International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 3 (2019), pp. 296-300

Electrochemical Characteristics of the Austenitic Stainless-Steel Pipe Welds in NaCl Solution

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Abstract:

The aim of this study is to analyze the welds about the electrochemical characteristic of austenitic stainless steel pipe welds such as STS 205 and STS 316L by electrochemical polarization experiment in 3.5% NaCl solution. The potentiodynamic test showed that corrosion current density($I_{cor.}$) values of STS 205 pipe welds were 1.3 times higher than those of STS 316L pipe welds in 50℃ NaCl solution. The cyclic potentiodynamic polarization test showed that pitting potential($E_{pit.}$) values of STS 205 pipe welds were 221 ㎷ lower than those of STS 316L pipe welds in 50℃ NaCl solution. As a result, the STS 316L pipe welds exhibited better pitting corrosion resistance than STS 205 pipe welds in 3.5% NaCl and this improved corrosion resistance in STS 316L could be attributed to be existence of Mo around the pitted region.

Keywords: Austenitic stainless steel pipe welds, Potentiodynamic test, Cyclic potentiodynamic polarization test, Pitting corrosion resistance

I. INTRODUCTION

The austenitic stainless steel is an alloy contained more than 12% of Cr and as it forms the passive film on the surface of the alloy showing high resistance against the corrosion by preventing the direct contact between the surface of metal and the surface of alloy and excellent mechanical property, for which it is used for the piping in petro-chemical plant, its demand tends to increase, but in the environment where the chlorine ion is high or in the corrosive environment where pH is low, pitting corrosion, crevice corrosion, and stress corrosion cracking are caused by the partial breakdown of film. Particularly, since differently from the uniform corrosion, the pitting corrosion occurs intensively in specific area accelerating partially the melting, which after all, leads to breakdown reducing significantly lifespan of the material, it is one of the dangerous types of corrosion. Particularly, since it damages the materials and degrades the corrosion resistance, lots of researches have been conducted[1-3].

200-series stainless steel was developed as an alternative steel for 300-series stainless steel and is widely used for its advantages that it is cheap and has excellent mechanical property than 300-series steel by reducing the Ni content and increasing Mn content by 6-14%[4]. However, its scope of use in the corrosive environment is narrow compared to the 300-series stainless steel. Especially, as 316L stainless steel contains 2-3% of Mo, it has excellent corrosion resistance, pitting corrosion resistance, high-temperature strength and intergranular corrosion resistance[5]. In this study, to examine the corrosion characteristics of the austenitic stainless steel in the corrosion environment contained the chlorine ion, pitting characteristics of the 205 and 326L stainless steel pipes welded with gas tungsten arc welding (GTAW) in the 3.4% of NaCl solution according to the temperature change were compared using electrochemical analysis method and the corrosion pattern in the weld zone was analyzed with SEM and EDX.

II. MATERIALS

2.1 Stainless steel pipe specimen and welding condition

The 205 and 316L stainless steels used in this study are the stainless steel generally circulated in the market and the chemical composition is shown in Table 1. According to chemical composition, 205-series stainless steel contains less than 0.1 of C, about 1.0 ~ 1.7 of Ni, more than 16.5 Cr but within the margin of error, and 9.32 of Mn, which is not reached to the standard of 14.0 ~ 15.5. 316L stainless steel contained less than 0.03 of C, 10.0 ~ 14.0 range of Ni, more than 16.0 of Cr and less than 2.0 of Mn. Both stainless steels contained the chemical elements within the standard range and are appropriate for experiment.

Table 1: Chemical compositions of specimens (wt.%)

Specimens	Compositions									
	C	Si	Mn	P	S	Cr	Ni	Mo	N	Cu
STS 205	0.10	0.41	9.32	0.06	0.003	16.18	1.02	-	0.15	1.82
STS 316L	0.02	0.64	0.72	0.024	0.002	17.77	12.23	2.18	0.013	0.16

International Journal of Engineering Research and Technology. ISSN 0974-3154, Volume 12, Number 3 (2019), pp. 296-300

Stainless steel pip for STS 205 was made with 15V of voltage, 200A of current and that for STS 316 was made with 17V and 180A using gas tungsten arc welding process. The weld feed speed for STS 316L was 1.2±0.5 m per minute and that for STS 205 was 0.8 ±0.5, about 70% of STS 316L. For the shielding gas, 10 ~15ℓ of Ar+10% H_2 was injected per minute. The microstructure of GTAW welding zone was observed by corroding it using aqua regia GTAW.

