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Detection and Characterization of Pitting Stress Corrosion Cracking on U- Bend of Austenitic SS304L under Chloride Concentration

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Abstract: Austenitic stainless steel is commonly used in refinery and chemical processing industry due to its excellent mechanical properties, heat resistance, weldability and corrosion resistance at various elevated temperature. Apparently, all 300 series of austenitic stainless steels are highly susceptible to Chloride induced Stress Corrosion Cracking (CI-SCC) when dealing with corrosive environment (hydrolysis of calcium, magnesium and chlorides salts) and tensile stress (applied or residual stress). In this project, the impact of sensitization on CI-SCC is examined using austenitic stainless-steel grade 304L (SS 304L). The specimens are shaped into U-bend as per ASTM G30 and exposed for long-term immersion test. U-bend samples are heat sensitized at 600ºC for 2 hours followed by air cooling. Samples are immersed in 0.1 wt%, 1.0 wt% and 3.0 wt% NaCl into the water bath at temperature of 28ºC (ambient condition) and 90ºC for 28 days. The specimens were monitored once in a week under visual examination of crack on the surface. Microscopic study was carried out to identify the CI-SCC and morphology of SS304L material.

Index Terms – Chloride Concentration, Corrosion Cracking, Austenitic Stainless Steel, Chloride induced Stress Corrosion Cracking

I. INTRODUCTION

Austenitic stainless steels are used extensively in chemical and nuclear plants on account of their excellent resistance to uniform corrosion, good fabric-ability, weld-ability, optimum combination of strength and toughness and as a result higher flaw tolerance and high resistance to radiation damage. Chloride induced stress corrosion cracking (CI-SCC) is a cracking damage mechanism under the combined action of tensile stress, co-rodents such as chloride environment and susceptible metal. Apparently, all 300 series of austenitic stainless steels are highly susceptible to CI-SCC when dealing with corrosive environment (hydrolysis of calcium, magnesium and chlorides salts) and tensile stress (applied or residual stress). In this project, the impact of sensitization on CI-SCC is examined using austenitic stainless-steel grade 304L (SS 304L).

Alloy 304L a T-300 series stainless steel austenitic, which has a minimum of 18% chromium and 8% nickel. Type 304L has a carbon maximum is 0.030. It is the standard “18/8 stainless” that is commonly found in pans and cooking tools. Alloys 304L is the most versatile and widely used alloy in the stainless-steel family. Ideal for a wide variety of home and commercial applications, Alloys 304L exhibits excellent corrosion resistance and has a high ease of fabrication, outstanding formability. The austenitic stainless steels are also considered to be the most weld-able of the high-alloy steels and can be welded by all fusion and resistance welding processes.

Austenitic stainless steel bar grade 304L was used as the test material. The element chemical composition and physical properties are provided in the table 1.1 and table 1.2 respectively.

Table 1.1: Percentage of Chemical Composition of Stainless Steel 304L

Grade	C	Mn	Si	P	S	Cr	Ni	Fe
Stainless Steel-304L	0.024%	1.57%	0.54%	0.038%	0.001%	18.1%	8%	71.73%

Table 1.2: Physical properties of Stainless Steel 304L

S. No.	Name of the physical property	Value

1	Densitylbm/in^3	0.285 at 68°F
2	Thermal Conductivity (BTU/hft. °F)	9.4 at 212 °F; 12.4 at 932 °F
3	Electrical Resistivity (x 10^{-6})	28.3 at 68 °F; 39.4 at 52 °F 49.6 at 52 °F
4	Modulus of Elasticity (psi x 10^6)	28
5	Coefficient of Thermal Expansion (in/in)/°Fx 10^{-6}	9.4 at 32-212°F; 10.2 at 32- 1000°F; 10.4 at 32- 1500°F
6	Specific heat (BTU/lb/°F)	0.1200 at 68°F to 212°F
7	Melting Range(°F)	2500 to 2590

II. LITERATURE SURVEY

A.N. Okpala, A et al., have investigated effect of sensitization on the corrosion of austenitic stainless steel in fresh water, and revealed the impact of Sensitization on the Corrosion of austenitic stainless steel, type 304L and 316L when immersed in fresh water at a temperature range of 550ºC – 750ºC followed by air cooling. On the other hand, a total of five sets of the samples of steel were given sensitization treatment by holding at a temperature range of 550ºC – 750ºC for different soaking time periods ranging from 30 minutes, 1 hour, 3 hours, 5 hours and 10 hours. The microstructure of the sensitized samples was observed under inverted metallurgical microscope. The corrosion rate of austenitic stainless steel type 304 and 316 was also determined using the total immersion technique. The result shows the corrosion rate for stainless steel type 304L increases progressively with increase in immersion time, while for stainless steel type 316L decreases progressively with increase in immersion time.

