POST WELD HEAT TREATMENT TO REDUCE INTERGRANULAR CORROSION SUSCEPTIBILITY OF DISSIMILAR WELDS BETWEEN AUSTENITIC 304 AND FERRITIC 430 STAINLESS STEELS

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Abstract

Dissimilar weld between ASS304 and FSS430 is susceptible to intergranular corrosion especially at heat-affected zone. Proper heat treatment is being required to mitigate this deterioration. Heat treatment conditions to reduce intergranular corrosion of these alloys are, however, different. Therefore, this work aims at achieving heat treatment condition for the ASS304-FSS430 dissimilar weld. The results suggested that post weld heat treatment (PWHT) at temperature of 900^{o}C followed by water quenching was an applicable procedure to reduce intergranular corrosion susceptibility of weld as it can reduce corrosion throughout the welds via the replenishment of metal-depleted zone.

Keywords: intergranular corrosion (IGC), degree of sensitization (DOS), post weld heat treatment (PWHT), stainless steel

Introduction

Dissimilar weld between ASS304 and FSS430 is used in specific applications such as superheater and reheater pipes in power plant. During welding metals are subjected to a specific temperature causing metal sensitized or susceptible to intergranular corrosion (IGC). The specific temperature is well-known as sensitized temperature. Sensitization caused from the formation of chromium carbide ($Cr_{23}C_6$) particles at grain boundaries resulted in the depletion of chromium at the adjacent area where corrosion preferentially attacks. Heat treatment after welding or post weld heat treatment (PWHT) is usually used to reduce IGC susceptibility. However, PWHT to reduce IGC of ASS304 and FSS430 is different—temperature to reduce IGC of ASS304 is a sensitization temperature of FSS430 and vice versa. Thus, this work is aimed to achieve PWHT condition to reduce IGC of dissimilar weld between ASS304 and FSS430.

Methodology

Chemical compositions of ASS304 and FSS430 used in this study are presented in Table 1.

Table 1 Chemical composition (wt.%) of stainless steels used in this study

Materials	C	Cr	Ni	Si	Mo	Mn	Fe
ASS304	0.07	18.36	7.92	0.42	0.11	0.93	Bal.
FSS430	0.05	16.79	0.25	0.30	0.02	0.33	Bal.

The ASS304 and FSS430 sheets size of 25 mm × 300 mm × 3 mm were joined by tungsten inert gas welding (TIG) process without filler. Welding current and arc voltage used were 98 A and 10 V correspondingly. Welding speed was constant at 2 m/s. After joining, it was cut into small pieces with a dimension of 50 mm × 10 mm × 3 mm. To study the effect of post weld heat treatment (PWHT) on intergranular corrosion susceptibility, the as-welded samples were aged at 800°C, 900°C and 1100°C for 10, 24 and 48 hours followed by different cooling procedure: air cooling (AC) and water quenching (WQ). Afterwards, they were ground and polished down to 1 μm followed by chemical etching to reveal their microstructures. Micro-hardness measurements were also achieved on cross-section of as-welded and aged samples to define weld zone (WZ), heat-affected zone (HAZ) and base metal (BM) along the welds. Intergranular corrosion susceptibility expressed in term of Degree of Sensitization (DOS) was determined by Double Loop Electrochemical Potentiokinetic Reactivation (DLEPR) method according to ASTM G 108. The measurements were performed in a mixture solution of 0.5 M H_2SO_4 and 0.001M KSCN at a scan rate of 2.5 mV/s using micro-electrochemical cell with a testing area of 1.1 square-millimeters as shown in Figure 1. The reference and counter electrodes used were Ag/AgCl electrode and Pt wire respectively. During performing DLEPR, the specimen was anodically polarized from open circuit potential (OCP) to +300 mV to form passive film afterwards it was reversely scanned to damage the corrosion susceptible area. Degree of Sensitization is a percentage of I_r/I_a, where the maximum current density of reverse scan and anodic scan are defined as I_r and I_a correspondingly. If DOS value is not more than 1%, it is defined as non-sensitized condition. DLEPR was performed at least 3 measurements at each zone along the welds. The damaged or attacked area after performing DLEPR was examined by SEM.

