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Assessment of the sulfide stress corrosion cracking characteristics in the multi-pass weld of the A106 Gr B steel pipe †

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Abstract

Sulfide stress corrosion cracking (SSCC) in crude oil field environment containing hydrogen sulfide (H_2S) has been recognized as a material degradation and damage mechanism. Laboratory data and field experience have demonstrated that extremely low concentration of H_2S may be sufficient to lead to SSCC failure of susceptible materials. In some cases, sulfides may act synergistically with chlorides to produce SSCC failures. SSCC mechanism is a form of hydrogen embrittlement that occurs in high strength steels and in localized hard zones in weld of susceptible materials. In the heat-affected zones adjacent to the weld, there are often very narrow hard zones combined with regions of high residual stress that may become embrittled to such an extent by dissolved atomic hydrogen. On the basis of this understanding, SSCC tests were conducted with smooth specimens of the multi-pass welded ASTM A106 Gr B steel pipe used in the oil industries. And SSCC resistance according to the welding processes was evaluated. From the results, the weld by GTAW+FCAW showed the largest resistance against SSCC.

Keywords: HAZ(heat affected zones); SSCC(sulfide stress corrosion cracking); Residual stress; HE(hydrogen embrittlement)

1. Introduction

Welding is used in follows every industry and is associated with a very large part of the country's gross national product. Welding processes are vital in the production and maintenance of pipelines and power plants, in the areas of heavy construction. However, welding processes produce residual stresses and change the metal structure as a result of the large nonlinear thermal loading created by a moving heat source. These formidable residual stress generation and metallurgical change by fusion welding process increase the cracking driving force and reduce the resistance of brittle fracture as well as environmental fracture [1-3]. In particular, the welds are more sensitive to corrosive environments than base metal. It is a serious problem with many alloys as well as A106 Gr B steel pipe. A106 Gr B steel used in the heavy chemical plant is degraded by corrosive environments such as the chlorides, the sulfides, and pH in the crude oil. In addition, it is damaged during service by various corrosion mechanisms. It is particularly remarkable in the line of crude oil transportation and so on [1]. Therefore, It is very important to investigate and evaluate its fracture mechanism by the corrosion fatigue or stress corrosion cracking and the fracture characteristics on the welds of the material for the safety and integrity diagnoses of facilities, life prediction of degraded materials, and establishment of the economical inspecting term.

By the way, a study on the environmental strength evaluation or fracture mechanism analysis of welds is

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difficult due to the complex residual stress distribution, metallurgical exchanges in welding processes. Beside these reasons, the complicated test procedures and taking long test period also become the big problems. One common problem associated with welding is welding residual stress as well as distortion of the finished products. At present, in spite of the data and information on environmental strength and fracture characteristics needed for safe design and damage protection of the welded structures and facilities, they are poor in comparison with the others due to such reasons.

Thus, in this study, a sulfide stress corrosion cracking test, which is based on the NACE TM 0177-90 [4], on the multi-pass welded A106 Gr B steel pipe was conducted in 5.0wt.% NaCl solution saturated with H_2S gas at room temperature. And, the sulfide stress corrosion cracking characteristics according to the welding processes was assessed.

2. Experimental SSCC assessment of A106 Gr B steel weldment

2.1 Material and specimen

A multi-pass welded A106 Gr B steel pipe used in this study is widely used in various plants as well as crude oil plants. Its chemical composition and mechanical properties are illustrated in Table 1 and Table 2, respectively. Fig. 1 shows the cutting location of specimen from welded pipe and configuration [5, 6]. Specimen of Fig. 1 includes weld metal, HAZ (heat affected zone), and base metal within its gage length. The welding procedures are GTAW (gas tungsten arc welding), GTAW+SMAW (shield metal arc welding), GTAW+FCAW(flux cored arc welding), and FCAW. Their welding conditions are illustrated in Table 3.

The thickness of the pipe is 28.58 mm, and the inner diameter is 273.1 mm. All specimens were prepared in the vertical direction to the weld line as in Fig. 1. The groove for welding was machined in a compound bevel type. Since the asperity and oily particles on the pipe surface affect corrosion reaction of metal, the surface of every specimen was cleaned with acetone after polishing

Table 1. Mechanical properties.

	Yield Strength (Mpa)	Ultimate tensile Strength(Mpa)	Elongation
GTAW	380	502	44
GTAW+SMAW	380	502	44
GTAW+FCAW	380	502	44
FCAW	430	507	37

2.2 Test equipment

Stress corrosion cracking is defined as a mechanism of material damage by a combination of the static stress and the corrosion environment. Therefore, the corrosion environment established under the static loading condition has to be maintained constantly during the whole test period. In case of SSCC test using the sulfide hydrogen (H2S), since the sulfide hydrogen is very poisonous, it must not leak from components such as the corrosion cell, tubes, fittings, and so on during the test period. The corrosion cell used in SSCC test is as shown in Fig. 2. To maintain a constant SSCC test condition and to prevent degradation by corrosion, the corrosion cell was made by using acryl and engineering plastic.

