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Research Note

The Effect of Concentration and pH of Magnesium Chloride Solution on Stress Corrosion Cracking of AISI304 Stainless Steel

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The stress corrosion cracking of AISI304 stainless steel is influenced by concentration of chloride ions and pH of the solution. In this paper, number, size and growth of cracks in stainless steel of the type 304 were investigated for a solution of deionized distilled water (DDW) and magnesium chloride in different amounts of 10, 50, 100, 200, 500, 1000, 2000 and 2500 g/lit. The effect is considered at different pH levels, i.e., 0.5, 1, 1.5, 2.2, 2.5 and at different temperatures. Constant load and strain tests were carried out according to ASTM G30–79 standard. The results of this investigation show that high chloride ion concentration of the test solution intensifies stress corrosion cracking susceptibility resulting in an increase in depth and size of the cracks. Furthermore, decrease in pH of the solution, from 2.5 to 0.5, increases the number of cracks. A metallographic examination of the fractured specimen revealed the transgranular mode of cracking.

INTRODUCTION

Preventing industrial and non-industrial installation breakdown has great influence on the economy of a country, in this regard stainless steel has proven to be efficient and, therefore, it has been used in manufacture of various industrial equipment [1]. The utilization of stainless steel in producing equipment reduces the cost of maintenance, prolongs the lifetime and results in higher quality merchandise, leading to a cost reduction in manufacturing. That is why nowadays, the use of stainless steel in various industries, such as petrochemical and chemical industries, food industries, transport, medical and nuclear power stations, is invitable [2].

Stainless steel possesses characteristics such as preservation of mechanical properties at high and low temperatures and resistance against oxidation in many corrosive conditions [3]. Among the four groups of stainless steel, austenitic steel is specified as being the most resistant steel, with good performance against corrosion [4,5].

A recent method used to evaluate the degree of sensitivity of stainless steel to stress corrosion cracking consists of immersion of a u-bend specimen in a boiling chloride solution. The fracture of the specimen occurs within a range of a few minutes to a few hours [6].

The 304 stainless steel undergoes cracking at high temperatures (66–93°C) in chloride and hydroxide solutions. In chloride solutions, the cracking modes are transgranular type while in hydroxide solutions, a mixture of transgranular and intergranular is observed. It should be noted that cracking does not occur at room temperature unless the steel becomes sensitive [7].

EXPERIMENTAL PROCEDURE

Specimens were made from a 304 stainless steel sheet according to ASTM G30-7a. An appropriate apparatus formed a 3 × 130 × 15 mm sheet into a u-shape sample (Figure 1).

The stress was applied by tightening the nuts on a bolt that had previously been driven through both sides of the specimen (Figure 2).

In order to prevent the galvanic effect, a coated plastic washer was placed between the specimen and the bolt.

The solution tests were prepared with deionized distilled water free from any undesired ions and 10, 50, 100, 200, 500, 1000, 2000, 2500 g/lit of magnesium chloride.

pH of the solutions was adjusted by addition of H_2SO_4. A condenser was utilized to prevent probable

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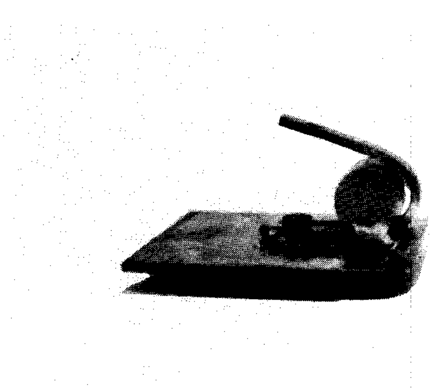

Figure 1. Apparatus used to make a u-bend shape specimen.

