Effects of Surface Finishes on Corrosion Resistance of Welded Stainless Steels

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Abstract

Corrosion resistance of welded stainless steels with different surface finishes was studied. The materials used in this study were the welded UNS S 30400/S 30400, S 30400/ S 31803 and S 31803/ S 31803. The welded pieces were mechanically ground then they were subjected to the different surface finishing processes which were as-received (S1), passivation (S2), fine grinding followed by passivation (S3) and grinding followed by electropolishing (S4). Corrosion resistance behavior of the welded specimens as well as the base metals were determined by poteniodynamic technique (PD) and the sensitization due to heat during welding was determined by electrochemical poteniokinetic reactivation technique (EPR).

It was found that for S 30400 and S 30400/30400, pitting potentials (E_{pit}) of S2, S3 and S4 were 3 times, 2 times and 3 ½ times respectively higher than those of S1. For S 30400/S 31803, E_{pit} of S2 and S4 were almost twice of the as-received one but E_{pit} of S3 was only 85 mV greater than that of S1. The surface finishes could increase corrosion resistance of S30400 and welded S 30400 significantly. For S 31803 and the S 31803/S 31803, S2 had the highest pitting potential and was 1 ½ time greater than that of S1. Sensitization was determined by the charges released from the welded specimens. The charges released values of S 30400/S 30400, S30400/S 31803 and S 31803/S 31803 are 176, 43 and 0.1 milli Coulomb/cm^2 respectively.

Keywords*: Passivation, electropolishing, sensitization, finishing processes*

1 Introduction

Corrosion resistance of stainless steel is excellent. Its resistance obtains from a passive chromium oxide film which forms on the surface. In general the stainless steels which contain high chromium content have high corrosion resistance [1]. The chromium content in the alloy affects the chromium content in the passive film. The chromium content in the passive film increases with increasing chromium in the bulk [2].

The surface finishes of stainless steels also affect their corrosion resistance. The different surface finishing processes applying on the stainless steel surfaces have an effect on the chromium content in the oxide film [2]. The different surface finishes also yield the different surface roughness. The rougher surface is more susceptible to corrosion than the smoother surface to localised forms of corrosion such as pitting and crevices corrosion [3]. The effect can be related to the surface nucleation of metastable pit preceding to propagation of the pit.

Improvement of corrosion resistance of stainless steel by surface polishing can be measured as increase in pitting potential. Passivation process also can improve corrosion resistance of stainless steels [1]. Passivation process not only changes the composition of the oxide film to more corrosion resistance form but also smoothes the surface with less defects [4]. The electropolishing process also has been used for high surface quality requirement such as for the equipment in pharmaceutical industry. The electropolishing process removes deformed layer as well as improve surface roughness. The high resistance oxide film can form. The polarization resistance of electropolishing stainless steel surface can be improved by more than 60%. From the AES and XPS analysis, the passive film of stainless steel

changes to chromium rich film after electropolishing process [5].

Welding is the process often used to fabricate or manufacture the parts or equipment. Heat from welding can affect the corrosion resistance of stainless steel by sensitization which lowers the corrosion resistance of the welded stainless steel. Intergranular corrosion of stainless steel is due to a chromium depletion resulting from the precipitation of chromium carbides along grain boundaries (sensitization) [1]. The heat from welding also can cause heat tinting on the welded stainless steel which can lower its corrosion resistance [6]. Tinted surface can be removed by pickling and mechanical grinding. Even though corrosion resistance of stainless steel can be impaired by welding but it can be improved by surface finishing treatments. In this study the corrosion resistance of welded stainless steels with different surface finishing treatments was determined by electrochemical techniques. The potentiodynamic test was used to determine corrosion behaviour of the specimens and electrochemical potentiokinetic reactivation was used to determine the sensitization of the welded specimens.

2 Identifying your paper

2.1 *Specimens*

The stainless steels UNS S30400 (304) and UNS S31830 (2205) samples were provided in the form of 60x100x4.5 mm. They were butt-welded by GTAW process. The base metals and welding electrodes used to produce the specimens were shown in table 1. The chemical compositions of these steels and welding electrodes were shown in table 2.

The welded samples were ground from the factory. This surface condition was considered as the as-received surface (S1).

2.2 *Surface preparations*

The base metals and the welded samples with surface finish S1 were prepared by different surface finishing processes. The finish treatments were:

S2 passivation
S3 fine grinding followed by passivation
S4 electropolishing

2.2.1 Passivation – S2

The specimens were degreased and cleaned with DI water. Then they were passivated in 25% HNO_3 solution at $50^{O}C$ for 5 minutes and rinsed 3 times with DI water.