2.2 Specimen for Polarization Test and Potentiodynamic Polarization Test

For the specimens for polarization test, hot mounting was performed with hardening resin, polished with #1200 SiC polishing paper for the surface appropriateness and used as specimen for polarization test after performing the ultrasonic cleaning with ethanol and drying. The potentiodynamic polarization test[6] was performed using DC104/PC from Gamry and for the reference electrode, the saturated calomel electrode (SCE) was used and for the counter electrode, high-density carbon rod was used. For the aqueous solution for polarization test, 3.35% NaCl solution, which is same concentration as seawater was made and used. Before the test, the corrosion potential was measured after maintaining for 30 minutes in the open circuit and the potentiodynamic polarization test was performed with the injection speed of 5 ㎷/sec at room temperature. After potentiodynamic test in 3.5% NaCl solution at 25℃ and 50℃, the corrosion current density was measured and the base metal and welding zone of 205 Stainless Steel pipe and 316L Stainless Steel pipe were compared. In the cyclic potentiodynamic polarization test, the maximum current was set to 10 ㎃ and after cyclic potentiodynamic polarization test according to the temperature change of solution, the pitting potential of the base material and welding zone of STS 205 and STS 315L were compared and the surface corrosion pattern was analyzed with SEM and EDX.

III. RESULTS AND DISCUSION

3.1 Microstructure of STS 205 and STS 316L Welding Zone

Fig. 1 is showing the microstructure of weld metal and heat-affected zone in the welding zone of STS 205 and STS 316L welded with GTAW.

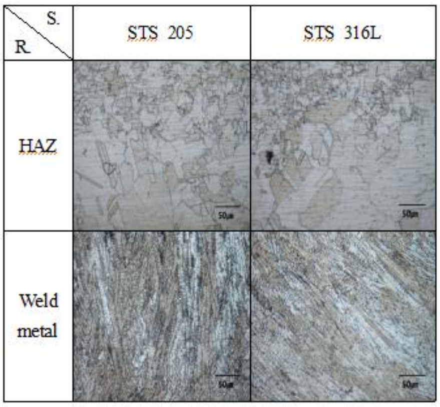


Fig.1 Optical microscope of GTAW specimens welds

It was found that in the weld metal, all the fine dendrites are directed toward the center. The solidification pattern of the weld metal can be forecasted according to the value of C_{req}/N_{ieq} by obtaining the equivalent ratio of Cr and Ni in the base material using below Hammer & Svensson formula[7].

$$Cr_{eq} = \%Cr + 1.37 \times \%Mo + 1.5 \times \%Si + 2 \times \%Nb + 3 \times \%Ti \quad (1)$$

$$Ni_{eq} = \%Ni + 0.31 \times \%Mn + 22 \times \%C + 14.2 \times \%N + 1 \times \%Cu \quad (2)$$

Since the value of Cr_{eq}/Ni_{eq} for STS 205 was about 1.66 and that for STS 316L was calculated as about 1,56, it can be considered that the delta ferrite is solidified in the STS 205 and in the STS 316L, the austenite and delta ferrite are solidified but the weld metal has a difference only in the fine degree of dendrite and the structure could not be distinguished. It was observed that the structure of heat-affected zone is coarsening austenite structure.

3.2 Corrosion Current Density in Welding Zone of STS 205 and STS 316L

Fig. 2 is showing the potentiodynamic polarization curve in the welding zone of STS 205 and STS 316L in NaCl solution at 25℃ and 50℃. The polarization curve can be divided into the active, passive area and trans-passive zone. After potentiodynamic polarization, the corrosion current density in the welding zone of STS 205 and STS 316L at 25℃ was measured as 0.28 and 0.18 ㎂/㎠, respectively. In the results of comparing at room temperature, that of STS 205 was increased by about 1.5 times than STS 316L and that of STS 205 and STS 316L at 50℃ was measured as 0.36, 0.27 ㎂/㎠ increased by about 1.3 times. This is considered that since the resistance in the welding zone of stainless-steel pipe for STS 205 is dropped in the room temperature or artificial seawater environment with increased temperature, the tendency that the corrosion occurs is increased.