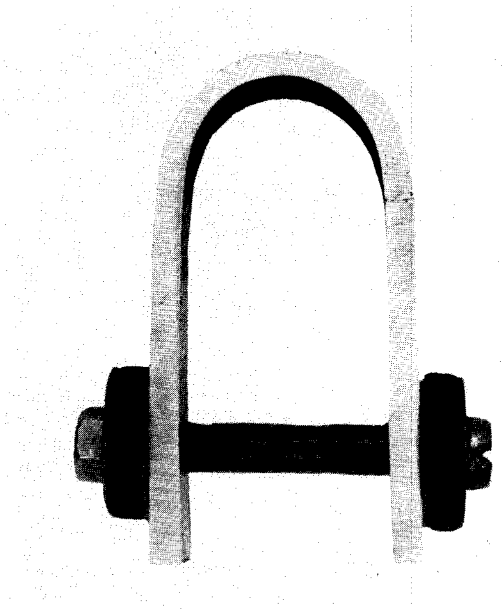

Figure 2. U-shaped specimen with insulated screw.

evaporation of H_2SO_4 at a working temperature of $70 \pm 5°C$.

The prepared samples were introduced into a 7cm diameter glass container, containing 100 ml of solution. Using a rubber lid, the condenser was installed on the lid and then the container was immersed into a hot water bath. The total time of exposure for each experiment was 168 hours.

RESULTS

Upto 1000 g/lit $MgCl_2$

Optical microscopic examinations of the specimen in solution with less than 1000 g/lit $MgCl_2$ revealed that the specimens did not suffer from stress corrosion cracking and, hence, no cracking was observed.

1500 g/lit $MgCl_2$ Solution

The initial pH of the solution was recorded to be 3.9, change in pH was obtained through addition of H_2SO_4 solution. Table 1 represents length and number of cracks at different pH solutions. Figure 3 demonstrate the variation in the number of cracks and the crack length versus pH, respectively. The microscopic examination of fracture surface can be seen in Figure 4 which reveals the type and shape of the cracks in that solution.

Table 1. Length and number of cracks at different pHs in 1500 g/lit $MgCl_2$ solution.

pH	0.5	1	1.5	2	2.5	3.9
Number of Cracks	28	25	20	14	12	9
Length of Cracks (mm)	0.37	2.14	1.95	1.61	1.39	1.12

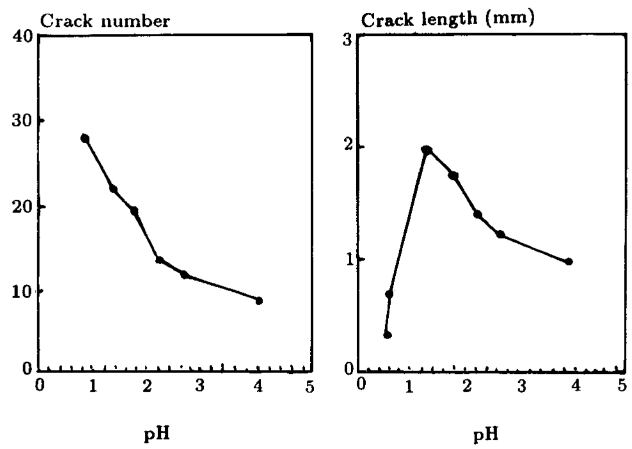

Figure 3. The variations of (a) number and (b) length of cracks with pH in 1500 g/lit $MgCl_2$ solution.

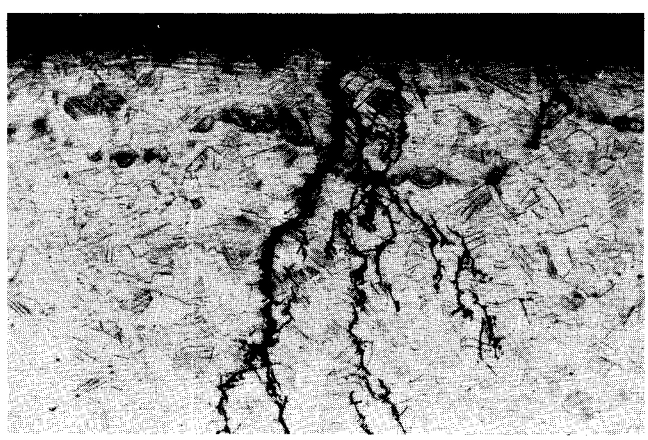

Figure 4. The produced cracks in 1500 g/lit $MgCl_2$ solution at pH = 1.5 (×160).