2.2.2 Fine grinding and passivation – S3

The specimens were ground with SiC papers: #120, 360, 500, 800 and 1000 respectively and passivated.

2.2.3 Electropolishing – S4

The specimens were degreased and cleaned with DI water. They were electropolished in phosphoric acid and sulfuric acid solution with current density of 0.5 A/cm^2, voltage of 12-15 V at $70^{O}C$ for 6 minutes. Then they were rinsed 3 times in DI water.

The surface roughness of each specimen was measured and shown in table 3.

Table 1: The welded specimens

Indentification	Base metals	Welding electrodes
W1	304 – 304	ER 308L
W2	304 – 2205	ER 2209
W3	2205 - 2205	ER 2209

Table 2: The chemical compositions of the base metals and welding electrodes

	304	2205	ER 308L	ER 2209
C	0.0375	0.0134	0.03 max	0.03 max
Si	0.448	0.389	0.30-0.65	0.9 max
S	1.54	1.46	0.02 max	0.03 max
P	<0.01	<0.01	0.03 max	0.03 max
Mn	<0.01	<0.01	1.0-2.5	0.5-2.0
Cr	18.54	22.60	19.5-21.0	21.5-23.5
Ni	7.92	5.57	9.0-11.0	7.5-9.5
Mo	0.326	2.99	0.30	2.5-3.5
Cu	0.548	0.189	0.30 max	0.75 max
N	-	-	-	0.08-0.20

Table 3: Surface finishes and roughness of the specimens

Surface finishes	Surface roughness (µm)	
	304	2205
S1 and S2	0.602	0.579
S3	0.065	0.065
S4	0.047	0.052

2.3 *The electrochemical measurements*

The measurements were performed using 3 electrodes cell with the specimen as a working electrode, the platinum as the counter electrode and the saturated calomel electrode (SCE) as the reference electrode. The equipment used was the BioLogic multichannel VMP3.

2.3.1 Potentiodynamic test (PD)

The electrolyte used in this test was deaerated 0.02 M NaCl solution at room temperature. The potentiodynamic measurements were made from -0.25 V OCP to 1.2 V vs SCE at the scan rate 1 mV/sec.

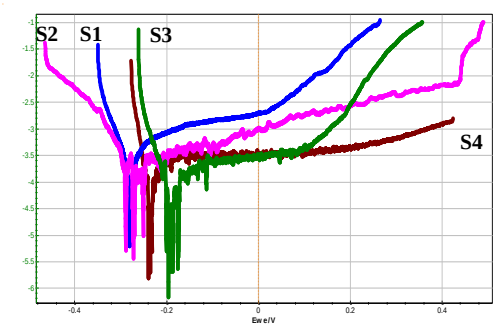
2.3.2 Electrochemical potentiokinetic reactivation (EPR)

The electrolyte used was 0.5 M H_2SO_4 + 0.01 M KSCN at 50^{O}C. The measurements were made from 0.2 V to - 0.25 V OCP at the scan rate 1 mV/sec.

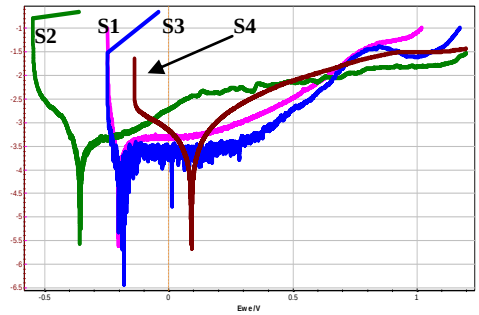
3 Results

3.1 *Potentiodynamic test*

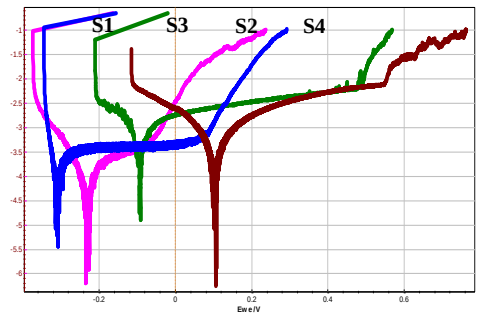
The polarization curves from the potentiodynamic tests showed the corrosion resistant behaviour of the specimens. Figure 1 a), b), c), d) and e were the polarization curves of the 304, 2205, W1, W2 and W3 with different surface finishes. From the polarization curves, the corrosion potentials (E_{corr}) and the pitting potentials (E_{pit}) of the specimens were obtained and their values were shown in table 4 and figure 2 (a) and (b) respectively.



