Research on Corrosion Behavior of Duplex Stainless Steel 2205 in Multi-Medium Environment

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Abstract
An experimental research on corrosion behavior of duplex stainless steel 2205 in multi-medium environment with different temperature, pH, chlorine ion content was done in this paper, the experiment methods of which were constant load tensile, SCC Stress Corrosion, Slow Strain Rate Test (SSRT), and the anti-corrosion capability of the duplex stainless steel 2205 was explained. The results showed that, duplex stainless steel 2205 performed well on anti-corrosion even in rigorist corrosive environment which was simulated the virtual environment. The research on corrosion behavior of duplex stainless steel 2205 would supported the relevant study of duplex stainless 2205, material selection of pressure vessel design in corrosive environment, and safety assessment of facilities in use with rich experimental data.
Keywords: DUPLEX STAINLESS 2205, CORROSION BEHAVIOR, EXPERIMENTAL METHODS, PH, TEMPERATURE, CHLORINE ION CONTENT, ANTI-CORROSION CAPABILITY.

1. Introduction

With the significant advantanges of yield strength, especially corrosion resistance than stainless steel 316 and 317L, the duplex stainlesss steel 2205 is more and more applied in pressure vessel, high pressure storage tank, high pressure pipe, heat exchanger and so on[1-4].

However, because the shortcomings such as lower plastic toughness than austenitic stainless steel, particularly at the medium temperature which will show brittle fracture behavior, the application of duplex stainless steel 2205 is slowed down in a certain degree[5-8].

In this paper, the corrosion behavior of duplex stainless steel in multi-medium with different pH, temperature, chlorine ion content was researched by 3 kinds of experimental methods, and the performances was explained.

2. The Preparation of Test Material and Corrosive Medium

2.1. Test Material Preparation

The test material was made into plates sample with 8mm thickness which was solid solution, and 100% UT and PT were carried out on these samples according to relevant standard which were assessed as I degree[9]. The SMAW was used in the butt welding on these sample plates according to the rules showed in Table 1. The chemical component and mechanical properties of the weld metal were showed in Table 2 and Table 3. The rule of the heat treatment on these samples was showed in Table 4, which were using as carbon steel lining. RT and PT were carried out on these samples according to relevant standards, which were assessed as II degree and I degree[9].

Table 1. Weld Rule

Item	Specification
Groove type	V
Bevel angle	65°
Power source	DC
Power polar	Reverse
Pre-welding heat treatment	NO
Interlayer-temperature	<180°C
Pre-welding norms	Φ3.2mm:bottom
	Φ4.0mm:weld
Pre-welding current/ Voltage	Φ3.2mm:90~110A /22~24V
	Φ4.0mm:150~170A/22~26V
Weld speed	Φ3.2mm:120mm/min
	Φ4.0mm:160mm/min

Table 2. The chemical component of the weld metal of duplex stainless steel 2205

Element	Content	Element	Content
C	0.49	*Cr*	22.53
Si	0.41	*Ni*	8.10
Mn	0.019	*Mo*	2.66
S	0.019	*N*	0.15
P	0.020		

Table 3. The mechanical properties of the weld metal of duplex stainless steel 2205

Item	Value	Item	Value
R_m/MPa	≥885	*A*/%	≥65
A_{KV}/J	WM≥67	*HB*	WM≥266
	HAZ≥70		HAZ≥254
	BM≥175		BM≥254
Bend *D*=16mm	Qualified		

Table 4. Heat treatment rule

Item	Specification
Heat treatment temperature	620±5ºC
Holding time	0.75h
Cooling mode	cooling to 190ºC in furnace then cooling in air

2.2. Corrosive Medium Preparation

According to the actual use environment of duplex stainless steel 2205, 4 kinds of corrosive medium were prepared, the components of which were showed in Table 5.

