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A Study of Thermal Aging Effects on Microstructures of Type-II Boundary in Dissimilar Metal Weld Joint

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1. Introduction

Austenitic steel Alloy 152 is frequently used as filler metal for joining Ni-based Alloy 690 and ferritic low alloy steel (LAS). This dissimilar metal weld joint (DMW) commonly used in light water reactors (LWR) at pressure vessel nozzles or steam generator nozzles. Before Alloy 152 filler metal, Alloy 182 was used in weld joints and have been acknowledged to be susceptible to the stress corrosion cracking (SCC). For this reason, the filler metal had been replaced by Alloy 152.

There is still no experience of SCC in the weld side of DMW where Alloy 152 is used as filler metal. However, it is believed that the current operational experience is not long enough to conclude that the high Cr Ni alloys are immune to SCC.

Additionally, many researchers conclude that when SCC reaches to fusion boundary, it propagates perpendicular to the fusion boundary. Fusion boundary region has complex microstructure because of welding heat and latter heat treatment that cause changes of mechanical property and corrosion resistance of material [1, 2]. Due to this reason, this region has very different characteristic with base metal or filler metal. Therefore, it needs to be more studied.

Nelson et al. found type-II boundary which is parallel to fusion boundary in the filler metal within 100μm in dilution zone is a potential crack path for SCC [2]. Mechanism of formation of type-II boundary is not clearly turned out. Nelson et al. suggest that the type-II boundary is created by changing process of solidification from body centered cubic structure of ferrite to face centered cubic structure of austenite at welding process [2]. But further research is required on this region.

As nuclear power plant operation time increased, concerns occur about decreased integrity of dissimilar metal weld about SCC due to thermal aging.

This study purposes to analyze the detailed microstructure of type-II boundary of Alloy 152 – A533 Gr.B weld joint, applying thermal aging effect simulation of nuclear power plant environment to evaluating integrity of this region about SCC. The microstructure of type-II boundary region of Alloy 152 – A533 Gr.B weld joint had been analyzed with optical microscope (OM), energy dispersive x-ray spectroscope attached to scanning electron microscope (SEM-EDX), Vickers micro-hardness tester.

2. Experiments

2.1 Materials

In the former research, DMW samples were fabricated by Argonne National Laboratory, joining Alloy 690 and low alloy steel A533 Gr. B with Alloy 152 filler metal by multi-pass shielded metal arc welding [3]. Latter heat treatment was followed. Specimens for OM, SEM, and Vickers hardness tests were prepared at weld root of mock-up samples

2.2 Thermal aging

The heat treatment was conducted to simulate thermal aging at LWR environment by long term operation at 320˚C. The accelerated temperature for thermal aging simulation is decided to 450˚C which is the highest temperature not making any excessive carbides or sigma phase which would not be created after long term operated at 320˚C. Equation (1) is used for calculating aging time needed to simulation.

$$\frac{t_{aging}}{t_{ref}} = \exp\left[-\frac{Q\left(\frac{1}{T_{ref}}-\frac{1}{T_{aging}}\right)}{R}\right] \quad (1)$$

t_{aging} is aging time needed to simulate thermal aging at nuclear power plant about t_{ref}. T_{aging} is thermal aging temperature and T_{ref} is actual operation temperature of nuclear power plant. R is gas constant and Q is activation energy for Cr diffusion which is 125 kJ/mol [3]. To simulate service time 30 years, heat treatment is needed about 2750 hours at 450˚C. We make 4 types of specimens, which simulated service time 15 years, 30 years, 60 years and non-heat treated.

2.3 Procedure

Every specimen used for experiments was cut off from weld root of fusion boundary region of each heat treated mock-up samples. Specimens for Vickers micro hardness test, OM and SEM are polished up to 0.04μm with colloidal silica and etched with 20% HNO_3 + HCl solution about 3 minutes.

3. Results and Discussions

Fig.1 shows that dendrite structure which found from all types of specimens. Some studies report that crack propagates through dendrite grain boundary.

Type-II boundary was also found along fusion boundary in every specimen, but it is not in uniform shape. This is because the specimens were welded by multi-pass welding.

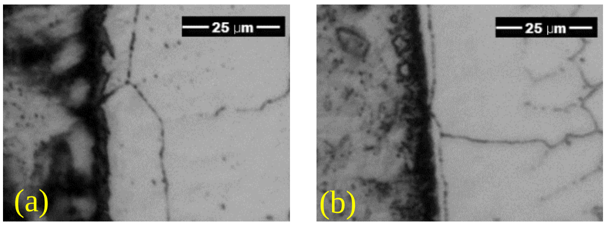

Fig. 1. Image of simulated (a) 15 years and (b) 60 years of service time obtained by OM.

