STUDY ON CORROSION FAILURE ANALYSIS AND MECHANISM OF STAINLESS STEEL PIPE WELDING JOINT IN SEAWATER

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Abstract

The problem of corrosion leakage of seawater desalting pipe system causes great economic loss of freshwater supply. By observing and concluding corrosion leakage pipes in the scene, we find that the leakage places of seawater corrosion are on the pipe welding joint and nearby.

In this paper, we lucubrate on the seawater corrosion failure in the field of steel pipe welding joint and nearby. By means of the analysis of chemical elements, metallic phase experiments, corrosion rate experiments, phase analysis of X-Ray Diffraction, σ phase discrimination etc, we find a corrosion failure mechanism of seawater desalting pipes.

Keywords: Seawater corrosion; Corrosion failure analysis; Heated affected zone; σ phase

1 Introduction

A seashore seawater desalination handling equipment pipeline presents leakage accident. By observing in the scene, we find that the low-pressured sections not present leakage and the high-pressured section's leakage is serious. All the leakage places of seawater corrosion are on the pipe welding joint and nearby, and the effects are not good after many times mending. In the paper, we lucubrate on the seawater corrosion failure analysis in the field of steel pipe welding joint and nearby. By means of the analysis of chemical elements, metallic phase experiments, corrosion rate experiments, phase analysis of X-Ray Diffraction, σ phase discrimination etc, we obtain the primary factor of corrosion failure. Through a series of analysis methods, we discover the corrosion failure mechanism of stainless steel in seawater, and lay the further foundation for solving corrosion leakage.

2 Experiment method

Experiment pipe is 00Cr18Ni14Mo2Cu2 austenitic stainless steel. The ordinary manual electric arc welding method is used to execute welding without heat treatment after welding. We analyze the material of welded joint and nearby. Finally, by means of the analysis of chemical elements, metallic phase experiments, corrosion rate experiments, phase analysis of X-Ray Diffraction, σ phase discrimination etc, we confirm the corrosion factors and the corrosion mechanism.

2.1 Chemical element analysis

Experiments of energy spectrum analysis and quantitative chemical element analysis have been done in the field of WZ, HAZ and BMZ respectively. Fig.1, 2 and 3 show the energy spectrum graphs in the field of WZ, HAZ and BMZ. Conclusion data show in Table 1.

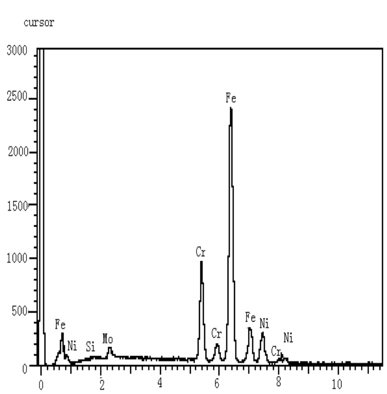

Fig1 BMZ energy spectrum graph

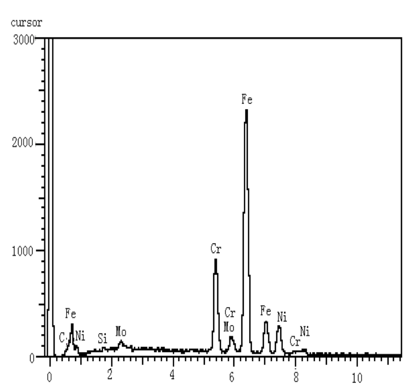

Fig2 HAZ energy spectrum graph

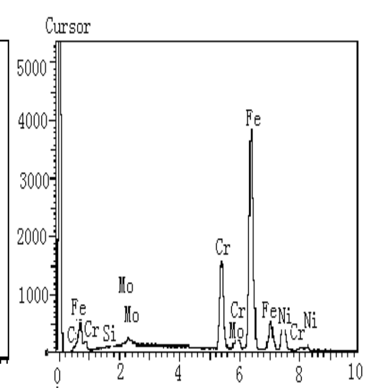

Fig3 WZ energy spectrum graph

Zones \ Elements	*Si*	*Mn*	*Ni*	*Cr*	*Mo*	*Cu*
Weld zone	0.35	paucity	14.13	17.74	1.32	paucity
Heat-affected zone	0.35	0.81	13.29	15.90	1.60	1.48
Base metal zone	0.21	1.03	12.65	16.38	1.69	1.87
GB/T14976-2002 00Cr18Ni14Mo2Cu2	≤ 1.00	≤ 2.00	12.00～16.00	17.00～19.00	1.2～2.75	1.00～2.50

Table 1 chemical elements（other: Fe）/mass percent

Note: content of C, S, P, Si and so on are according to the GB/T 14976-2002 standard about 00Cr18Ni14Mo2Cu2. Little difference exists in the WZ and HAZ about content of C, S and P etc.