Table 5. The components of the corrosive medium

Medium Components	M1	M2	M3	M4
$Cl^-/\times10^3 mg\cdot L^{-1}$	170	100	57	1
$F^-/mg\cdot L^{-1}$	40	40	0	0
Na^+	Other			
P_{CO_2}/MPa	5.0	2	2	1

3. Experimental Methods and Results Analysis

3.1. Constant Load Tensile

According to the method of constant load tensile[10], the experiment was carried out on the plates samples which were 20mm×2mm, in the condition of that the loading stress ranged from 0.6σ_s to 0.95 σ_s ,pH value increased from 2.8 to 3.2, and the test temperature was kept at 25ºC±1ºC, and the maximum cycle was 720h. It was found that the samples did not lose fail in the whole test period when the loading stress under 0.95σ_s , while the samples fail in the test period when the loading stress exceeded 0.95σ_s ,and the curve of the loading stress was showed in Figure 1,the fracture morphology were showed in Figure 2 and Figure 3.

The crack propagation mode was brittle fracture, which were mainly concentrated in the ferrite region and extended to the grain boundaries of ferrite and

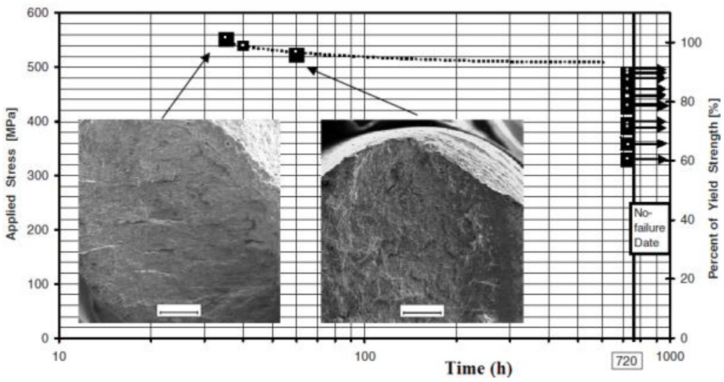

Figure 1. The loading stress and failure time

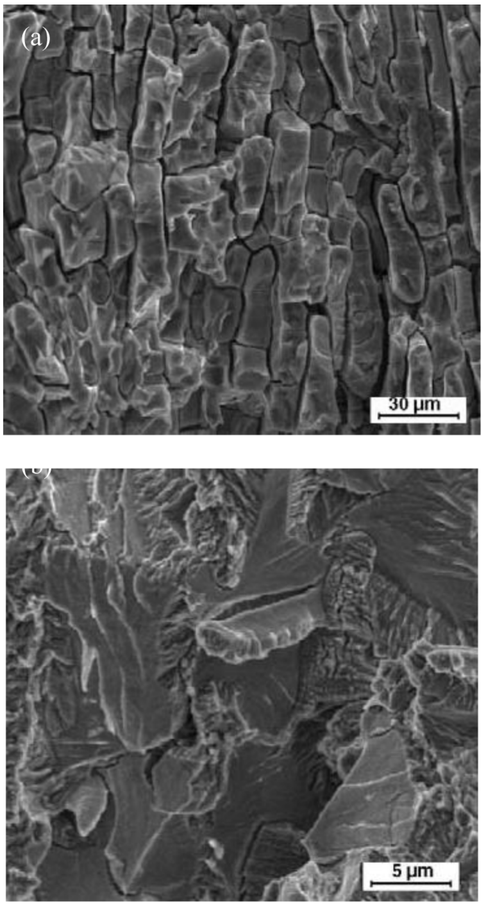

Figure 2. The fracture morphology when the loading stress was 0.95 σ_s (a) 30µm (b) 5µm

austenite, while there were only small dimples in the austenite. It was said that in the stress corrosion process the ferrite would adsorb H and become brittle when the samples immersed in the medium with H_2S, and with the loading stress increasing the ferrite would fail caused by a certain degree of hydrogen induced embrittlement, while the austenite would only tear in a certain degree, which were showed in Figure 4.

3.2. SCC Stress Corrosion

According to the method of SCC stress corrosion[11][12], the bending test was carried out on the U type samples, the test data was showed in Table 6, and macro crack on the sample (142ºC) after the stress corrosion was showed in Figure 6.