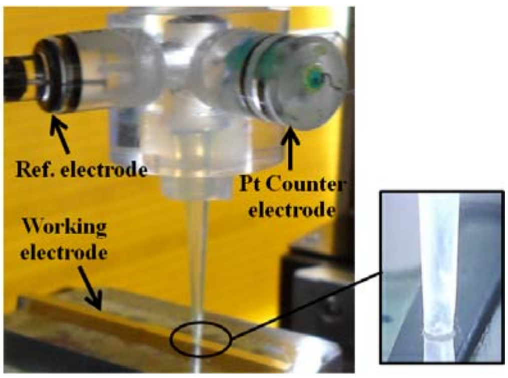

Figure 1 Micro-electrochemical cell used in this study

Results and Discussion

Micro-hardness across the welds.

Micro-hardness measurements along the welds were performed to define weld zone (WZ), heat-affected zone (HAZ) and base metal (BM). Plots of average micro-hardness values versus distance from weld center line are displayed in Figure 2. Hardness profiles of as-welded and PWHT welds were a reverse U-shape at which welded zone has a higher micro-hardness value than that of base metal and heat-affected zone. From welded zone hardness value decreased to reach a minimum value that defines heat-affected zone. Beyond this point, the hardness value slightly increased until reach constant value of base metal (≈180-250 H_v for ASS304 and 150-180 H_v for FSS430). This behavior was found in both of as-welded and PWHT-welds.

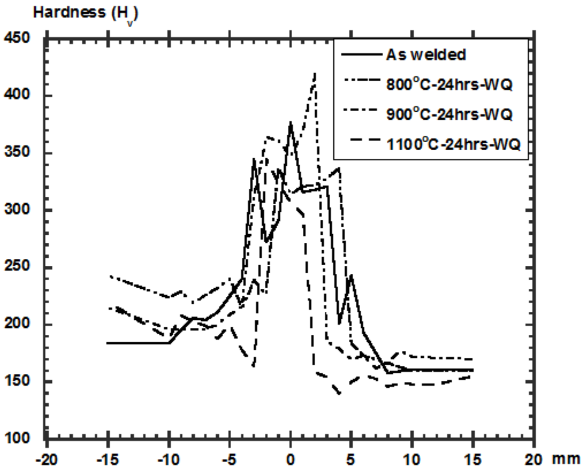

Figure 2 Typical micro-hardness profiles of PWHT-welds compared with as-welded specimen

Intergranular corrosion susceptibility of dissimilar weld (as-welded).

Figure 3 (a) shows DLEPR curves of each zone on as-welded specimen. Thermal from welding did not affect BM of ASS304 that denoted by DOS value of 0.31% and evidence in Figure 3 (b). On the other hand HAZ of ASS304 in Figure 3 (c) underwent IGC manifestly and corresponded to DOS value of 1.78% which was classified as sensitized condition. At WZ where ASS304 and FSS430 were melted and recrystallization happened, its microstructure consisted of austenite (γ-phase), ferrite (δ-phase) and martensite (α′-phase) (Lippold and Kotecki 2005; Kou 2003). DOS of this zone was 0.67% corresponding to the gentle damage illustrated in Figure 3 (d). For FSS430 side, at HAZ, martensite phase at grain boundaries was observed similar to that found in the previous reports (Davis 2006; Kou 2003). The damages observed are around martensite phase and at grain interiors in the form of pitting corrosion (Figure 3 (e)). The results agreed with previous researches (McGuire 2008; Sidhom et al. 2010) that the attacks had been found around martensite phase as this area is chromium-depleted zones (McGuire 2008, Sidhom et al. 2010). Because of the corrosion current could generate from attacks around martensite phase at grain boundaries and pitting corrosion within grain; therefore, high DOS value (28.87%) at this zone resulted from both of IGC and pitting corrosion. In contrast to BM of FSS430 (Figure 3 (f)), only pitting corrosion was significantly observed.