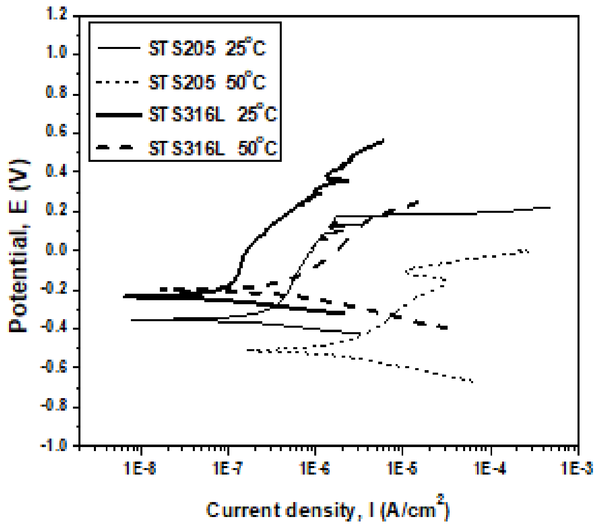


Fig.2 Potentiodynamic polarization curves of specimen welds in NaCl solution

3.3 Pitting Potential and Pitting Behavior in base metal and welding zone of STS 205 and STS 316L

Fig. 3 is showing the cyclic potentiodynamic polarization curve of base material and welding zone of STS 205 and STS 316L in the NaCl solution at 25℃ and 50℃. Table 2 is showing the pitting potential ($E_{pit.}$) in the welding zone of STS 205 and STS 316L by analyzing the cyclic potentiodynamic polarization curve. The pitting potential of the base material and welding zone of STS 205 was measured as 185 and 27 ㎷, respectively at the room temperature and that of STS 316L was measured as 530 and 405 ㎷, respectively at room temperature. It is observed that since at the room temperature and at 50℃, the pitting potential of base material and welding zone of STS 205 was measured low than STS 316L, the pitting corrosion occurs a lot in STS 205 than STS 316L. The pitting potential is the potential occurred as the pitting corrosion is generated locally and it is known that if the value of pitting potential is lowered, the resistance against the pitting corrosion is lowered[8].

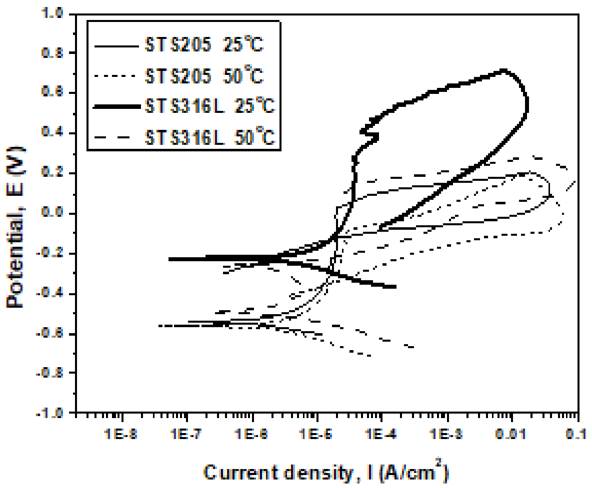


Fig.3 Cyclic potentiodynamic polarization of specimens welds in NaCl solution

Table 2: Pitting potential of specimens base metal and welds in NaCl solution.

Specimens	Region	Pitting potential (㎷)	
		3.5% NaCl Solution	
		25℃	50℃
STS 205	Base	185	-45
	Welds	27	-76
STS 316L	Base	530	158
	Welds	405	145

Particularly, since the sensitive welding zone of STS 205 in the artificial seawater environment at 50℃, the temperature increased than the room temperature, was measured as about 221㎷ lower than STS 316L, the pitting corrosion occurs a lot in the welding zone of STS 205 than STS 315L together with the value of corrosion current density and the resistance against the pitting corrosion is lowered than STS 316L.

Fig. 4 shows the results of observing the surface of base material and welding zone of STS 205 and STS 316L using SEM after the cyclic potentiodynamic polarization test. According to the SEM observation results, the pitting corrosion was found in the surface of base material and the welding zone of both STS 205 and STS 316L in the NaCl solution at room temperature and 50℃. As the size of pitting corrosion of base material and welding zone of STS 206 at room temperature and 50℃ was in the range of 60～140㎛ and that of STS 316L was in the range of 40～60㎛, it is observed that the pitting corrosion behavior of the base material and the welding zone of STS 205 in the artificial seawater environment at room temperature and increased temperature became greater than STS 316L.