It could be found from the Table 6 that, when the test temperature was under 100 ºC there was no macro crack during the test period (504h); when the test temperature was under 110ºC, macro crack occurred on the welded joint and the heat-affected zone of the samples; when the test temperature was above 120ºC, macro crack also occurred on the base metal besides the welded joint. Besides, the macro crack occurrence time and the crack penetration time of the welded joint were both longer than those of the base

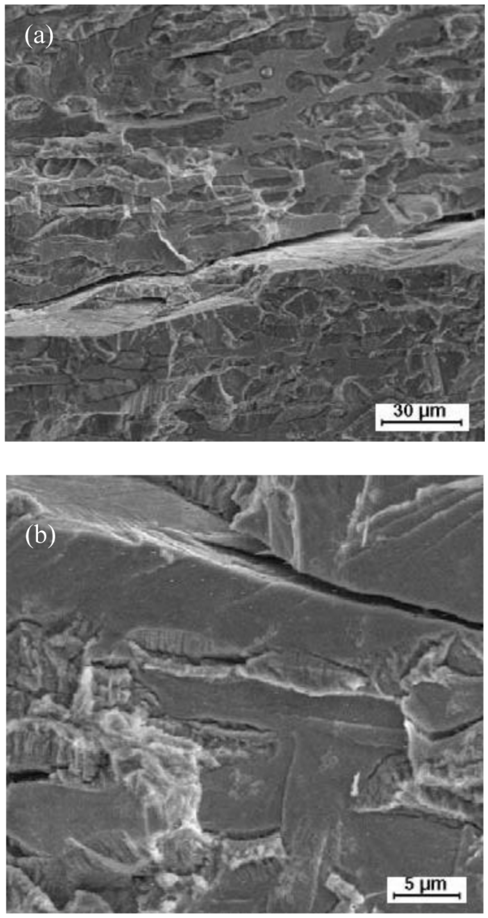

Figure 3. The fracture morphology when the loading stress was 1.05 σ_s (a) 30µm (b) 5µm

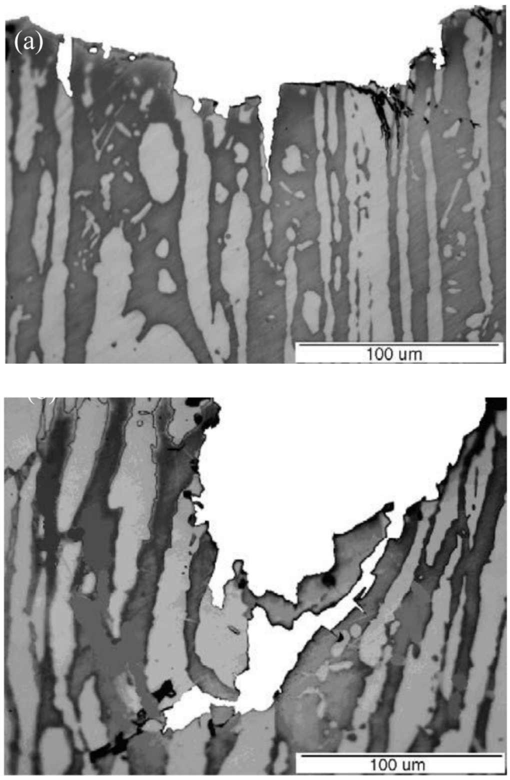

Figure 4. The crack propagation mode under different loading stress condition (a) 0.95 σ_s (b) 1.05 σ_s

metal, and the crack amount of the welded joint was more than those of the base metal in the same area. From above all, the anti-cracking ability of the base metal was better than that of welded joint.

