Jurnal Mekanikal
June 2018, Vol 41, 78-84

Stress Corrosion Cracking of Steel Component Exposed in Simulated Seawater

M. Amaluddin M. Sabri, Esah Hamzah* and Lau Jia Ming

School of Mechanical Engineering, Faculty of Engineering
Universiti Teknologi Malaysia
81310 UTM Johor Bahru
Johor, Malaysia

ABSTRACT

Stress corrosion cracking (SCC) is the fracture of susceptible material under sufficient tensile stress and exposed to the corrosive environment. A reliable experimental setup for SCC is required to determine the material performance in artificial environment before being deployed in actual situation. Creep machine was modified to establish a constant load SCC test setup for round and plate specimens. The furnace was removed and replaced by the designed machine parts including test solution chamber, grips, leakage prevention mechanism and other related components. The reliability of the established SCC test setup was evaluated by comparing the elongation and hardness of specimen after SCC in corrosive environment and tensile test under constant load at ambient temperature without any corrosive liquid. Both experiments were conducted with a fixed time period before the elongation and hardness of each specimen were recorded. The load of 60 kg and 30 kg for round and plate specimens, respectively were applied in the corrosive environment of 3.5% NaCl simulated seawater for the SCC test. It was found that SCC caused the specimen to have more elongation and lower the hardness compared to the specimen tested in air without any liquid. This is due to the presence of the corrosive environment containing the chloride ions that caused corrosion on the specimen under stress. Consequently, the specimens that have undergone the SCC test suffered more deformation compared to those tested in air. It can also be concluded that the experimental setup for the SCC test was successfully designed, fabricated and validated.

Keywords: *Stress corrosion cracking, corrosion in simulated seawater*

1.0 INTRODUCTION

The annual cost of corrosion and preventive measures towards it is pretty high nowadays. An organization or institution might have to allocate a certain budget each year for corrosion prevention, maintenance and replacement of damaged products and components affected from corrosion. It is almost impossible to eliminate corrosion entirely but it can be reduced through proper understanding of corrosion and its preventive measures such as appropriate material selection and proper maintenance on products and components [1-2]. Stress corrosion cracking (SCC) is a metal failure as a result of the interaction between applied mechanical stress, corrosive environment and susceptible metal [3].

*Corresponding email: esah@utm.my

This type of localized corrosion can reduce significant amount of mechanical strength of metal and subsequently may lead to fracture and failure of the components and structures. SCC is a rare occasion, however the failure is costly and destructive enough to components and products. It is therefore important to understand the material behavior that it may suffer from SCC through controlled laboratory conditions to develop corrective measures in order to avoid any unpredicted and premature field failures in real life applications. The aim of this investigation is to determine the susceptibility to SCC of low carbon in the form of round and flat shapes exposed in a simulated seawater (3.5% NaCl solution) under contact stress. The main part of the research is to modify, redesign and fabricate the existing creep machine so that it can be used in the SCC test under constant loading condition.

2.0 METHODOLOGY

The research was conducted by using a high temperature creep testing machine which was equipped with a furnace. The creep element was then modified by removing the furnace and placed with a chamber filled with 3.5% NaCl simulated seawater solution. Modification was also made on the specimen holders so that the specimen could be placed in the chamber when the load was applied. The following subsections explain how modification of the creep was made.

2.1 Modifications of Creep Machine to Stress Corrosion Test Setup

The high temperature furnace was first removed and replaced with a small rectangular (55 × 85 mm) chamber which was fabricated from transparent acrylic material. The chamber was used as an immersion container which was filled with 3.5% NaCl solution. The grips which were fitted to the loading system of the machine to hold the specimens was designed and fabricated from stainless steel materials. A chamber holder, column fittings and chamber fittings were also fabricated and fitted to the machine to keep the specimen and the chamber in place throughout the SCC test. All the designs were made using 3D modeling software, SolidWorks. The illustrations of the initial condition and after modifications of the creep machine are shown in Figures 1 (a) and (b).

(a) (b)

Figure 1: Illustration of the creep machine (a) before modification and (b) after modification.

2.2 Design of Stress Corrosion Cracking Experimental Test Setup

The parts that were needed to be fabricated include the grips, connector, chamber, leakage prevention mechanism, column and chamber fitting as well as a straight bar. Figure 2 illustrates the assembly of the fabricated parts. The round and plate specimens were made from low carbon steels and were cut in accordance to ASTM E8 with 12.5 mm and 25 mm gage lengths, respectively.