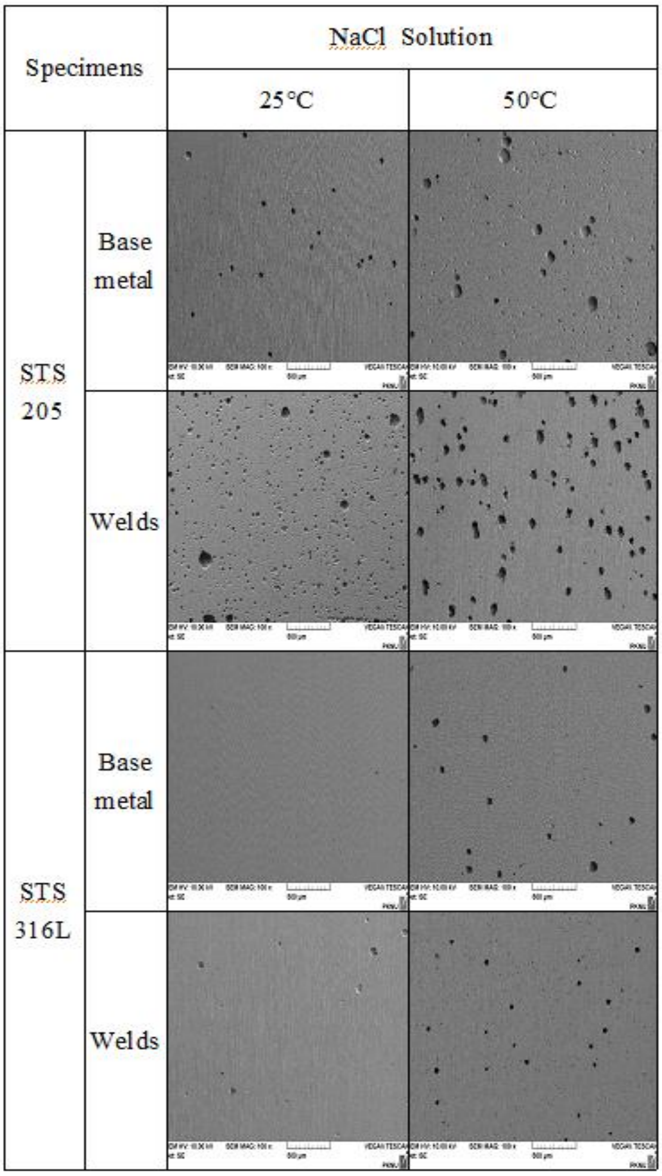
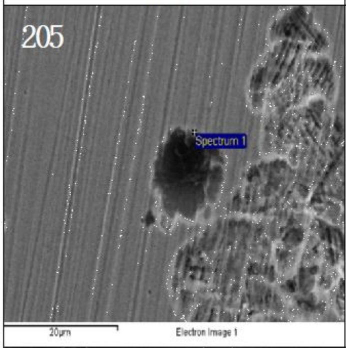


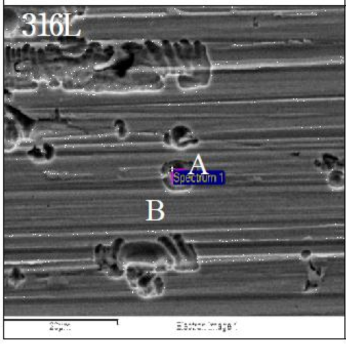
Fig. 4 SEM micrographs of specimens base metal and welds after cyclic polarization test in NaCl solution.

Fig. 5 shows the results of analyzing the welding zone of STS 205 and STS 316L in the 3.5% NaCl Solution at 50℃ using SEM/EDX. According to the results of SEM observation, it is observed that the pattern of pitting corrosion size in the welding zone of STS 205 and STS 316L are different, the pitting corrosion occurred locally and there is carved area around them. Generally, since in the artificial seawater environment, there is chlorine ion, the passive film is growing slowly and as the chlorine ion is adhered to the film increasing the vacancy concentration and causing the local exfoliation of film[9].

SEM	EDX



Element	wt.%	at.%
Si K	0.38	0.75
Cr K	16.05	17.00
Mn K	9.39	9.41
Fe K	71.22	70.22
Ni K	0.88	0.83
Cu K	2.08	1.80
Totals	100	100



Element	A wt.%	B wt.%
Si K	0.27	0.64
Cr K	20.79	18.85
Fe K	68.07	66.56
Ni K	9.65	11.45
Mo K	1.22	2.50
Totals	100	100

Fig. 5 SEM/EDX results of pitting region from specimens welds in 50℃ NaCl solution.