2.2 metallographic experiments

The experimental materials are sampled from WZ to BMZ. The results are shown in Fig.4 to Fig.6 (metallurgical inclusion) and Fig.7 to Fig.9 (metallurgical structure).

2.3 Corrosion experiments

By SCE (mercury/calomel-saturated KCl) reference electrode, the working electrode's potential is measured. Black platinum electrode is used as auxiliary electrode, and the test samples are sealed by 407 synthetic glue. Electrochemical experiment medium is 4.35 % KCl water solution at 25 ℃. The effective area of working electrode is about 0.5 square centimeters, and the scanning rate is about 2 millivolts per second. The electrochemical experiment is done respectively with the materials of BMZ, WZ and HAZ, and the results of the electrochemical experiment are shown in Fig. 10 to13.

By the computer numerical fitting calculation and the three-parameter method of low polarization curve, the corrosion electrochemical dynamic parameter, the corrosion current and the corrosion rate of BMZ, WZ and HAZ are computed by correlated software. Fitting data results are shown in Table 2.

By means of the polarization curves, we can find that the electrode polarizes plus-minus conversion potentials of BMZ, WZ and HAZ are about -35mv, -104mv and -256 or -373 mV.

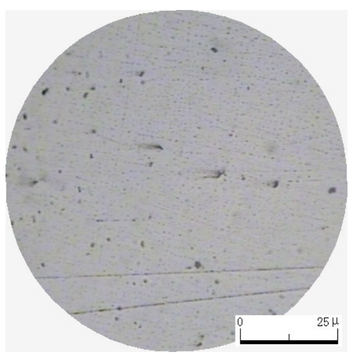

Fig. 4 HAZ metallurgical inclusion

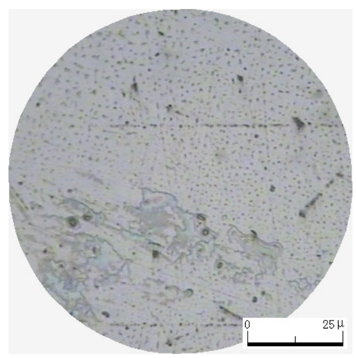

Fig. 5 WZ metallurgical inclusion

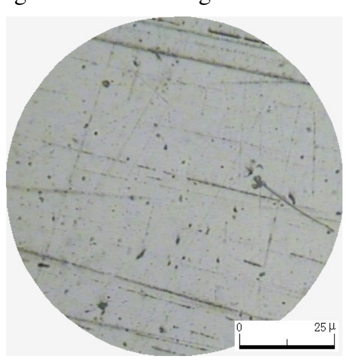

Fig. 6 BMZ metallurgical inclusion