Table 6. Bending test data of U type samples

LOC	N	ID	t/ºC	T_1/h	T_2/h	A/branch
Base metal	1	1 2 3	154	172 169 149	195 198 194	3, 2, 3
	2	4 5 6	142	278 370 380	412 446 435	1, 2, 2
	3	7 8 9	120	398 >504 476	>504	1, 0, 1
	4	10 11 12	110	>504	/	flawless
	5	13 14 15	100	>504	/	flawless
Welded joint	1	1 2 3	154	148 171 154	194 191 189	3, 4, 3
	2	4 5 6	142	274 250 249	360 384 384	2, 3, 2
	3	7 8 9	120	371 384 395	>504	2, 1, 1
	4	10 11 12	110	456 >504 >504	>504	1, 0, 0
	5	13 14 15	100	>504	/	flawless
	6	16 17 18	90	>504	/	flawless

* note: LOC: Location; N: Test number; ID: Sample ID; t : Test temperature; T_1 : Macro crack occurrence time; T_2 : crack penetration time; A: Crack amouts

Figure 5. The macro crack on the sample after the stress corrosion (142ºC)

As was showed in Figure 6 that the crack propagation model and morphology of the samples after 120h stress corrosion in the boiling saturated $MgCl_2$ solution, that the crack grown from the surface to interior

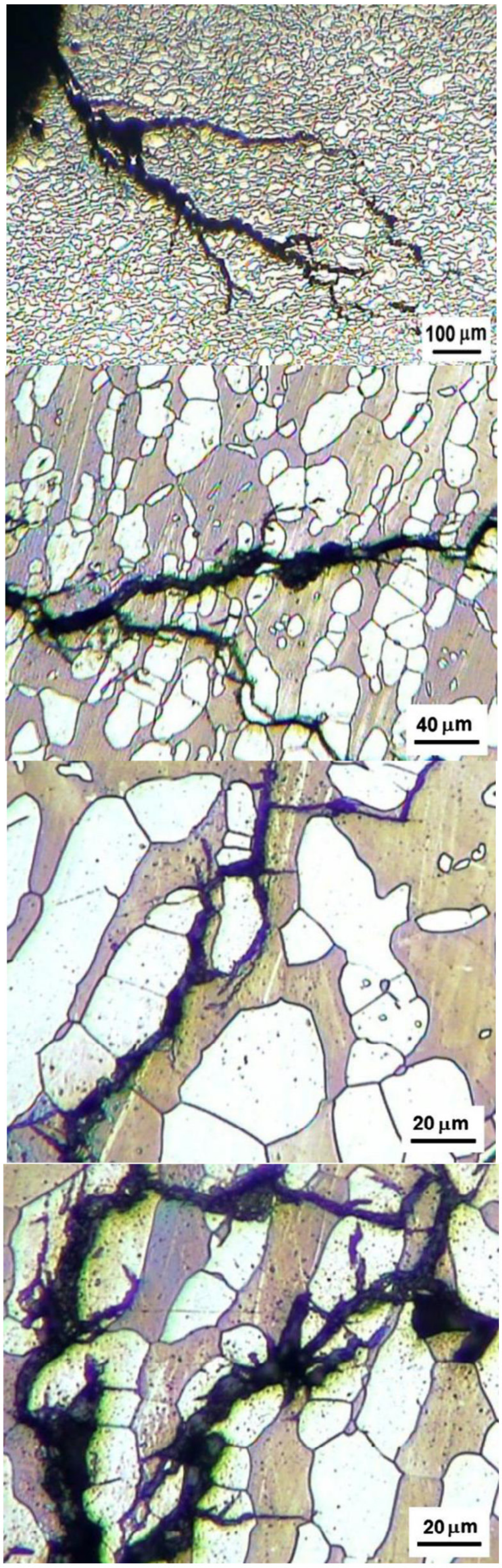

Figure 6. The crack propagation model and morphology of stress in $MgCl_2$ solution

as the corrosion time went on, and new branches continuously emerged along the way, which were almost along the grain boundaries of ferrite and austenite. Therefore, the crack propagation mode of stress corrosion was different from that in the H_2S medium, but was similar to that in the chlorine solution.