III. METHODOLOGY

A stainless-steel bar grade SS304L flat bar is machined into specimens of dimensions 200mmx25mmx5mm before they are stressed into U-bend shape as per ASTM G30. Stressing of U-bend specimen is accomplished in two-stage method by allowing the elastic strain to relax completely at the first stage and followed by the second stage.

The U-bend legs held straight by fastening with stainless steel bolts, washers and nuts which were pre-coated with a special epoxy-based composite paint (Pro-guard CN 200-SRB) to avoid galvanic corrosion at the contact. The U-bend SS304L specimen configuration is shown in fig.3.1.

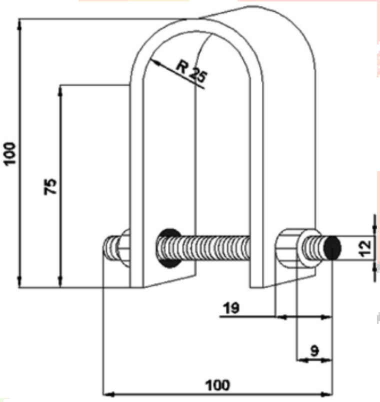

Fig.3.1: U-bend SS304L specimen configuration as per ASTM G30

The U-bend specimens are divided into two groups: as-received and sensitized. The as-received specimens are prepared as usual while the sensitized specimens are heat treated in a furnace (muffle furnace C-10P) at 600ºC for 2 hrs followed by air cooling to create sensitization inside the metal. All U-bent specimens were surface cleaned as per ASTM G1. Different concentrations of chloride solutions are prepared by dissolving 0.1, 1.0 and 3.0 wt% sodium chloride (NaCl) in de-ionized water, respectively. The solution pH was adjusted to 6.0.

Each specimen is immersed in a chloride solution filled in a beaker. The beaker top is covered with aluminum foil to avoid excessive evaporation. Two levels of temperature are tested: Ambient (28ºC) and 90ºC for total immersion duration of 20-30 days. For elevated temperature conditions, the samples are placed in a water bath chamber maintained at 90ºC, respectively. The test matrix below summarized the overall of the experiment to investigate the effects of the sensitized metal, different temperatures and chloride concentrations. There are 12 test specimens used to investigate pit stress corrosion crack, each specimen was tested under different conditions, details of the tests are provided in table 3.1

Table 3.1: Test matrix

Material: SS304L	**pH Value: 6.0**						**Duration: 28 Days**					
Temperature	28ºC (ambient condition)						90ºC					
Specimen category	**As-received**			**Sensitized**			**As-received**			**Sensitized**		
NaCl Concentration(wt %)	0.1	1.0	3.0	0.1	1.0	3.0	0.1	1.0	3.0	0.1	1.0	3.0
Specimen Number	1	2	3	4	5	6	7	8	9	10	11	12
Evaluation Method	Visual, Microscopic study under magnification 500x											

IV. EXPERIMENTATION

The U-bend specimens are divided into two groups: as-received and sensitized. The as-received specimens are prepared as usual while the sensitized specimens are heat treated in a furnace (muffle furnace C-10P) at 600°C for 2 hours followed by air cooling to create sensitization inside the metal.

Fig.4.1 (a) Fig.4.1 (b)

Fig.4.1: Shows specimen (a) Heat treated (b) Sensitized

All U-bent specimens were surface cleaned as per ASTM G1. Different concentrations of chloride solutions are prepared by dissolving 0.1, 1 and 3wt% sodium chloride (NaCl) in de-ionized water, respectively. The solution pH was adjusted to 6.0. Each specimen is immersed in a chloride solution filled in a beaker.

Fig.4.2 (a) Fig.4.2 (b)

Fig.4.2: Shows specimen immersion in NaCl bath (a) 0.1 Concentration (b) 1.0 Concentration

The test specimens were immersing in NaCl bath at two different temperatures of 28°C (Ambient condition) and 90°C for the duration of 28 days. The immersed specimens were observed once in a week to identify any presence of a crack on the surface. The specimens are returned to the microscopic test after 28 days, as the experiments are stopped and all specimens are extracted. They are visually checked, cleaned and subjected to metallographic examination.