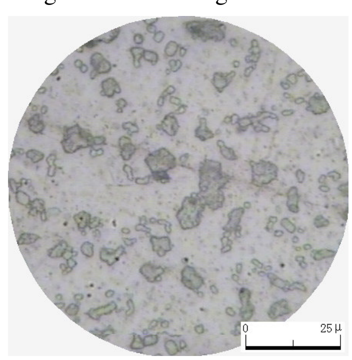

Fig. 7 HAZ metallurgical structure

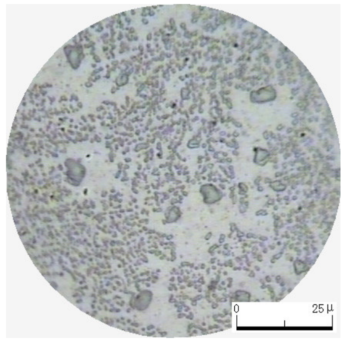

Fig. 8 WZ metallurgical structure

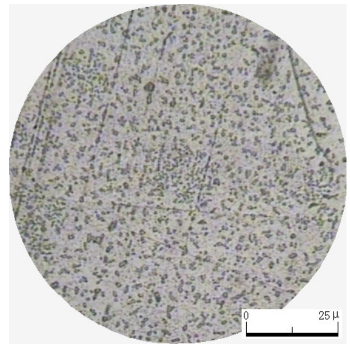

Fig. 9 BMZ metallurgical structure

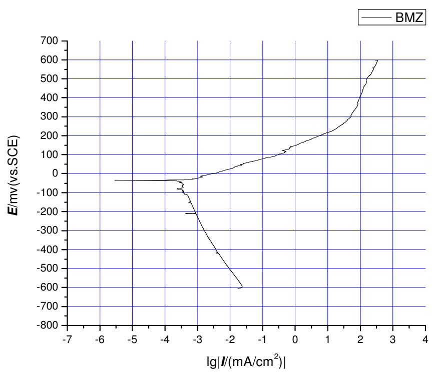

Fig 10 BMZ polarization curve

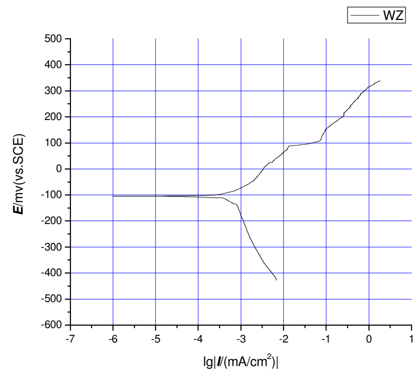

Fig 11 WZ polarization curve

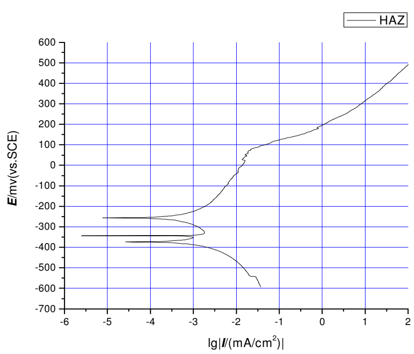

Fig 12 HAZ polarization curve

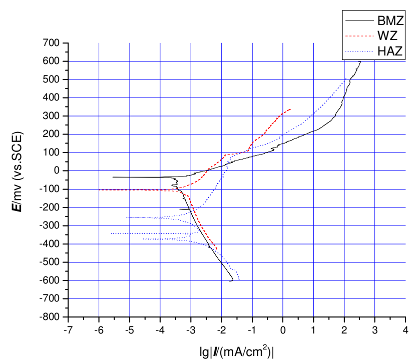

Fig 13 comparison polarization curve

items / zones	*Fitting accuracy*	*Tafel slope bA(mV)*	*Tafel slope bC(mV)*	*Corrosion current density（mA/cm2）*	*Corrosion rate（mm/a）*
Base metal zone	0.99	47.90	221.98	7.02×10-4	8.03×10-3
Weld zone	0.99	63.89	102.77	5.65×10-4	6.46×10-3
Heat-affected zone	0.95	32.99	202.70	4.61×10-3	5.27×10-2

Table 2 Fitting Data Results

Following the above experiment analysis, we can find that the heat-affected zone is the serious corrosion region.

2.4 XRD phase analysis

In order to discover the internal factor of corrosion occurrence, with phase analysis of X-Ray Diffraction to analysis the HAZ's phase composition. Fig. 14 is the peak graph of XRD diffraction, Table 3 is the sample peak graph of XRD.

Through the PDF card search, the definite phase is Cr0.19Fe0.7Ni0.11 (substrate) and Fe-Cr (σ phase). In order to obtain the content of σ phase in the phase, we use the XRD phase quantitative evaluation (direct correlation method).We know that the content of σ phase approximately is 4.68 %, the other is austenite [3].