Sensitization of HAZ in ASS304 resulted from experiencing to sensitization temperature of 425°C-815°C during welding. Once the formation of $Cr_{23}C_6$ at grain boundaries happens, the adjacent area depleted in chromium and corrosion damage is favorable. In case of FSS430, there are high amount of metal carbide, mostly chromium carbide (Lippold and Kotecki 2005; George and Shaikh 2002), precipitates within grain. Around these precipitates there are metal-depleted zone where corrosion attack is preferable. The damage observed appeared around these precipitates that looked like pitting corrosion.

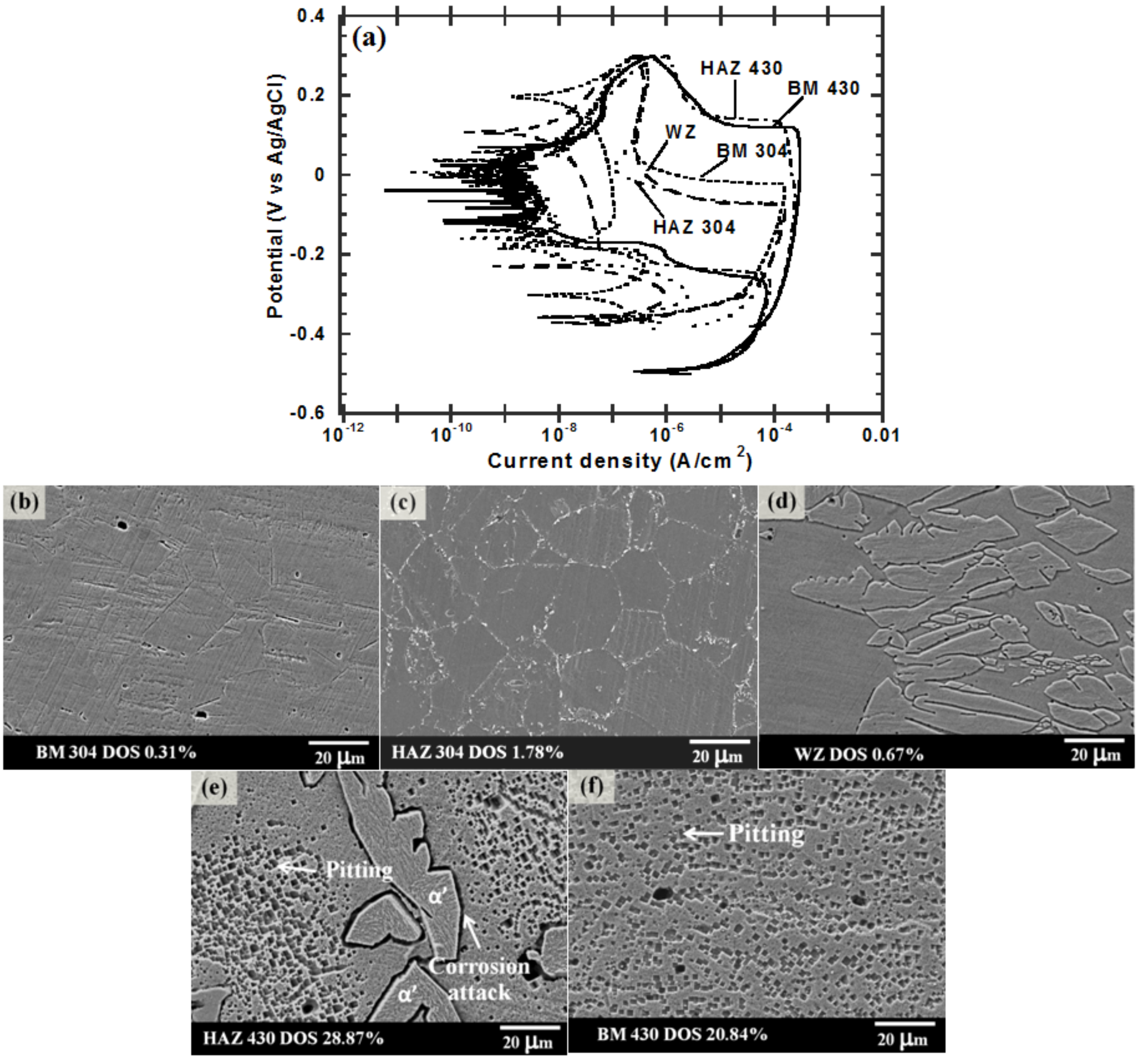

Figure 3 (a) DLEPR curves of each zone along the weld, attack morphologies after performing DLEPR at (b) base metal ASS 304, (c) HAZ ASS 304, (d) welded zone, (e) HAZ FSS 430 and (f) base metal FSS 430 of dissimilar weld

Intergranular corrosion susceptibility of welds after heat treatment at 800°C.

DOS of welds after heat treatment at 800°C followed by air cooling and water quenching are shown in Table 2. BM and HAZ in ASS304 side (both of cooled by air and water) were sensitized (DOS ≈ 6.38% – 25.32%) after PWHT at 800°C as shown in Figure 4 (a) and (b). It can be explained that during PWHT, BM was directly exposed to sensitization temperature of 800°C; therefore, IGC was susceptible. At HAZ where IGC was aggressive in as-welded condition, PWHT at temperature of 800°C was not only unable to dissolve $Cr_{23}C_6$ at grain boundaries (Lippold and Kotecki 2005) but also promoted the formation of new $Cr_{23}C_6$ at grain boundaries (Jones 1997; McGuire 2008). Hence, IGC was extensively aggressive at this area. Attacks were also found in WZ (Figure 4 (c)) along grain boundaries (arrow) including at martensite phase but not as aggressive as at BM and HAZ.