Fig.4.3 (a) Fig.4.3 (b) Fig.4.3 (c)

Fig. 4.3: Shows specimen immersion in NaCl bath (a) at 28°C (ambient condition) (b) & (c) at 90°C

V. RESULTS AND DISCUSSIONS

The experimental results were obtained under the microscopic study at a magnification of 500X, after 28 days immersion of the specimen in NaCl bath under the temperature conditions of 28°C and 90°C. The images were captured on 12 specimens using the microscope at a magnification of 500X. It was revealed pitting corrosion spots on plain area as well as on curved areas which are shown in the fig.5.1 to fig.5.12 and discussed in detail in the conclusion section.

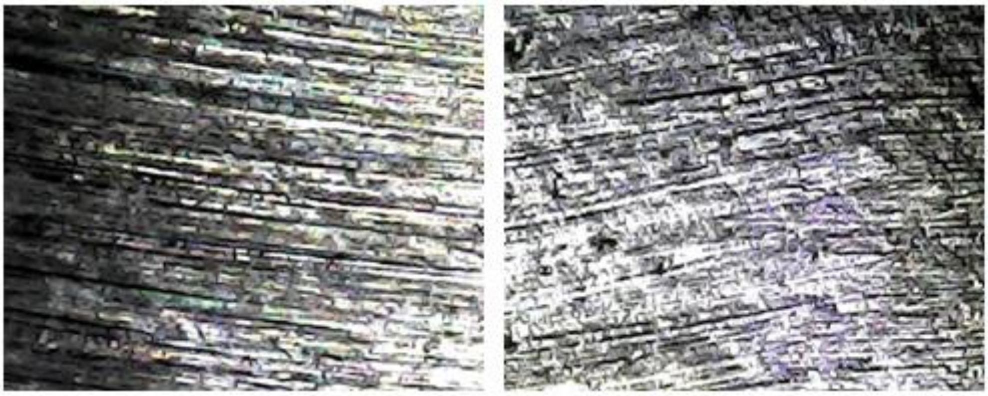

Fig.5.1 (a) Fig.5.1 (b)

Fig.5.1: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.1

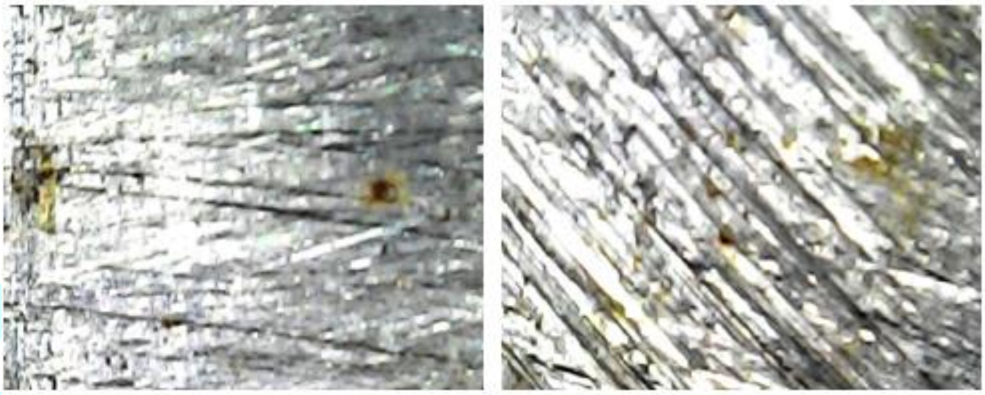

Fig.5.2 (a) Fig.5.2 (b)

Fig.5.2: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.2

Fig.5.3 (a) Fig.5.3 (b)

Fig.5.3: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.3

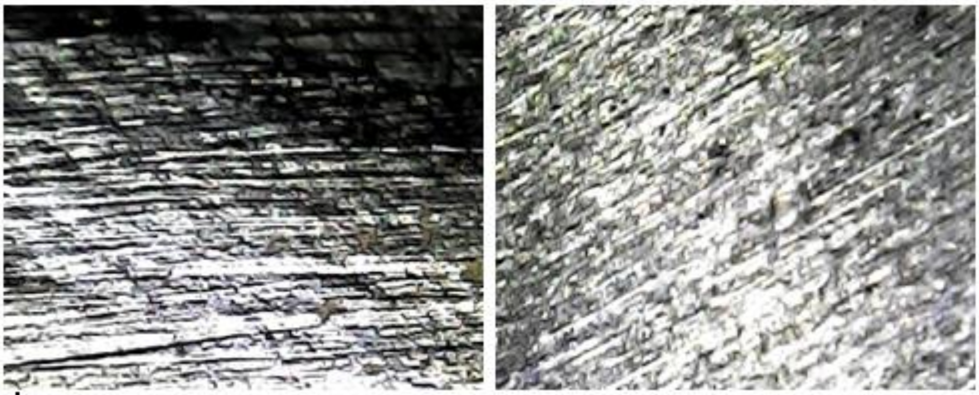

Fig.5.4 (a) Fig.5.4 (b)