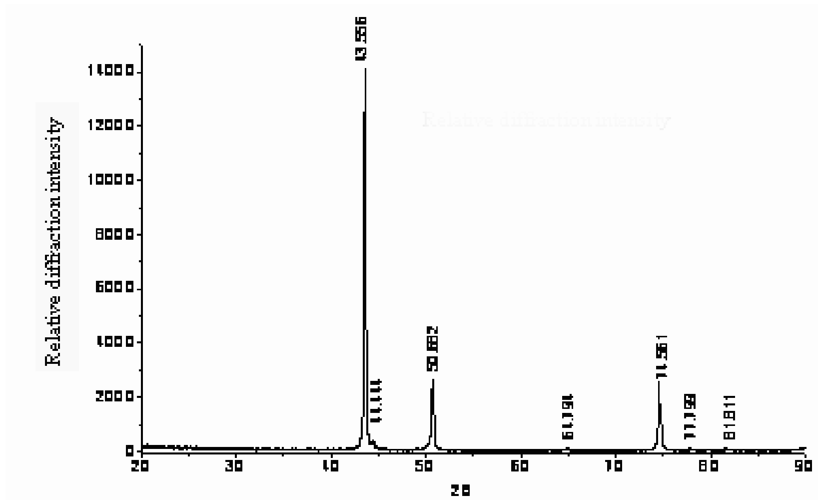

Fig 14 XRD diffraction peak graph

Table 3 XRD sample peak value and PDF card matching information

Phase No 1：33-0397 $Cr_{0.19}Fe_{0.7}Ni_{0.11}$												
Phase No 2：34-0396 Fe-Cr（σ phase）												
Sample peak	*2θ*	*d(A)*	*Peak value I*	*I%*	*Card number*	*d(A)*	*I%*	*h*	*k*	*l*	*2θ*	*△2θ*
1	43.556	2.0762	11012	999	33-0397							
2	44.444	2.0367	176	15	34-0396	2.035	999	1	1	0	44.521	-.077
3	50.682	1.7997	2036	184	33-0397							
4	64.794	1.4377	68	6	34-0396	1.438	199	2	0	0	64.836	-.042
5	74.561	1.2717	2102	190	33-0397							
6	77.881	1.2255	31	2								
7	81.811	1.1763	23	2	34-0396	1.174	499	2	1	1	82.064	-.253

2.5 σ phase discrimination

Use the alkalinity potassium ferricyanide peroxide solution (potassium ferricyanide 10 g + potassium hydroxide 10 g + water 100 ml) to discriminate the σ phase in the steel. The method is that the test specimen are boiled in this reagent for 2~4 minutes, the colour of austenite is obviously bright, σ phase's color is from brown to black .As shown in Fig.15.

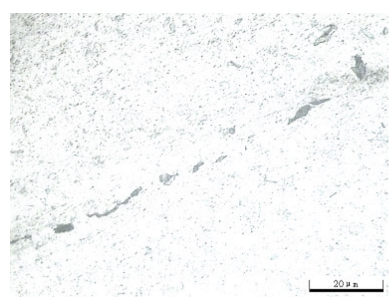

Fig 15 σ phase in Heat-affected zone and nearby of fusion-line, corrosion by alkalinity potassium ferricyanide peroxide solution 800×

3 Analysis of experimental results

Seawater includes lots of chloride ion, and the chloride ion is the major factor, of which stainless steel pipe occurs corrosion in seawater. The powerful binding force between chloride ion and metallic bond is very strong, and then chloride ion intrudes easily into passivating film and breaks passivating film. In the field of stainless steel pipe welded joint and nearby, as affected by heat cycle effect of welding, the welded joint field's metallurgical structure varies very much. Therefore, besides for destruction of chloride ion, the field tends to occurring local selective corrosion and intercrystalline corrosion. Especially, the effect of corrosion is more serious after welding without heat treatment [2].

In Table 1, the content of Cu is little in WZ, and the content of Cu is lower in HAZ than in BMZ. But in the seawater medium, the ability of steel's resistant corrosion affected by Cu element is very weak. The content of Mn is also little in WZ, and the content of Mn is lower in HAZ than in BMZ. Mn element in stainless steel exists in the form of MnS compound. In condition that it is heated by welding, the MnS compound is melted easily. And then it quenches and separates out. In the process, the MnS compound is solidified incompletely. Therefore minute sulfide is scattered around the MnS compound, and it promotes corrosion easily. So to sum up, lack of Mn element in WZ, the ability of resistant corrosion in WZ doesn't vary; the ability of resistant corrosion in HAZ is worse than others. Without the process of recrystallization, the ability of resistant corrosion also doesn't vary. Elements of Cr, Ni and Mo are the essential elements of seawater corrosion resistant steel, and the variation of their elements' content affects directly the abilities of its steel's resistant corrosion. In Table 1, such content means mass percent content, and Cr mass percent is the highest in WZ, higher in BMZ than in HAZ. So the ability of resistant seawater corrosion is the best in WZ, better in BMZ than in HAZ. Ni mass percent is the highest in WZ, higher in HAZ than in BMZ. The ability of resistant seawater corrosion is the best in WZ, better in HAZ than in BMZ. Mo mass percent is the highest in BMZ, higher in HAZ than in WZ. So the ability of resistant seawater corrosion is best in BMZ, better in HAZ than in WZ. Synthetically analysis provides that the variation of their elements' content affects the abilities of its steel's resistant corrosion, we can find the resistant seawater corrosion ability is better in WZ and BMZ than in HAZ.

