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Introduction of Repair/ Maintenance Techniques for SCC in Primary Loop Recirculation System Piping

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1. Introduction

In recent years, Stress Corrosion Cracking (SSC) has been found at many welded joints of Primary Loop Recirculation (PLR) piping in Boiling Water Reactor (BWR) plants. The piping is made up of low-carbon stainless steel (SUS316LC) as it was thought that SCC generated by sensitization would be prevented by using low-carbon material. However, the results of later mock-up tests and experiments confirmed that hardened surfaces increased susceptibility to transgranular SCC, which progressed to IGSCC in crack growth experiments under simulated reactor water conditions. These results indicate that in areas where there is a high amount of stress and cracking susceptibility is increased by hardness due to surface machining, even if low-carbon stainless steels are used, transgranular SCC may generate, go down around to the depth of surface machining, and then may further advance as IGSCC, depending on the amount of stress and the chemical conditions in which crack tips are located. It is known that SCC is generated due to three factors superposed, i.e. materials, environments, and stresses. Needless to say, it is effective to eliminate those factors to suppress SCC generation.

This report introduces some repair methods and preventive maintenance techniques for SCC in PLR piping.

2. Examples of repair methods and preventive maintenance techniques for SCC in PLR piping

This section describes major examples for repair methods and preventive maintenance techniques related to material improvement and residual stress relaxation for SCC in PLR piping.

2.1. CRC：Corrosion Resistant Cladding
2.2. Internal Polishing
2.3. IHSI: Induction Heating Stress Improvement
2.4. SHT：Solution Heat Treatment
2.5. HSW：Heat Sink Welding
2.6. Weld Overlay

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2.1 CRC: Corrosion Resistant Cladding[1]

The CRC method is used to reduce SCC susceptibility by cladding the wetted inner-surface of sensitized portions near the welded joints of piping with non-sensitized deposited metal (Fig. 1). There are various methods to clad the wetted part inside the piping with deposited metal (inside weld overlays) and the method typically used is shown in Fig. 2.

The SCC susceptibility is reduced by securing high ferrite content on the wetted inner-surface of the piping's welded joints.

Fig.3 shows that generally in the low-carbon zone, no SCC is observed in the area where ferrite content is over about 5%[2].

Table 1 indicates that, in the SCC-resistance experiments, SCC are well suppressed in the region the inside weld overlay method was performed.

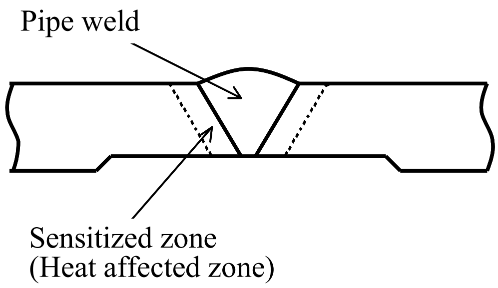


Fig.1. Typical Welded Joints

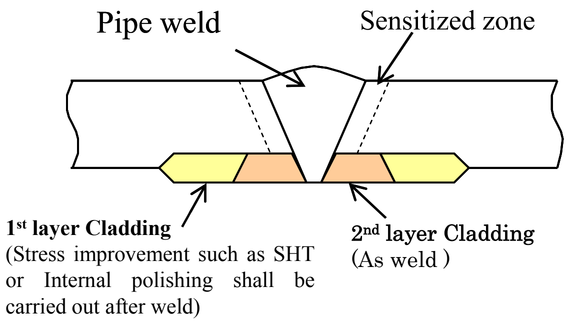
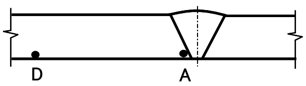
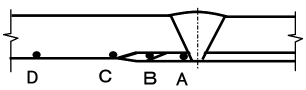
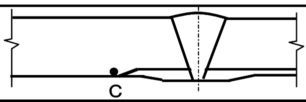
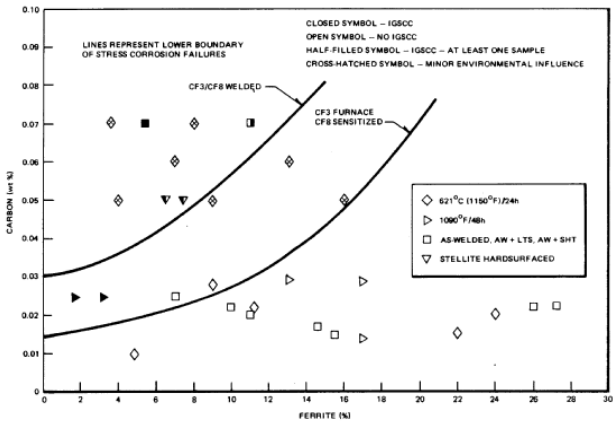