Martensite phase at grain boundaries was also found at HAZ of FSS430 (Figure 4 (d)). However, only slight damages around martensite phase and small amounts of pitting corrosion at grain interiors were observed. This phenomenon causes from further soluble of carbon in ferrite phase (Stansbury 2000) and the fulfilment of metal-depleted zone was promoted (Stansbury 2000; Jones 1997). Because of the reason mentioned, its DOS was less than that of as-welded condition. At BM of 800°C-PWHT-FSS430, DOS value reduced from as-welded condition and only small amounts of pitting corrosion was observed (Figure 4 (e)). It is due to heat treatment improved metal diffusivity and metal-depleted zone was fulfilled. Comparison of PWHT followed by air cooling and water quenching; DOS values of air-cooled samples were higher than that of water-quenched especially in ASS304 side. Cooled in air, chromium and carbon had sufficient time for diffusion to grain boundaries and form $Cr_{23}C_6$ whereas the formation of $Cr_{23}C_6$ was limited in case of water rapid cooling.

Table 2 Average DOS of PWHT-welds compared with as-welded specimen

Temp. (°C)	Time (hrs)	Cooling	Average DOS (%)				
			BM ASS 304	HAZ ASS 304	WZ	HAZ FSS 430	BM FSS 430
As-welded			0.31	1.78	0.67	28.87	20.84
800	10	AC	23.87	25.32	5.68	6.60	10.43
	24		15.98	18.7	3.89	7.03	9.87
	48		7.53	22.31	4.58	10.58	14.59
	10	WQ	18.33	17.90	4.77	8.14	10.58
	24		6.73	14.20	3.43	8.76	8.57
	48		6.38	17.56	3.08	6.34	7.05
900	24	AC	0.19	0.76	0.32	15.93	14.58
	48		0.27	0.13	0.87	14.43	13.23
	24	WQ	0.08	0.06	0.97	12.54	13.03
	48		0.21	0.34	0.79	13.78	12.98
1100	24	AC	0.02	0.07	0.04	34.20	38.31
	48		0.05	0.07	0.08	29.59	36.56
	24	WQ	0.04	0.04	0.03	23.76	29.08
	48		0.03	0.04	0.09	N/A	N/A