Metallographic experiment results are shown in Fig. 4 to 9, Metallurgical inclusions with alcohol photographic developer are shown in Fig. 4 to 6. In Fig. 4, brittle oxide, which looks like black mini-dots without deforming, takes up majority, and plastic sulfide which looks like black dots with deforming takes up minority. It is HAZ metallurgical inclusion picture. In Fig. 5, most compound inclusions (sulfide and SiO2), which look like black annulus with alight center (black circle is sulfide and alight center is SiO2), and a little simple oxide and sulfide are shown [1]. It is WZ metallurgical inclusion. In Fig. 6, most of simple oxide which looks like black mini-dots, some simple sulfide which looks like black dots and a little compound inclusion (sulfide and SiO2) are shown. It is BMZ metallurgical inclusion picture. The results are according to data of Table 1.In Fig. 7, it is weld bond picture, and coarse HAZ metallurgical structure is shown on the left and subtle dendrite arm WZ metallurgical structure is shown on the right. In Fig. 8, homogeneous subtle austenitic structure is shown and it is BMZ metallurgical structure. In Fig. 9, subtle grain and dendrite arm metallurgical structure are shown and they are WZ metallurgical structure. With the view of metallurgical structure, why the ability of HAZ resisted seawater corrosion degrades more is correlated with coarse grain, non-homogeneous distribute and high content of inclusions. Why the ability of BMZ resisted seawater corrosion is good, is correlated with subtle homogeneous grain, which possesses homogeneous corrosion and stable passivating film. Why the ability of WZ resisted seawater corrosion is good, is correlated with subtle dendrite arm structure, which possesses homogeneous corrosion, stable passivating film and good intensity and corrosion resistant character.

Polarization curves measured by corrosion experiment are shown in Fig. 11 to 13. In the HAZ polarization curve, unstable phenomenon exists in the conversion process from cathode polarization to anodic polarization, especially near the weld bond. It correlates with the inhomogeneity of metallurgical structure in HAZ. In Fig. 11 to 13, the HAZ corrosion potential is more negative and is about from -256 to -373 mV. The BMZ and WZ corrosion potential is more positive and is about -35 mV and -104 mV respectively. By the computer numerical fitting calculation and the three-parameter method of low polarization curve, the results are shown in Table 2. The BMZ and WZ corrosion rate is about 8.03×10-3 and 6.46×10-3 millimeters per year (mm/a), respectively, and the HAZ corrosion rate is about 5.27×10-2 mm/a. Finally the HAZ corrosion is obviously speeder than the WZ and BMZ corrosion and even an order of magnitude, and the WZ corrosion rate is little slower than the BMZ corrosion rate.

Some datum point out that when there presents 5 % (volume) σ phase in the steel, the impact value will reduce to original 1/4. The appearance of σ phase may also reduce the oxidation resistance performance and cause the intercrystalline corrosion sensitivity. Due to the formation of chromium-rich σ-phase, there appear uneven Oxidation and intergranular corrosion in poor Chromium areas of the solid solution. X-ray diffraction phase analysis and identification of σ-phase experiment prove the existence of σ phase in HAZ and the content up to 4.68 %. When the content of σ phase reaches the excess marginal value, the heat-affected zone is prone to happen intergranular corrosion, which caused by σ phase. When the intergranular corrosion occurred, the state of imbalance will exist in passive film. Along with the development, the corrosion evolves into pitting corrosion, even produce much worse corrosion.

4. Conclusions

1. The content of σ phase in HAZ is too high and leads to intergranular corrosion, seriously reduces the life of the water pipeline.
2. The content of chromium is low in HAZ and separates out σ phase, the corrosion rate is big, and it indicates that the poor chromium causes the localized corrosion acceleration.
3. The stability of inclusion content, Microstructure shape, polarization curve in the weak polarization area indicate the resisted seawater corrosion performance.
4. The resisted seawater corrosion ability of stainless steel pipe welded joint and nearby have discrepancies, and the ability of HAZ is the worst; when welding we should pay attention to avoiding the appearance of σ phase.

Reference

[1] Shanghai Institute of Machinery Manufacturing Technology editor-in-chief, metallographic analysis technique [M], Shanghai: Shanghai Science and Technology Literature Publishing House, 1987,6.

[2] Ji Xiaomei, CAO Cunan, Material Corrosion Principles [M], Beijing: Chemical Industry Press, 2002, 9.

[3] Zuo Yansheng, Chen Wenzhe, Liang Wei, Modern materials analysis [M], Beijing: Beijing University of Technology Press, 2000, 12.

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