Relationship between Microstucture and Ductility Dip Cracking resistance of Alloy 600/690 weld metals

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1. Introduction

Ni-Cr-Fe alloys are used extensively in nuclear power systems for their resistance to general corrosion, localized corrosion, and environmentally assisted cracking. However, concerns with stress corrosion cracking of moderate chromium (14–22 wt-%) alloys such as Alloy 600 and its filler metals(FMs) (E-182 and EN82) have driven the application of higher chromium (28–30 wt-%) alloys like Alloy 690. While Alloy 690 and its FMs show outstanding resistance to environmentally assisted cracking in most water-reactor environments, these alloys are prone to welding defects, most notably to ductility dip cracking(DDC)[1].

The DDC occurs at temperatures between 0.5 and 0.8 of their melting temperature. This ductility drop may result in intergranular elevated temperature cracking often referred to as DDC. The DDC may occur during the high temperature processing of these alloys or during welding if the imposed strain exhausts the available ductility within this temperature range. Several alloy systems including Ni-base alloys, Ni–Cu alloys, Cu alloys, stainless steels and steels, have been reported to be susceptible to DDC. A complete understanding of the DDC mechanism does not exist, which makes DDC control in actual production conditions a very difficult task[2].

In this study, the DDC resistance was evaluated with different FMs which have different chemical composition. The microstructural features of FMs such as precipitation behavior and garin boundaries morphorogy were observed, and it were correlated with the DDC susceptibility. The hot ductility test and strain-to-fracture test was used to evaluate the DDC susceptibility at high temperature.

2. Experimental Procedure

Three Ni-base FM, designated FM-52, FM-52M and FM-82(AWSA5.14 ERNiCr-3 and ERNiCrFe-7, respectively) were used in this study. FM-52, FM-52M and FM-82 are commonly used to weld alloys 690 and 600, respectively. These three FM alloys were also routinely used to perform dissimilar welds involving low alloy steels. The chemical composition of the FMs is presented in Table.1.

The test samples were sectioned and prepared for OM and SEM by grinding and polishing up to 0.25μm, and then electrolytic etching with a 15% HCl solution at 3.4V for 20s.

Table 1 Chemical composition of the alloy (wt%).

	Ni	Cr	Fe	C	Nb	Ti	S	Zr	B
FM-82	Bal..	20.10	0.70	0.04	2.60	0.47	0.002	-	-
FM-52	Bal..	29.10	8.88	0.026	0.02	0.05	0.004	-	-
FM-52M	Bal..	30.04	8.42	0.02	0.85	0.21	0.001	0.015	0.004

The hot ductility test was performed in a Gleeble1500 thermo-mechanical simulator. The specimens in vacuum chamber were heated between 600 and 1300℃ at the rate of 100℃/s, Then they were began to be tensioned at the stroke rate (0.60cm/s) after holding for 2 min until they are broken.

For STF test, The specimens were tested at 950℃, and stroke rate was 0.39cm/s. The STF samples were then observed using a binocular microscope to determine the presence of cracks.

3. Results and Discussion

Figure 2 shows the SEM images of the FMs. In the case FM-82, formation of grain boundaries(GBs) were tortuous and numerous eutectic NbCs were precipitated along the FM-82 GBs(Fig.2(a,d)). It has been reported that the intragranular eutectic NbC precipitates of FM-82 were formed at the end of solidification. They pin the GBs and prevent grain growth. Hence the presence of NbC would cause the formation of more tortuous GBs in FM-82. This GB tortuosity has a mechanical locking effect on the GBs, limiting GB sliding[3,4]. On the other hand, FM-52 shows the small amount of large TiN-like precipitates and straight grain boundaries (Fig.2(b,e)). Because the large TiN-like precipitates were formed sporadically in the microstructure, the effect of GB restriction were less effective than FM-82. Therefore, the average GB pinning effect of large particles with low fractions was negligible. The microstructure of FM-52M is almost similar to FM-52 and there are no difference between the FM-52 and FM-52M with respect to GB pinning effect (Fig.2(c,f)). It is predicted that the DDC resistance of FM-82 would be improved compared to FM-52 due to the balanced effect of GB sliding control caused by both the intergranular precipitates and the GB tortuosity.