Remarks

N/A : not perform the test due to high temperature oxidation occurred

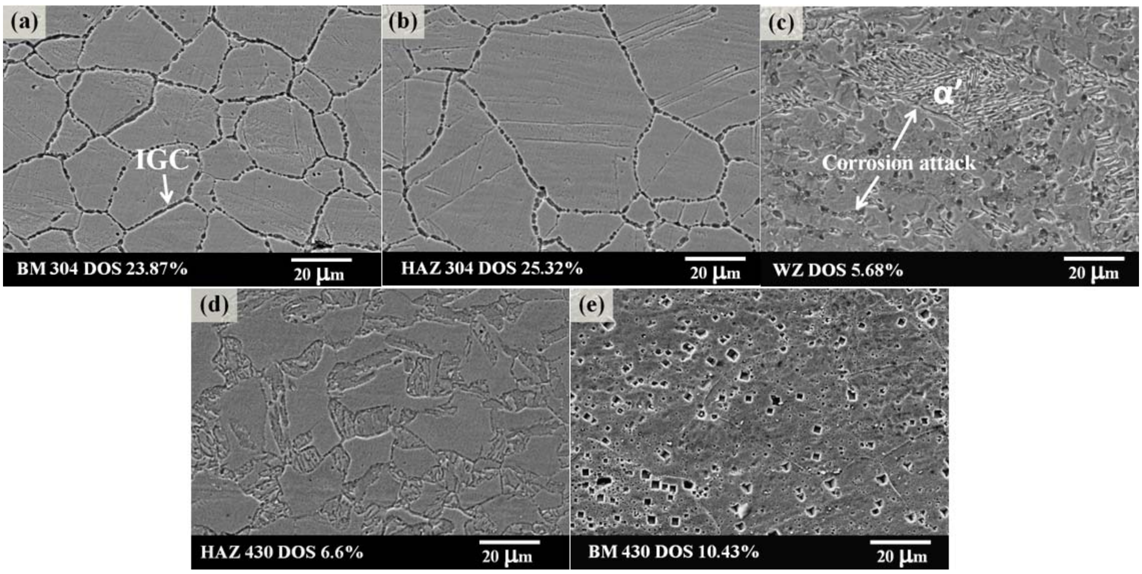

Figure 4 Morphologies after performing DLEPR at (a) base metal ASS 304 (b) HAZ ASS 304 (c) weld zone (d) HAZ FSS 430 and (e) base metal FSS 430 of the weld heat-treated at 800^{o}C for 10 hrs followed by air cooling

Intergranular corrosion susceptibility of welds after heat treatment at 1100^{o}C.

Temperature of 1100^{o}C is a sensitization temperature of FSS430 and a heat treatment temperature to reduce IGC of ASS304. From Table 2 DOS of ASS304 both at BM and HAZ were less than 1% (0.02% − 0.07%) that agreed with their gentle attack morphologies in Figure 5 (a) and (b). Since this temperature is not a sensitization temperature of ASS304, IGC did not take place at BM. At HAZ where IGC was susceptible in as-welded condition, after PWHT at 1100^{o}C $Cr_{23}C_6$ at grain boundaries dissolved (Stansbury et. al 2000; Jones 1997) then IGC was not susceptible anymore. At WZ after PWHT at high temperature of 1100^{o}C recrystallization and the formation of new phase possibly occurred as illustrated in Figure 5 (c). This phenomenon probably induced chemical compositions homogenization and reduction in corrosion that supported by DOS value of 0.03%. For HAZ of FSS430 (Figure 5 (d)), martensite phase around grain boundaries that found in as-welded and 800^{o}C-PWHT welds disappeared. It is possible that PWHT at this temperature could dissolve martensite phase and promote the diffusivity of metal from metal carbide particles to replenish metal-depleted zone simultaneously. In case of BM, IGC was more predominant than pitting corrosion because this temperature is a sensitization temperature of FSS430. However, pitting corrosion within grains reduced that caused from the fulfilment of metal-depleted zone around carbide precipitates similar to that happened at HAZ.