Fig.2. Concept of the CRC Method

Table.1. SCC-Resistance Effect with CRC Method

Type \ Item	Detail of weld joint	CBB test results Maximum crack depth (μm)	
(a) Normal weld joint		A	298
		D	0
(b) 2-layer inner cladding technique with SHT		A	0
		B	0
		C	0
		D	0
(c) Modified single-layer inner cladding technique		C	0

*1: Testing temperature 289degC, Oxygen concentration 20 ppm, Testing time 100hours



IGSCC resistance may be predicted by the combined influence of carbon content and percent ferrite.

Fig.3. SCC Susceptibility vs. Ferrite Content

2.2 Internal Polishing[3]

To relieve residual stress of the inner-surfaces of piping, top surface stress is shifted to compressed sides by polishing the inside surface. This reduction in residual stress results in the suppression of SCC generation. Fig.4 shows the results of CBB tests performed on several kinds of surface polished materials. It is confirmed that polishing is found to be an effective measure for SCC suppression by reducing residual stress on the surfaces.

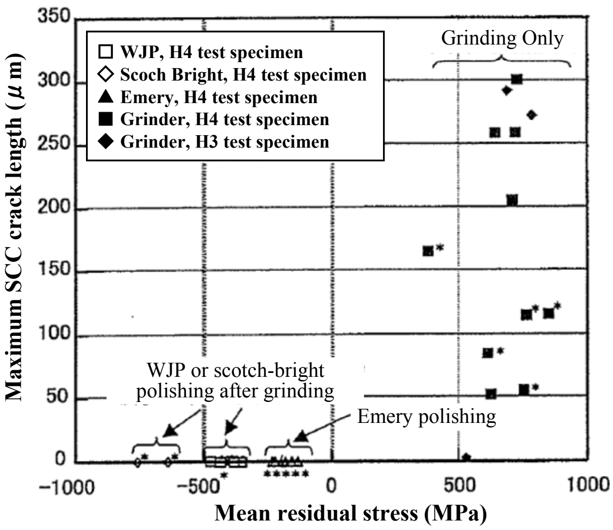


Fig.4. Relief of Residual Stress on Surfaces by Polishing and its Effect on SCC Suppression

2.3 Induction Heating Stress Improvement (IHSI)

To generate the same temperature difference found at the heat effective zone that goes through the thickness of the pipe, the outer-surface is heated by the high-frequency induction heating method and the inner-surface is simultaneously cooled by water. The thermal stress generated by this process relieves the inner-surface residual stress of the piping. Fig. 5 shows the general idea of the IHSI method. The stress distribution, deformation, and the temperature distribution at the time IHSI is executed are shown in Fig. 6. In the IHSI method, a large temperature difference throughout the pipe wall emerges due to simultaneous cooling through applying water on the inside surface of the welded joints and the heating of the outside surface to a specified temperature set by the high-frequency induction heating method. At this time, the compressive yield and tensile yield is generated on the outside and the inside surface, respectively (Fig. 6 (a)). When heating is stopped (cooling on the inside is continued), the temperature difference becomes smaller and stress on the outside surface that was generated in the heating process changes to tensile stress. Stress on the inside surface turns into the compression stress and remains as residual stress (Fig. 6 (b)). Through IHSI, residual tensile stress on the inside of welded pipes can be relieved or changed to compressed sides. As examples of IHSI application (600A), measurements of residual stress on the inner-surfaces along the axial direction of the piping after the IHSI method was performed for typical grooves (the temperature difference between the inside and the outside is 397℃), and for narrow grooves (the temperature difference is 299℃) are shown in Fig.7 and Fig.8 respectively. The results show that the IHSI method changes inner-surface residual stress to compressive residual stress in the vicinity of welding and thus, residual stress is reduced. Moreover, the method is found to be more effective for narrow grooves when compared to typical grooves, as the reduction of inside residual stress along the axial direction of piping is greater, even though the temperature difference between the outside and the inside surface is smaller.