The loading unit was made with a ring-type frame, load cell, and indicator as recommended by NACE

Table 2. Chemical composition of material.

	C	Mn	Si	S	Ni	Cr	Mo
GTAW	0.2	0.88	0.17	0.005	0.02	0.05	0.01
GTAW+ SMAW	0.2	1.02	0.25	0.005	0.02	0.06	0.01
GTAW+ FCAW	0.2	0.88	0.17	0.005	0.02	0.05	0.01
FCAW	0.06	1.18	0.41	0.01	0.01	0.02	0.01

Table 3. Welding condition.

A 106 Gr B	GTAW	GTAW+FCAW		GTAW+SMAW	
		GTAW	FCAW	GTAW	SMAW
GAS (%)	Ar 99.99	Ar99.99	Ar 80+CO2 20	Ar99.99	.
Flow rate (ℓ/min)	20	20	28	20	.
Filler metal	TIGFIL-T2	TIGFIL-T2	TIGFIL-T2	TIGFIL-T2	TEN ALLOY
Current (A)	109 - 175	135 -196	190 -215	128-199	99 - 137
Volts Range(V)	11 -13	9 - 10	22 -23	9 -10	18 -20
Travel speed (cm/min)	6 -13	6.2 -11.1	23.1 -39.5	6.1 -10.1	9 -14

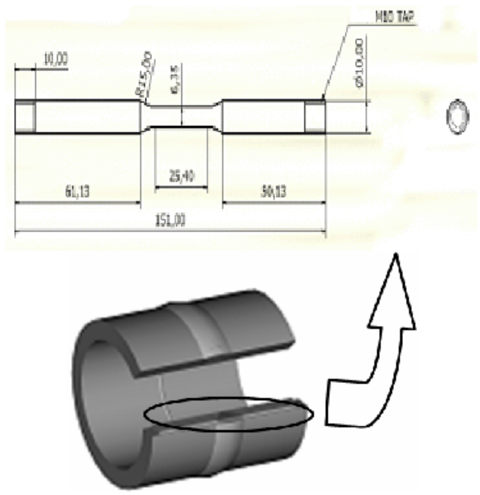


Fig. 1. Cutting location of specimen from welded pipe and configuration of SSCC test specimen.

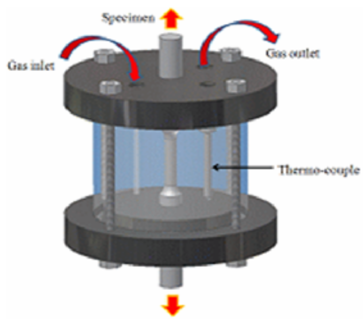


Fig. 2. The corrosion cell use in SSCC test.

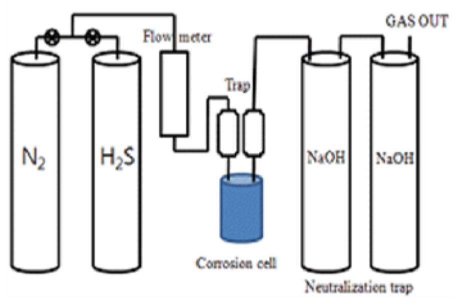


Fig. 3. Schematic diagram of the SSCC tester.

TMO177-90. In particular, by using flat type springs having high stiffness to the loading units instead of bolts, the variation of load applied to the test specimen could be constantly compensated during the test period. Fig. 3 illustrates a schematic diagram of the SSCC test equipment. Teflon tubes and fittings were used for the test equipment, and the connections between the tubes and corrosion cells were made by the SUS316 tubes. One of

Table 4. SSCC test condition.

Static load ($0.8\sigma_y$)	
Preprocess	N_2 gas purging for 20min H_2S gas saturation for 20min
Solution	5.0wt% NaCl+0.5wt.% CH_3COOH+Distilled water H_2S gas bubbling 20cc/min
Temperature	R. T.
Solution(pH)	2.7 - 4.0
Test period	720 hrs

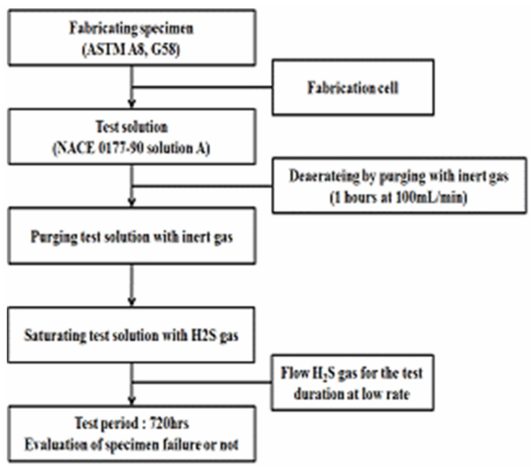


Fig. 4. Schematic SSCC test procedure.

the most important units in the SSCC test equipment is the neutralization unit. To maintain chemical equilibrium of the test solution in the corrosion cells through the SSCC test period, sulfide gas should be continuously supplied with a few bubbles per minute. Then, a neutralization unit should be provided for safe treatment of the sulfide gas flown out through the corrosion cells. In this study, the neutralization units as shown in Fig. 3 were provided with the reverse flow preventing units of solution.