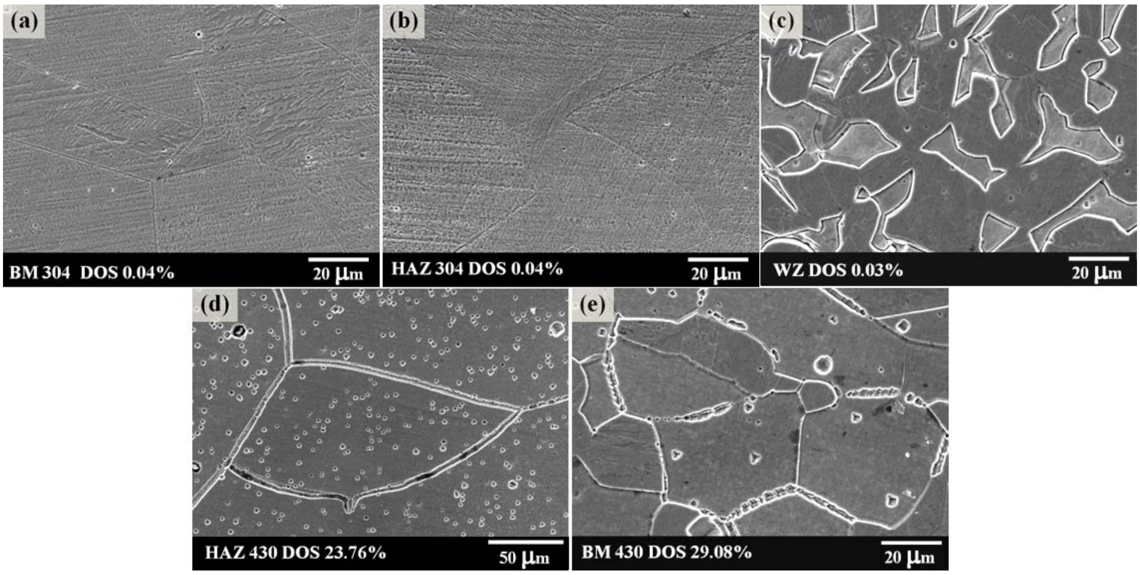

Figure 5 Morphologies after performing DLEPR at (a) base metal ASS 304 (b) HAZ ASS 304 (c) weld zone (d) HAZ FSS 430 (e) base metal FSS 430 of the weld heat-treated at 1100^{o}C for 24 hrs followed by water quenching

Intergranular corrosion susceptibility of welds after heat treatment at 900^{o}C.