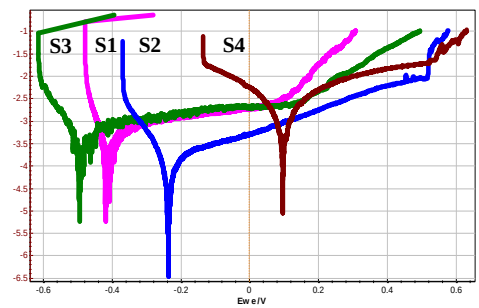
a) 304



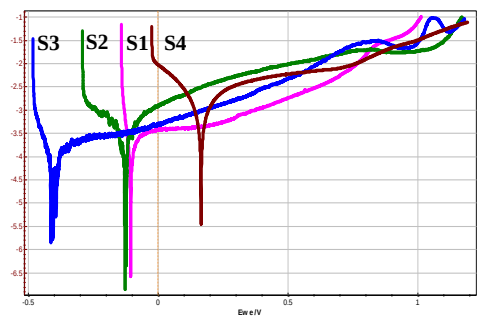
b) 2205



c) W1

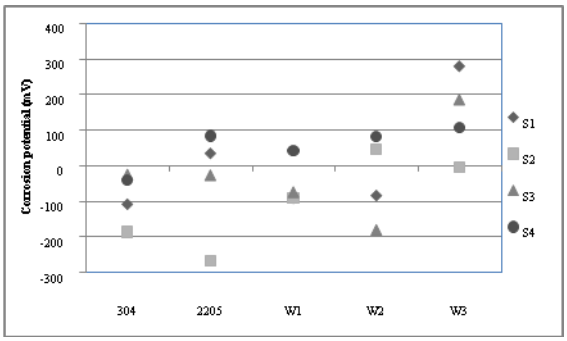


d) W2

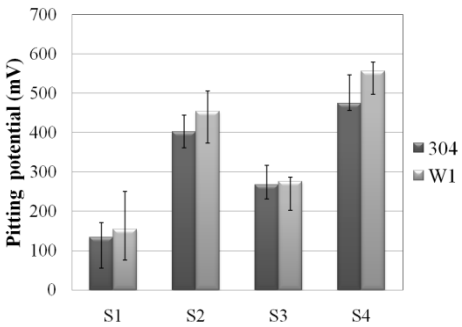


e) W3

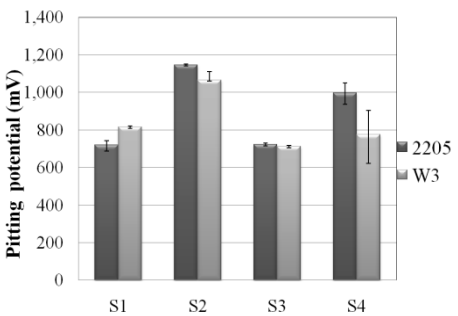
Figure 1: The polarization curves of the specimens



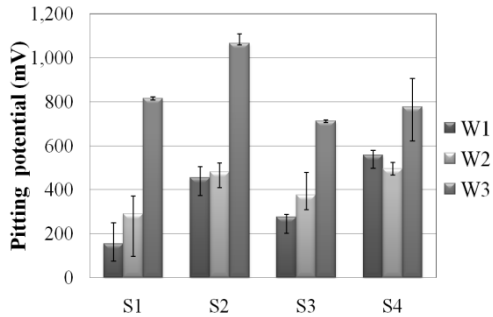
a) Corrosion potentials of all specimens



b) Pitting potentials of 304 and W1



c) Pitting potentials of 2205 and W3



d) Pitting potentials of W1, W2 and W3

Figure 2: The corrosion and pitting potential of the specimens with different surface finishes

From the potentiodynamic test results: it showed that the corrosion resistance of the same specimen with different surface finishes was different.

304, E_{corr} values of S1 and S2 were around 150 mV lower than those of S3 and S4. The current densities in the passive range of S1 and S2 were around 1 order of magnitude higher than those of S3 and S4. E_{pit} were in the following order, S1 < S3 < S2 < S4 which E_{pit} of S1 and S4 were 130 mV and 475 mV respectively. E_{pit} of S4, S2 and S3 were 5 times, 3 times and 2 times of E_{pit} of S1.

2205, E_{corr} of S2 was lower than that of S1 and S4 was the highest at 83 mV. The current densities in the passive range of S1, S2 and S3 were insignificantly different. The current density of the passive region of S4 was the highest. E_{pit} values were in the following order, S1 and S3 (720 mV) < S4 (1,000 mV) < S3 (1145 mV).