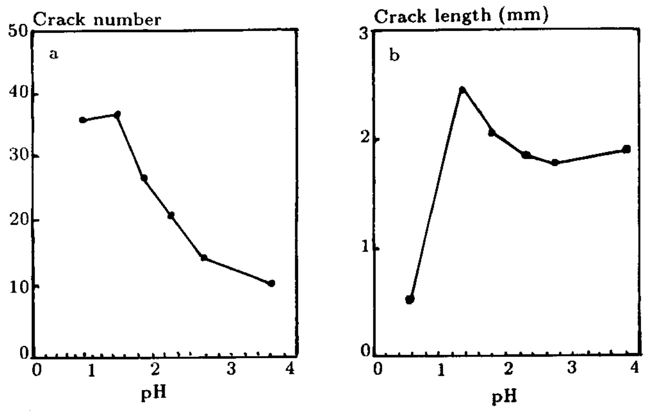

Figure 5. The variations of (a) number and (b) length of cracks with pH in 2000 g/lit $MgCl_2$ solution.

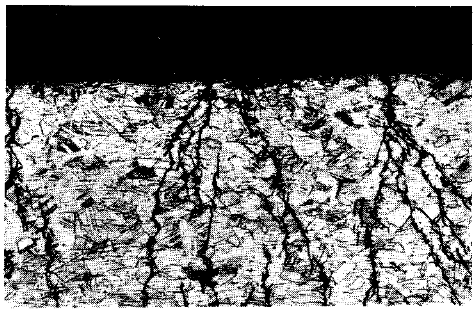

Figure 6. The produced cracks in 2000 g/lit $MgCl_2$ solution at pH = 3.5 (×160).

Table 2. Length and number of cracks at different pHs in 2000 g/lit $MgCl_2$ solution.

pH	0.5	1	1.5	2	2.5	3.5
Number of Cracks	37	38	29	23	17	13
Length of Cracks (mm)	0.58	2.47	2.11	1.91	1.81	1.95

2000 g/lit $MgCl_2$ Solution

Variation in number and length of the cracks versus pH can be seen in Table 2 and Figure 5, while the optical microscopic examination of fractured surface is shown in Figure 6.

2500 g/lit $MgCl_2$ Solution

Table 3 and Figure 7 show the change of length and number of cracks versus pH, while Figure 8 represents the type and shape of cracks at pH = 3.3 in the above solusion.

Table 3. Length and number of cracks at different pHs in 2000 g/lit $MgCl_2$ solution.

pH	0.5	1	1.5	2	2.5	3.3
Number of Cracks	40	42	30	21	19	14
Length of Cracks (mm)	0.83	2.53	2.26	1.85	1.93	2.17

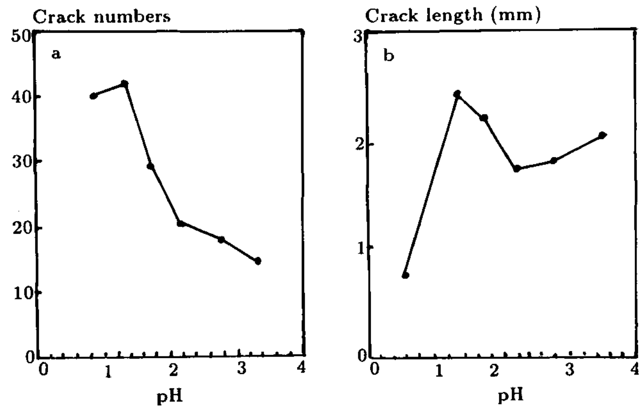

Figure 7. The variations of (a) number and (b) length of cracks with pH in 2500 g/lit $MgCl_2$ solution.

Figure 8. The produced cracks in 2500 g/lit $MgCl_2$ solution at pH = 3.3 (×160).

DISCUSSION AND CONCLUSION

Stress corrosion cracking in metals and alloys depends upon both the tensile stress and environmental conditions.

In this investigation, the effects of variation in pH and concentration of chloride ion on length and number of cracks after a period of 168 hours were determined and the following results were concluded:

- An increase in the concentration of chloride ions in the solution will increase the number and length of cracks.
- At higher values of pH, the number of cracks increases while the length of the cracks decreases.
- Shorter cracks were observed at pH = 0.5 compared to other solutions with different concentration of chloride. This can probably be due to corrosion products which form a protective layer, or a result of an increase in the radius of the crack tip by corrosion, which decreases the crack growth rate.
- The cracks in the samples propagated in a transgranular mode.

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