Fig.5.4: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.4

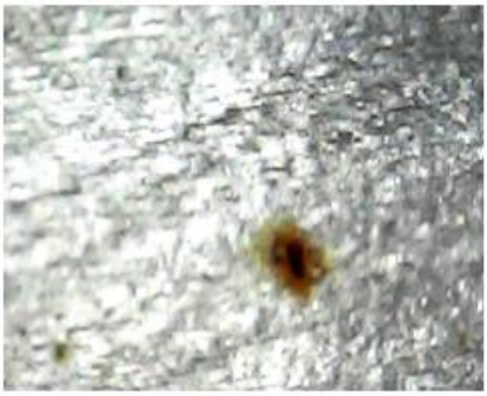
Fig.5.5 (a)


Fig.5.5 (b)

Fig.5.5: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.5

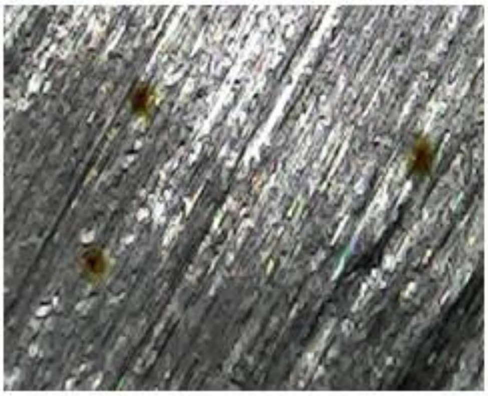
Fig.5.6 (a)


Fig.5.6 (b)

Fig.5.6: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.6

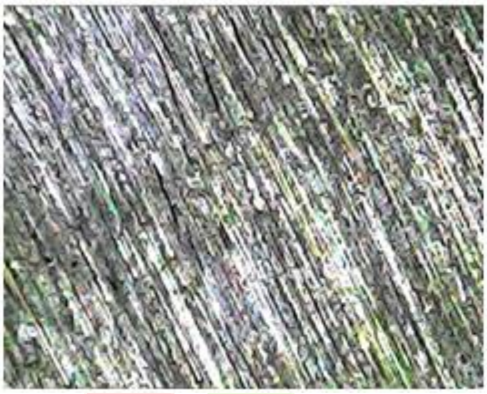
Fig.5.7 (a)


Fig.5.7 (b)

Fig.5.7: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.7


Fig.5.8 (a)

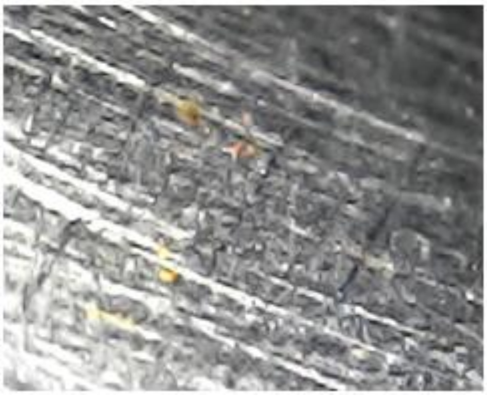
Fig.5.8 (b)

Fig.5.8: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.8

Fig.5.9 (a)

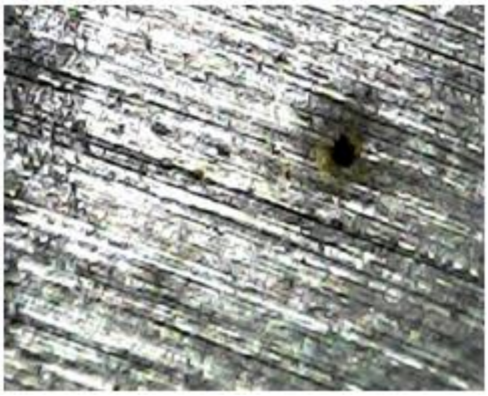

Fig.5.9 (b)