Table 4: The corrosion potentials and pitting potentials of the specimens

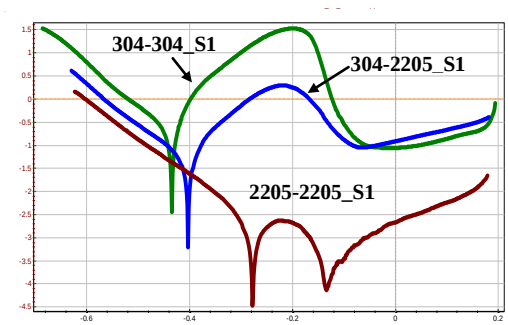
Specimens	304		2205		W1		W2		W3	
Surface finishes	E_{corr} (mV)	E_{pit} (mV)	E_{corr} (mV)	E_{pit} (mV)	E_{corr} (mV)	E_{pit} (mV)	E_{corr} (mV)	E_{pit} (mV)	E_{corr} (mV)	E_{pit} (mV)
S1	-109.5	134.2	33.9	720.0	-92.3	154.7	-84.8	290.0	279.0	815.5
S2	-187.5	402.5	-268.0	1145.0	-91.8	454.0	45.7	482.0	-4.4	1065.0
S3	-24.5	267.0	-26.4	721.5	-73.9	276.3	-180.0	375.0	186.0	713.0
S4	-40.9	475.0	83.7	996.0	41.2	556.3	81.5	495.5	107.2	776.0

Welded specimens, E_{pit} of W1, W2 and W3 were in the same order which were S1 < S3 < S2 < S4.

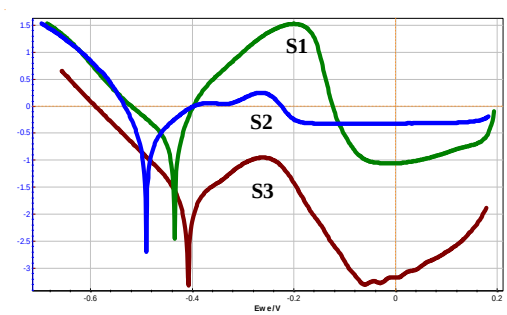
- W1: E_{pit} of S1, S2 and S4 were 155, 454 and 550 mV respectively. Epit of S2 and S4 were 3 and 3.5 times of S1.
- W2: E_{pit} of S1, S2 and S4 were 290, 482 and 500 mV respectively. E_{pit} of S2 and S4 were 1.5 and 1.7 times of S1.
- W3: Epit of S1 was 815 mV and S2 had the highest value of 1065 mV. E_{pit} of S4 and S2 were lower than that of the original surface S1.

3.2 *Electochemical Potentiokinetic Reactivation (EPR)*

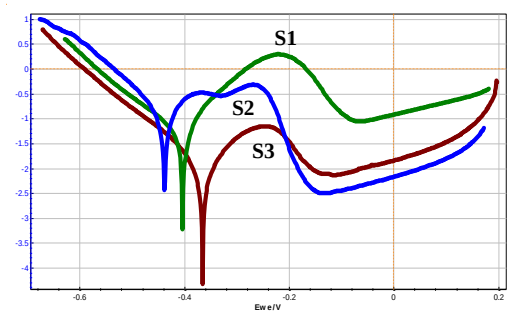
The results of this test were the charges released from the specimens. If the specimens were sensitized by the welding, the chromium carbide precipitated and the chromium depleted area presented at the grain boundaries. This area would be determined by this test. The higher the charges released was the larger chromium depleted area. The tests were performed only on the welded specimens with different surface finishes. Other than the chromium depleted area, the effect of surface finishes was also observed. The overlaid curves from the tests were shown in figure 3. The charges released from the welded specimens were shown in table 5 and figure 4.



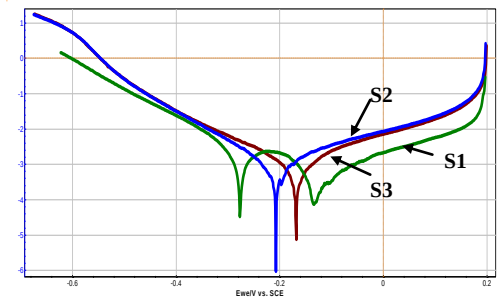
a) The welded specimens with surface finish S1



b) W1 with different surface finishes



c) W2 with different surface finishes



d) W3 with different surface finishes

Figure 3: the polarization curves of the welded specimens with different surface finishes