Fig.2 shows SEM image and results of Vickers hardness test. Hardness was the minimum at low alloy steel, the base metal, getting increased as it goes to fusion boundary and maximized near type-II boundary region. There are several reasons for this: residual stress, precipitates and misorientation. As heat treatment time increased, hardness increased.

From SEM image, dendrite structure and non-uniform type-II boundaries are noticed. White dots are found at boundaries of SEM images. This could be carbon carbides, niobium carbides and titanium carbides according to former study about similar dissimilar metal welds [4].

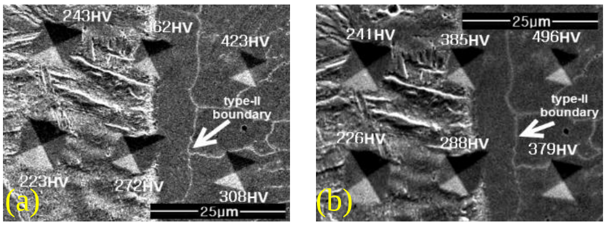

Fig. 2. Results of Vickers hardness test of simulated (a) 15 years and (b) 60 years of service time obtained by SEM.

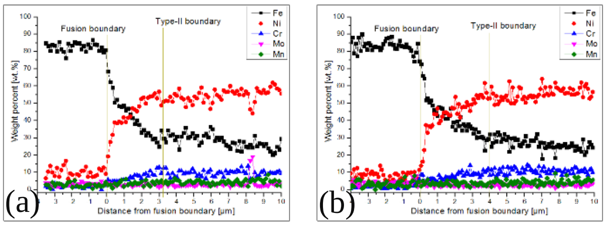

Fig. 3. EDX results of simulated (a) 15 years and (b) 60 years of service time.

Fig.3 is chemical composition along fusion boundary and type-II boundary. Stiff compositional gradient is shown at narrow zone between type-II boundary and fusion boundary. This stiff gradient will cause galvanic corrosion which makes low resistivity to SCC [4].

Iron contents decreased and chromium contents increased as thermal aging proceeded at filler metal. Iron has body centered cubic structure which has lower solubility to carbon than face centered cubic structure of filler metal. So decreasing of iron will reduce amount of carbides at this region. The effect of precipitates to resistance of SCC is hard to be evaluated since it affects many factors. But precipitates are known to form chromium dilution zone near it and it make low resistivity to SCC.

Chromium dilution zone is found at filler metal side. Massive carbides are formed by carbon atoms which are diffused from base metal and this zone is known to have high susceptibility to SCC.

4. Conclusion

In order to characterize the thermal aging effect on microstructures in the fusion boundary and type-II boundary, the DMWs consisting of Alloy 690-Alloy 152-A533 Gr. B were analyzed with several instruments.

I. Hardness was maximized at narrow zone near type-II boundary. Reason for this phenomenon may include residual stress, precipitate and stiff composition gradient. There are studies which report that SCC is easily propagates at the region with higher hardness, so integrity to SCC at this region must be considered.

II. After heat treatment, nickel and chromium contents which are effective to resist to SCC propagation are increased near type-II boundary of filler metal.

III. Stiff gradient near type-II boundary could make galvanic corrosion that would make high susceptibility to SCC so integrity to SCC must be considered.

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REFERENCES

[1] T. W. Nelson, J. C. Lippole, M. J. Mills, Nature and Evolution of the Fusion Boundary in Ferritic-Austenitic Dissimilar Weld Metals, Part 1 — Nucleation and Growth, Welding Journal 78 329S-337S (1999)

[2] T. W. Nelson, J. C. Lippole, M. J. Mills, Nature and Evolution of the Fusion Boundary in Ferritic-Austenitic Dissimilar Weld Metals, Part 2 — On-Cooling Transformations, Welding Journal 79 267S-277S (2000)

[3] K.J.Choi et al., Three dimensional atom probe study of Ni-base alloy/low alloy steel dissimilar metal weld interfaces, Nuclear engineering and technology 44 673-682 (2012)

[4] J. Hou, Q. J. Peng, Y. Takeda, J. Kuniya, T. Shoji, J. Q. Wang, E.-H. Han, W. Ke., Microstructure and mechanical property of the fusion boundary region in an Alloy 182-low alloy steel dissimilar weld joint, Journal of Materials Science 45 5332-5338 (2010)