Fig.5.9: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.9

Fig.5.10 (a)

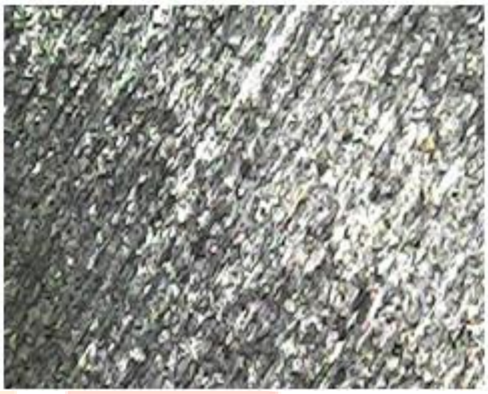

Fig.5.10 (b)

Fig.5.10: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.10

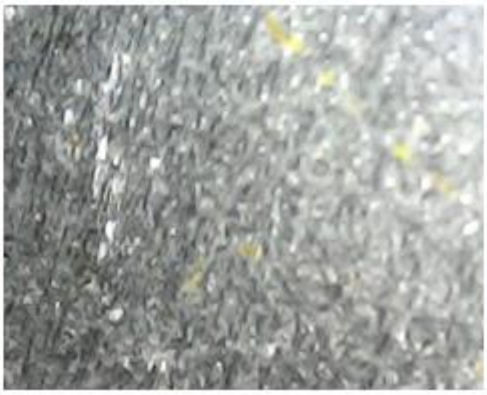

Fig.5.11 (a)

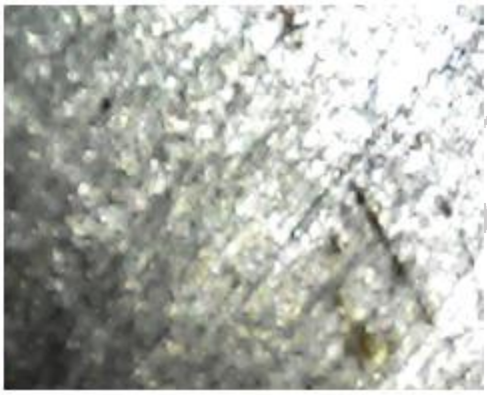

Fig.5.11 (b)

Fig.5.11: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.11

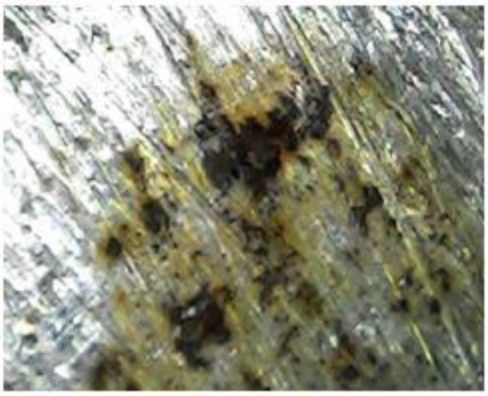

Fig.5.12 (a)

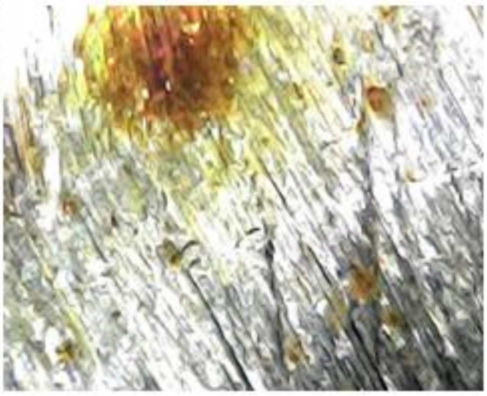

Fig.5.12 (b)

Fig.5.12: Shows microscopic view under the magnification 500X (a) Plain Area (b) Curved Area of Specimen No.12

VI. CONCLUSIONS

Experimental work was carried out to investigate the influences of temperature and chloride concentration on the susceptibility of CI-SCC for as-received and sensitized U-bend SS304L specimens using immersion test. The following observations were drawn.

- Size of corrosion spot increased with increase in % of NaCl Concentration.
- Pitting and corrosion patterns were observed on plain surfaces than the stressed surfaces.
- Pitting and corrosion patterns were observed at higher temperature i.e., 90ºC than the ambient temperature 28ºC.
- Pitting is observed on sensitized samples than the as-received specimens.

VII. ACKNOWLEDGMENT

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