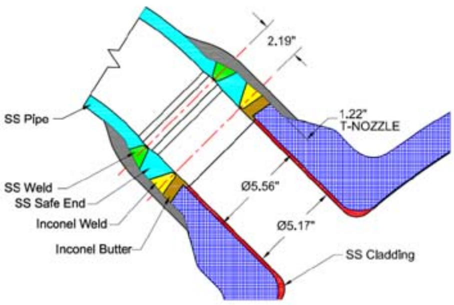

Fig. 2 Concept of weld overlay repair on pressurizer nozzle

2.4 Stress improvement

Use of the Mechanical Stress Improvement Process (MSIP™) has been an effective method of PWSCC remediation of sensitive locations in PWRs. The MSIP™ is a stress related mitigation method that produces a favorable stress pattern by removing "as-welded" tensile residual stresses and generating compressive residual stresses at the ID regions of the pipe.

Water Jet Peening is another option for compressive stress improvement at the surface in weld metal which is susceptible to PWSCC.

2.5 Mechanical repair

The Mechanical Nozzle Seal Assembly (MNSA) is a mechanical device that provides sealing and structural support for small bore nozzle connection. It was developed starting in 1993 as an alternative to weld repair for leaks in J-groove welds in PWR intrumentation nozzles.

The MNSA is installed from the outside of the vessel and can be installed on a leaking nozzle. These have been installed on PWR pressurizers and hot leg nozzles without having to remove fuel from the reactor or drain the primary system.

2.6 Part replacement

Full depth nozzle repair is a part replacement technique. The SCC resistant alloy 690 nozzle is used for replacement. Some South Korean plants adopted this technique for Alloy 600 nozzles (small bore SG drain or instrumentation nozzles).

A half nozzle repair for a small bore thick wall penetration, like a steam generator drain nozzle or an instrumentation nozzle having SCC in its weld region could be considered as one repair option.

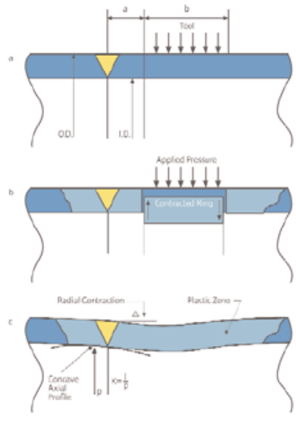

Fig. 3 Concept of mechanical stress improvement process (MSIP)

It has been demonstrated that the crevice corrosion behavior of low alloy steel(LAS) is not so significant in the primary operating conditions with a low level of oxygen.

3. Summary

(1) PWSCC events and some countermeasures were reviewed.
(2) Recently, two cases of boric acid precipitation were reported on the bottom head surface in two units of a SG in South Korea.
(3) Mitigation and repair techniques currently applied or designed are material changes, isolations, weld metal changes, design changes, weld overlay, stress improvement, environment improvement, mechanical repair, part replacement etc.
(4) Weld overlay was applied in South Korean plants, and SCC resistant alloy 690 nozzles were installed (small bore SG drain or instrumentation nozzles)

REFERENCES

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