Temperature of 900^{o}C is neither a sensitization temperature of ASS304 nor FSS430. Morphology of BM ASS304 in Figure 6 (a) presented that IGC was not found that corresponded to low DOS value. At HAZ in Figure 6 (b), PWHT at temperature of 900^{o}C could successfully reduce IGC (DOS = 0.06%) because chromium diffusion was allowed to replenish chromium-depleted zone at grain boundaries. PWHT followed by water quenching could reduce IGC effectively since rapid cooling capably suppressed the formation of new chromium carbide. The heat treatment period did not likely affect IGC susceptibility that noted by similar DOS values. Microstructure at WZ in Figure 6 (c) was similar to that of 800^{o}C-PWHT welds. However, the attack at WZ after 900^{o}C-24hrs- PWHT was rarely found as the diffusivity of metal was promoted. At HAZ of FSS430 in Figure 6 (d), martensite phase disappeared similar to PWHT at 1100^{o}C. It is implied that martensite phase dissolved since this temperature. However, pitting corrosion within grains was still observed but in smaller amount than that of as-welded condition. This occurrence probably resulted from partially replenishment of metal-depleted zone around metal carbide particles. Furthermore heat treatment at 900^{o}C did not allow the formation of new $Cr_{23}C_6$; thus, IGC was not susceptible. By the reason mentioned, DOS of this area caused from pitting corrosion rather than IGC. At BM in Figure 6 (e), pitting corrosion after PWHT at 900^{o}C was less than that of as-welded condition because of replenishment of metal-depleted zone by heat treatment. However, cooling procedure and heat treatment period did not significantly affect IGC susceptibility.

Among heat treatment temperatures, PWHT at 900°C is an applicable heat treatment for dissimilar weld between ASS304 and FSS430 as it can reduce intergranular corrosion susceptibility throughout the weld. Moreover, PWHT followed by water quenching could suppress the formation of carbide precipitates giving intergranular corrosion reduced.

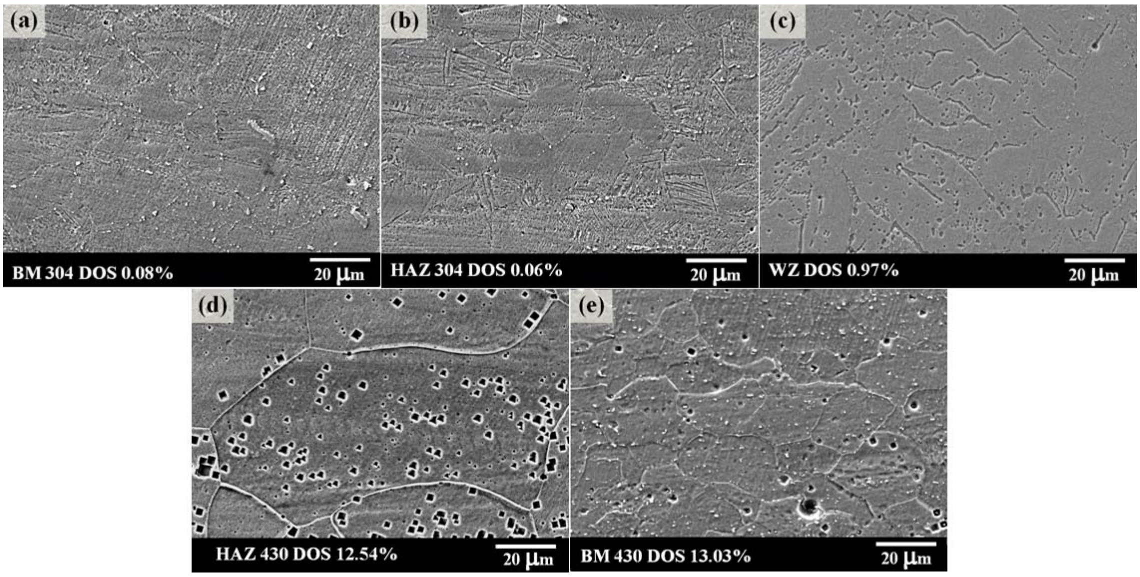

Figure 6 Morphologies after performing DLEPR at (a) base metal ASS 304 (b) HAZ ASS 304 (c) weld zone (d) HAZ FSS 430 (e) base metal FSS 430 of the weld heat-treated at 900°C for 24 hrs followed by water quenching

Conclusion

PWHT at temperature of 900°C followed by water quenching is an applicable PWHT procedure to reduce intergranular corrosion susceptibility of dissimilar weld between ASS304 and FSS430. This procedure does not only inhibit the formation of chromium carbide at grain boundaries but also promote the replenishment of metal-depleted zone.

Acknowledgements

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