3.3. SSRT

At the instance of the actual use environment, the SSRT was carried out on the samples, of which the strain rate was 10^{-6}/sec, the test temperature was 80ºC, and the corrosive medium was M1 in which the pH value was 4, while the contrast test was in air, and the stress-strain curves of the SSRT in M1 and air were drew in Figure 7. The initial sections of the two curves described the linear elasticity phase which were nearly overlapped with each other; the two curves obviously separated with each other when the samples turned into the elastic-plastic phase; the fracture started at 6% strain and ended at 9% strain when the samples were in M1, comparing that started at 20% strain and ended at 28%. Therefore, the samples of the SSRT in M1 were seriously brittle.

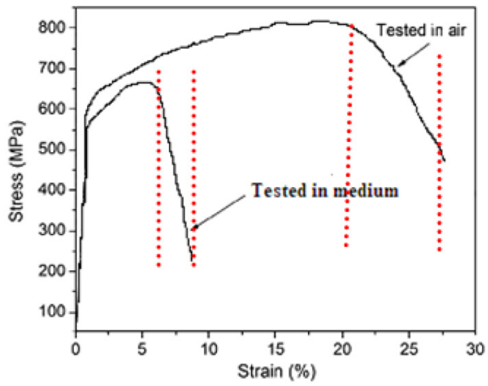

Figure 7. The stress-strain curves of SSRT

There were many macro cracks in the area of welded joint and heat-affected zone, the size of the area was about 5~6cm, and the secondary crack occurred, which were showed in Figure 8.

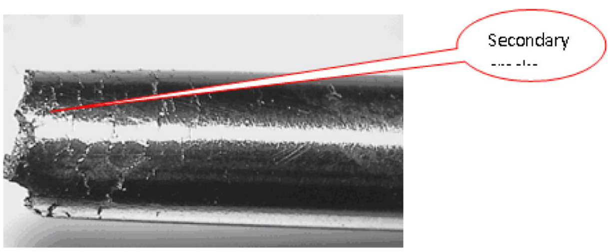

Figure 8. The morphology of the macro crack and the secondary crack

As was showed in Figure 9 that crack initiate on the surface as well as in the interior, which illustrated that diffusible hydrogen caused the metallographic structure brittle when the samples were in H_2S medium. Furthermore, cracks became slender or terminated in the area of austenite (labeled in red circle), which was consistent with the explanation in paper [13].

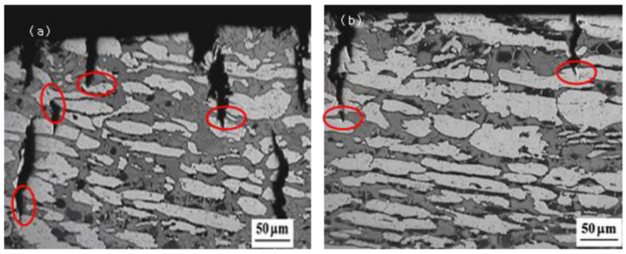

Figure 9. The morphology of SSRT crack

Conclusions

Constant load tensile test was carried out according to NACE TM0177 when the loading stress ranged from 0.6σ_s to 0.95σ_s, the sample did not fail during the whole test period (720h); when the loading stress exceeded 0.95σ_s, the sample failed and the fracture mode was mainly brittle fracture which could be deduced from the cleavage crack, and during the loading process the structural embrittlement of the sample in multi-medium environment started from the ferrite region to the austenite region where the structural embrittlement was tiny.

As the SCC stress test indicated that, the crack propagation mode was similar to the mode of austenitic stainless steel in chlorine solution, which developed from the corrosion surface to the interior along the grain boundaries of ferrite and austenite.

As SSRT showed that, the embrittlement was serious with many secondary cracks occurring on the sample when it was in the multi-medium environment, and the macro crack occurred in the area of welded joint and heat-affected zone.

Hydrogen induced embrittlement primarily started from the ferrite region in H_2S solution.

Acknowledgements

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Study on Damage Failure Criterion of Concrete under Sulfate Attack and Drying-Wetting Cycles

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