Table 5: The charges released from the welded specimens

Specimens	Charges released, Q(mC.cm^{-2})		
	S1	S2	S3
W1	2197.2	176.41	8.06
W2	114.15	43.31	3.63
W3	0.11	0	0

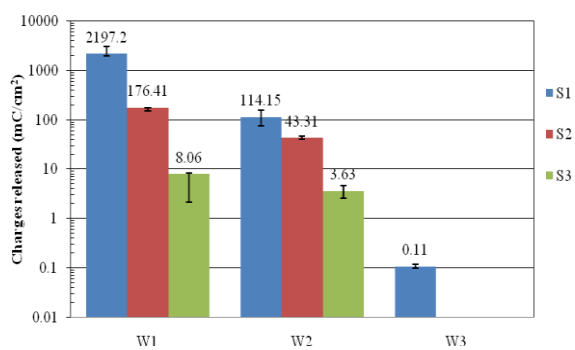


Figure 4: The charges released from the welded specimens

From the EPR test results: the sensitizations of the specimens from the highest to the lowest were W1, W2 and W3. In fact W3 had no sensitization. From the polarization curves it showed that surface finishes had an effect on the critical current density (i_{crit}) which was the highest current density of the activity peak. The specimens which had the i_{crit} values of from the highest to the lowest were S1 > S2 > S3.

4 Discussions

4.1 The potentiodynamic test

Corrosion resistance of 304 was significantly increased by the surface finishing treatments. The original surface, S1, was the shop grinding surface. The passivated S1 could increase E_{pit} to 3 times of the original one. The electropolished surface had E_{pit} 5 times higher than that of the original. The surface finishing processes changed the chemical composition of passive film of the stainless steels [2, 5, 6]. E_{pit} of W1 (surface finish S1) was higher than that of 304 (the same finish surface). The specimen W1 composed of the base metal and weld metal. The weld metal was the mixture of the filler and base metal. The filler metal used was 308L which had the higher Cr, Ni and lower C contents than those of 304. Therefore, the weld metal had the higher chemical composition than the base metal.

E_{pit} of 2205 surface S1 was already high. The surface finish treatment could not significantly increase E_{pit} of the specimens. The electropolishing treatment could increase E_{pit} from 720 mV (S1) to 996 mV (S4). E_{pit} of S2 was the highest of 1,145 mV. This value might be the limitation of the testing since the pitting potential of the specimen might be higher than the oxygen reaction potential [7]. The current density obtained could be the current from this reaction not the pitting corrosion reaction.

For W1 and W2 with surface S1, E_{pit} of W2 was around 140 mV higher than that of W1 since W2 composed of the base metals (304 and 2205) and weld metal (2209). The filler metal had high alloying elements. E_{pit} of the other surface finishes, S2, S3 and S4, of W1 and W2 were insignificant different.

E_{pit} of W3 with surface S1 was 865 mV which considerably high. But E_{pit} of S3 and S4 were lower than that of the original one (S1). E_{pit} of S2 was the highest of 1,065 mV. Again this value might not be the pitting potential of the specimen. It could be the oxygen reaction. Therefore the pitting potential of W3 with surface S2 might higher than 1,065 mV.

4.2 The EPR test

W1 was welded 304 with 308L. The base metal 304 contained 0.037 wt% C which was high enough for $Cr_{23}C_6$ to form. Therefore, chromium depleted area was found in W1. W3 composed of 2205 and 2209 which their carbon contents were very lower. There was not sensitized by welding.

The surface finishing treatments had an effect on the critical current densities of the sensitized welded stainless steels. For both W1 and W2, the critical current density of S2 was 1 order of magnitude and S3 was 2 orders of magnitude lower than that of S1. The surface finish treatments had no effect on W3 since it was not sensitized by welding.

5 Conclusions

The corrosion resistance of 304 and W1 (welded 304 with 308L) could significantly increase by the surface finishing processes. The easiest way to improve corrosion resistance was the nitric acid passivation which could increase the pitting potential (of them from the ground surface) 3 times. In the case of small tolerance of contamination as in the pharmaceutical equipment the electropolishing could be used since it could increase E_{pit} 5 times of the original surface.

For the high alloyed stainless steel such as 2205, the corrosion resistance was already high. The surface finishing processes increased its pitting potential but not as high as the lower alloyed 304. The welded 2205, W3, with the passivation treatment improved the corrosion resistance but the others, S3 and S4 lowered it.

The surface finish processes also improve the corrosion resistance of the sensitized welded stainless steel.

Acknowledgements

The authors would like to thank Patkol Public Company Limited for providing the materials for this study and TFII for providing the equipments to perform the experiments.

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