Therefore, it is observed that in STS 205, the size of pitting corrosion is bigger and the carved area is widely distributed on the surface of welding zone. In the results f analyzing the welding area with EDX, in the pitting corrosion of welding zone of STS 205 and STS 316L, Cr was measured as about 16 and 20 wt.%, respectively, which is deemed that since in the early stage of corrosion, the thin chromium oxides is generated as shown in Fig. 2 and 3 and the film is exfoliated by the chlorine ion, Cr was measured inside and outside of the pitting corrosion. In the results of comparing and reviewing the Cr content inside of the fine pitting corrosion generated in the welding zone of STS 316L and surrounding zone, Cr content in the welding zone was about 20 wt.% measured higher by 3% than the base material, which is deemed that as the cathodic reaction[10,11] occurs actively around the fine pitting corrosion by the diffusion of Cr ion generating Cr oxides continuously, Cr content is measured high. In addition, Mo content inside of pitting corrosion and surrounding area was measured as 1.22wt.% and 2.50 wt.%, which is deemed that the Cr oxides can be maintained by Mo and Mo is served as inhibiting the growth of pitting corrosion[12,13]. Therefore, as shown in Fig. 4, since the size of the pitting corrosion in the welding of STS 316L was smaller than STS 205 and the distribution of pitting corrosion was small, it was confirmed that adding Mo has impact on the pitting corrosion behavior in the welding zone of STS 316L.

IV. CONCLUSION

In the results of analyzing the electrochemical characteristics of the welding zone of STS 205 and STS 316L welded with GTAW by SEX/EDX, following conclusion was obtained.

1) As in the corrosion current density in welding zone at 25℃ and 50℃, STS 205 was measured 1.5 times and 1.3 times than the STS 316L, it was confirmed that the corrosion resistance of the STS 205 in the artificial seawater was lower than STS 316L.

2) In the pitting potential ($E_{pit.}$) in the welding zone at 50℃, STS 205 was measured low by 221㎷ than the STS 316L, the pitting corrosion of STS 205 is greater than STS 316L.

3) After the cyclic potentiodynamic polarization test in the solution at 50℃, Mo content inside and surrounding area of STS 316L was about 1.22 wt.% and 2.50 wt.%, which is deemed that it inhibits the growth of pitting corrosion and the pitting corrosion resistance in the welding zone of STS 316L is superior than the STS 205.

Acknowledgements

This work was supported by a Research Grant of Pukyong National University (2017 year).

REFERENCES

[1] J. C. Scully. : Stress corrosion crack propagation: A constant charge criterion : Corrosion Science., 1975: 15: 207-224.

[2] T. R. Beck and S. G. Chan. : Experimental Observation and Analysis of Hydrodynamic Effects on Growth of Small Pits : Corrosion., 1981: 37: 665-671.

[3] G. T. Burstein. et al. : Origins of pitting corrosion : Corros. Eng., Sci. Tech., 2004: 39: 25-30.

[4] J. R. Davis. et al. : Stainless Steels : ASM Specialty Handbook, The Materials Information Society., 1996: 2: 13-37.

[5] Stephen D. Cramer and Bernard S. Covino, Jr. : Corrosion, Materials., ASM Handbook., The Materials Information Society., 2005: 13: 54-74.

[6] B. W. Lee and H. L. Choi. : Corrosion, Characterization of Fe-aluminide Alloys with Various Sulphuric Acid Solution : J. of KSPSE., 2006: 10: 83-88.

[7] B. W. Lee and S. M. Joe. : A Study on the Welds Characteristics of Stainless Steel 316L Pipe Using Orbital Welding Process : J. of KSPSE., 2010: 14: 71-77.

[8] F. Tehovnic and B. Arzensek et al. : Microstructure Evolution in SAF 2507 Super Duplex Stainless Steel : Material and Technology., 2011: 45: 339-345.

[9] Yang and J. L. Luo. : The hydrogen-enhanced effects of chloride ions on the passivity of type 304 stainless steel : Electrochimica Acta., 2000: 45: 3927-3937.

[10] P. C. Pistorius and G. T. Burstein. : Aspects of the effects of electrolyte composition on the occurrence of metastable pitting on stainless steel : Corrosion Science., 1994: 36: 525-538.

[11] W. Tian. et al. : Metastable pitting corrosion of 304 stainless steel in 3.5% NaCl solution : Corrosion Science., 2014: 85: 372-379.

[12] H. C. Choe and K. H. Kim. : The Pitting Behavior of Ion-Nitrided Austenite Austenite Stainless Steel(II) : J. of the Kor. Inst. of Met. & Mater., 1995: 33: 475-482.

[13] M. B. Ives. et al. : Corrosion behaviour of molybdenum-implanted stainless steel : Corrosion Science., 1990: 31: 367-676.