In order to evaluate the DDC resistance, hot ductility test were performed as shown in Fig.3. The FM-82 shows the highest ductility than other FMs due to a GB pinning effect. The ductility of the FM-52M is higher than that of FM-52 because of the grain boundary strengthening by B and Zr addition. Moreover, the percentage of area reduction between 700 and 900℃ was lowered in FM-52 and FM-52M while it was not lowered in FM-82.

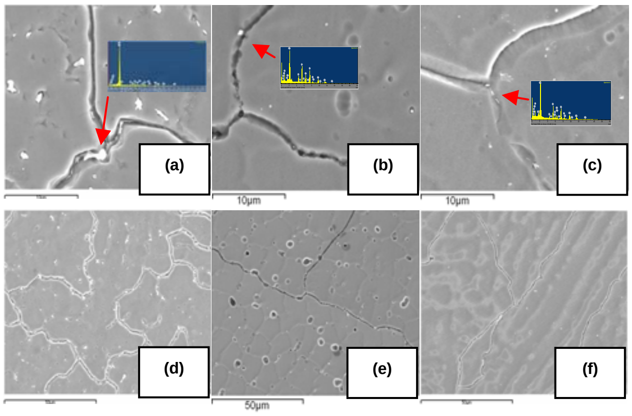

Fig.2 SEM images of FMs (a) NbCs in the FM-82 (b) TiN-like precipitates in the FM-52 (c) TiN-like precipitates in the FM-52M (d) Tortuous GBs in the FM-82 (e) Straight GBs in the FM52 (f) Straight GBs in the FM-52M.

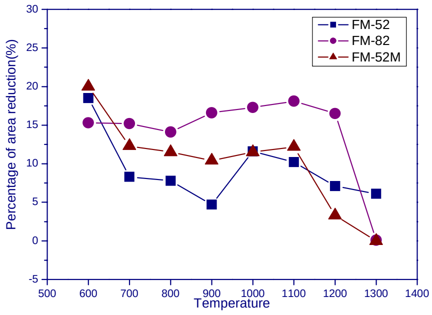

Fig.3 Hot ductility test results of FMs.

To indentify the DDC temperature clearer, the fracture surfaces of the FM-52 were observed by SEM(Fig. 4). The microcracks in wavy regions were observed at 900℃(Fig.4(b)). The wavy regions are the typical fracture surface morphology of DDC[4]. However, the fracture surfaces at 600℃ exhibited the ductile fracture(Fig. 4(a)). The solidification cracking led to the fracture at 1200℃(Fig.4(c)).

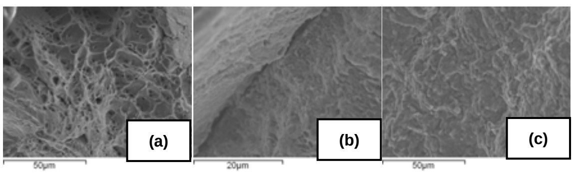

Fig.4 SEM images of fracture surfaces in the FM-52(a) at 600℃ (b) at 900℃ (c) at 1200℃

Therefore, it can be predicted that the DDC is mainly occurred in the temperature range of 700 and 900℃ in FM-52 and FM-52M. The difference of the DDC resistance at this temperature range will be discussed with the STF test results in detail.

4. Summary

The DDC resistance of FM-82, FM-52 and FM-52M was evaluated with the observation of microstucture and the ductile tests, such as hot ductility test and STF test. The effective GB pinning caused by numerous NbCs in FM-82, occurs the formation of tortuous GBs which improve the DDC resistance. On the other hand, the limited GB pinning effect of the sporadic TiN-like precipitates observed on FM-52 did not promote the GB tortuosity and lower the DDC resistance. Therefore, the ductility of FM-52 is remarkably decreased between 700 and 900℃ which certified the DDC temperature range.

5. Acknowledgement

This research was supported by Doosan Heavy Industry & Construction.

6. References

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