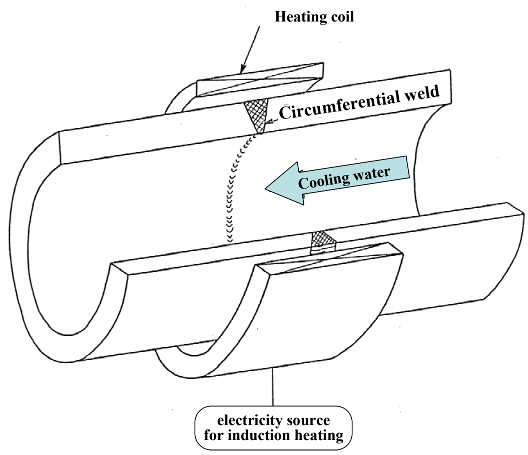


Fig.5. Concept of the ISHI Method

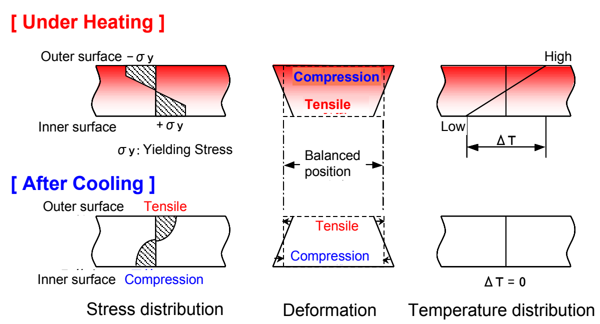


Fig.6. Stress Distribution, Deformation, and Temperature Distribution at the Time of IHSI Application

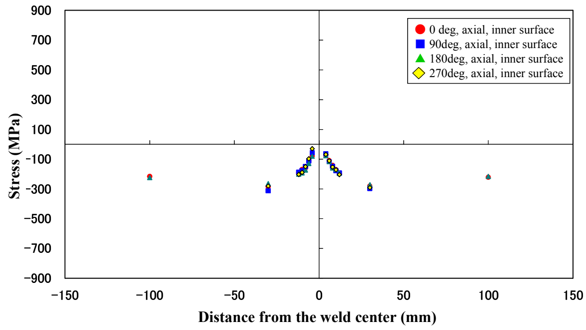


Fig.7. Residual Stress Distribution on the Inside Surface Along the Axial Direction of the Piping (Typical Groove)

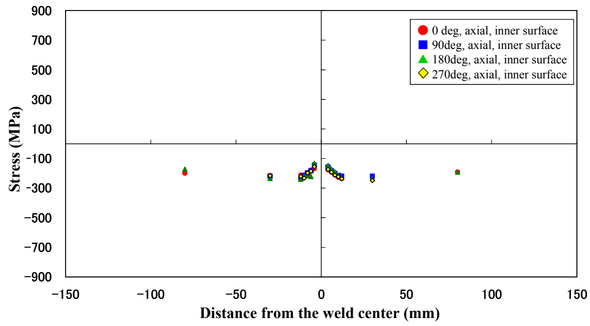


Fig.8. Residual Stress Distribution on the Inside Surface along the Axial Direction of the Piping (Narrow Groove)

2.4 Solution Heat Treatment (SHT)[4]

Chromium rich carbide precipitation from the grain boundary is decomposed when heated by high temperature (over 1000℃) and dissolves uniformly into the base material, which causes the chromium-depleted-layer around the grain boundary to disappear. This heating method, called solution heat treatment (SHT), can eliminate sensitized areas in the material formed by welding and, as shown in Fig. 9, reduces residual stress at the same time[5]. Note that a furnace is needed for this method and it is recommended that it is applied to welded joints at factories.

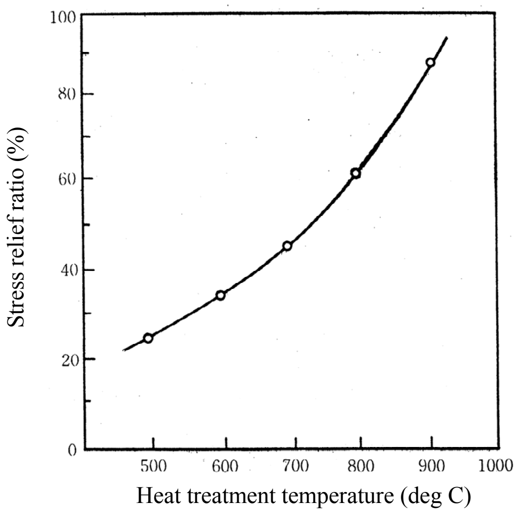


Fig.9. Stress Relief vs. Solution Heat Treatment Temperature

2.5 Heat Sink Welding (HSW)[4]

As shown in Fig. 10, HSW is a method which the inside of pipes are welded while cooled by flowing water or sprays after partitions are formed by the in gas welding for up to two or three layers. Using this method, thermal stress is generated by the temperature difference of the outside and inside of piping that goes through the thickness of the material. This thermal stress reduces tensile residual stress, which is the cause of SCC around the inside surface of the welded pipes.