2.3 Test condition and procedure

The SSCC test procedure and condition were based on NACE TMO177-90, and those are illustrated in Fig. 4 and Table 4. Corrosion environment was made up with 5.0wt.% NaCl+0.5wt.% CH3COOH solution at room temperature[4]. Dissolved oxygen in the test solution weakens the protective film generated by the corrosion products on the surface of the specimen and promotes corrosion reaction, so in order to remove the dissolved oxygen in the test solution, prior to test start, we purged with nitrogen gas for 1 hr at a rate of 100

Table 5. SSCC test result.

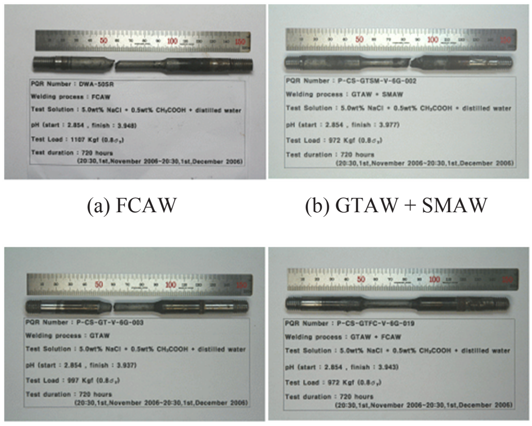
	Welding Process		Load(p) (N)	pH		Failure or not
				Start	End	
1	GTAW		9,800	2.85	3.99	Fail
2	GTAW		9,771	2.85	3.94	Fail
3	GTAW		10,016	2.85	3.99	Fail
4	GTAW	SMAW	9,526	2.85	3.96	Not fail
5	GTAW	SMAW	9,526	2.85	2.98	Fail
6	GTAW	SMAW	9.859	2.85	3.98	Fail
7	GTAW	FCAW	9,584	2.85	3.97	Not fail
8	GTAW	FCAW	9,526	2.85	3.94	Not fail
9	GTAW	FCAW	9,526	2.85	3.94	Not fail
10	FCAW		10,849	2.85	3.96	Not fail
11	FCAW		10,849	2.85	3.95	Fail
12	FCAW		11,025	2.85	3.98	Not fail

ml/min, and saturated the solution with sulfide hydrogen gas for 20 minutes at a rate of 100-200 ml/min. After the solution was saturated with sulfide hydrogen gas, a continuous flow of sulfide hydrogen gas was maintained at a rate of 20cc/min for the test duration (720 hrs). Static stress level applied to the specimens was 0.8σy (where σy: yield strength of A106 Gr B steel). SSCC resistances against the sulfide of specimens were assessed as fail or not fail during the test duration.

2.4 Test result and discussion

SSCC test results for weld of the A106 Gr B steel pipe are illustrated in Table 5.

After 720 hrs under the environment of sulfide hydrogen gas and static tensile stress of $0.8\sigma_y$, as illustrated in Table 5, all specimens by GTAW failed. And two cases by GTAW+SMAW and one case by FCAW failed. However, those by GTAW+FCAW showed good SSCC resistance, and did not fail. Since failure directions of all failed specimens were not 45° as shown in Figure 5, which means all specimens were failed not just by mechanical shear but by normal SSCC mechanism. That is, when the surface pits and cracks generated by SCC mechanism were grown to the critical depth or the critical size, they failed. These results were also certified by fracto-graphic observation. Failure positions of some cases among failed specimens were at HAZ of the weld. According to the result of the relationship between applied load and corrosion rate, it was evaluated that corrosion rate



(a) FCAW (b) GTAW + SMAW

(c) GTAW (d) GTAW +FCAW

Fig. 5. Specimen conditions after SSCC test.

increased. Because of weaker coherence as applied load, it could be happened easily of corrosive active factor invasion. As a result of the residual stress evaluation with the welding department with FEM or HDM(Hole drilling method), the highest residual stress occurred in the heat-affected zone and the welding department, not the base metal department. With the base on this, corrosive rate take place most quickly in the heat-affected zone existing tensile residual stress and then the rupture can be occurring in the heat-affected zone.

3. Conclusion

As a fundamental investigation for providing information on welding design and reliability of the A106 Gr B steel pipes, sulfide stress corrosion cracking of the A106 Gr B steel pipes with different welding processes was assessed under 5.0wt.% NaCl+ 0.5wt.% CH3COOH solution at room temperature and static stress level of $0.8\sigma_y$ for 720 hrs. From these results, the conclusions are as follows.

(1) For A 106 Gr B steel pipe weld, it is expected that the GTAW+FCAW welding process is the most recommended, considering the SSCC reliability and environmental design

(2) The failure at HAZ of the weld is due to the complicated reaction of welding residual stresses and SSCC mechanism.

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