The results shown in Fig. 11 confirm that HSW is more effective than conventional methods used in gas welding to reduce tensile residual stress.

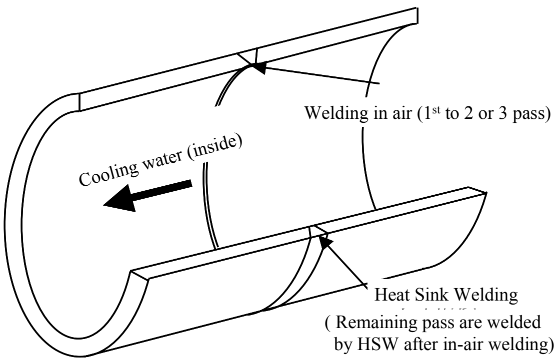


Fig.10. Concept of the HSW Method

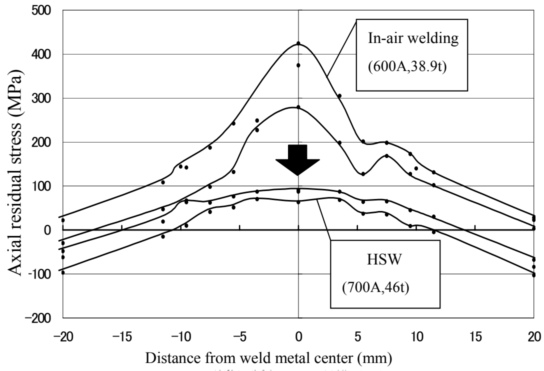


Fig.11. Effect of stress improvement by HSW

2.6 Weld Overlay[6]

In weld overlays, high ferrite welded metal that is superior in SCC resistance is overlaid in a belt around the outside of welded joints in piping with SCC (Fig.12). Strength was secured in the belt-shaped overlay welded part of the piping, thus covering up for lost strength in the part of the piping where the crack occurred (Fig. 13).

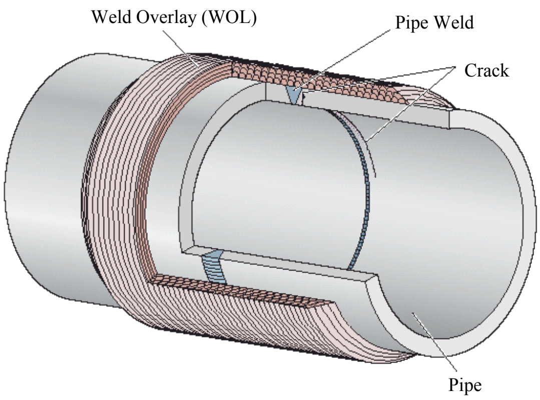


Fig.12. Concept of the Weld Overlay Method

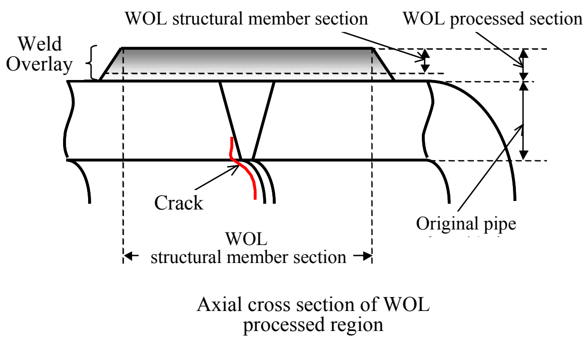


Fig.13. Outline of Piping Cross-Section for the Weld Overlay Method

3. Conclusion

As SCC is caused by the superposition of three factors, materials, stresses, and environments, major methods and techniques for repairs and preventive maintenance that eliminate the affects of the first two factors are discussed in this paper.

Further development of new techniques will be continued, while taking into account new knowledge obtained from research on low-carbon stainless steel SCC.

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