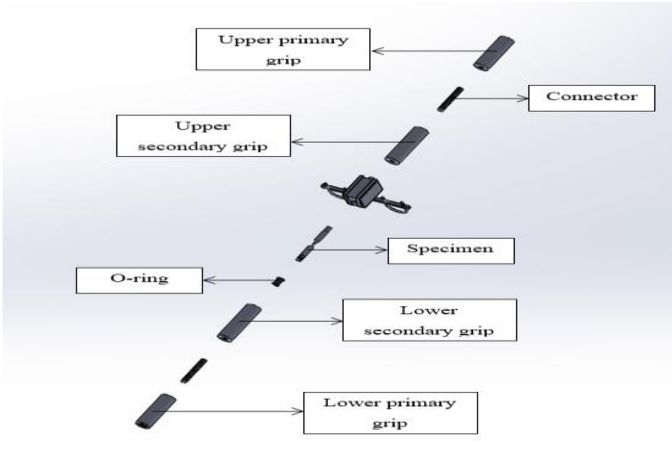


Figure 2: Assembly of the fabricated parts of the SCC test setup

2.3 Stress Corrosion Cracking (SCC) Parameters

The parameters for the SCC test were a constant applied load of 60 kg for round specimen and 30 kg for plate specimen and corrosive environment of 3.5% NaCl simulated seawater solution. For comparison purposes, similar loads were applied for the specimens conducted in non-corrosive environment, i.e., the test was conducted without the immersion chamber. The test duration for round specimen was one day (24 hours) whereas for the plate specimen, the duration of the test was three days (72 hours). The gage lengths of the specimens were measured before and after the tests in order to obtain the percentage of elongation.

2.4 Hardness Test

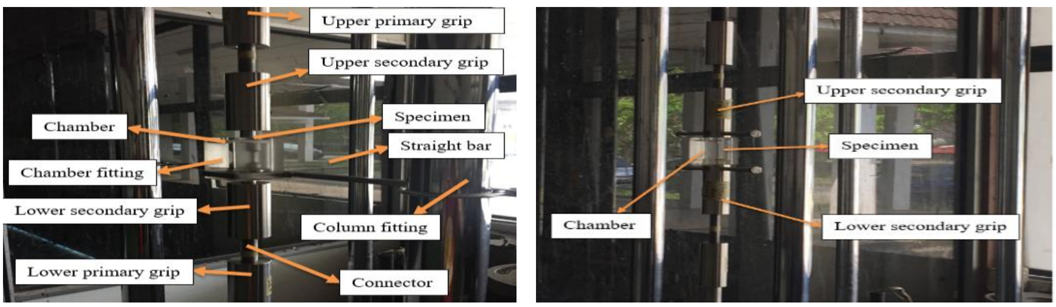
Hardness test has been performed on the specimens that had undergone SCC test and tensile tests with a constant load without any corrosive environment using *Vickers* hardness test machine with a 30 kg load.

3.0 RESULTS AND DISCUSSION

The main output of the research was a modified creep machine with added test solution chamber and fabricated specimen holder as well as other related parts which were designed to hold the specimens in place. The modified design was for the SCC test.

3.1 Assembly of Stress Corrosion Cracking Test Setup

The fabricated parts including the chamber were assembled as shown in Figures 3 (a) and (b) for round and plate specimens for the SCC tests.



(a) (b)

Figure 3: Complete assembly of the modified creep machine for SCC test for (a) round spesimen and (b) plate specimen

The tensile test with constant load without corrosive environment was performed using the same setup but with the test solution chamber removed. In other words, the test was carried out in air without the chamber.

3.2 Microstructure of The Test Specimen

The microstructure of test specimen which was made from low carbon steel was observed using optical microscope. Prior to microstructure observation, the specimen was metallurgically prepared by grinding on silicon carbide papers from grit 240 to 800 on a grinding machine followed by polishing on a cloth using polishing machine until a mirror-like surface was obtained. The polished sample was then etched in 2% Nital solution for a few seconds, washed with water and dried using a small blower. The specimen was taken to an optical microscope for microstructural observation. The microstructure of the low carbon steel sample is illustrated in Figure 4 which shows the light region as ferrite phase and the dark region as pearlite structure [4].

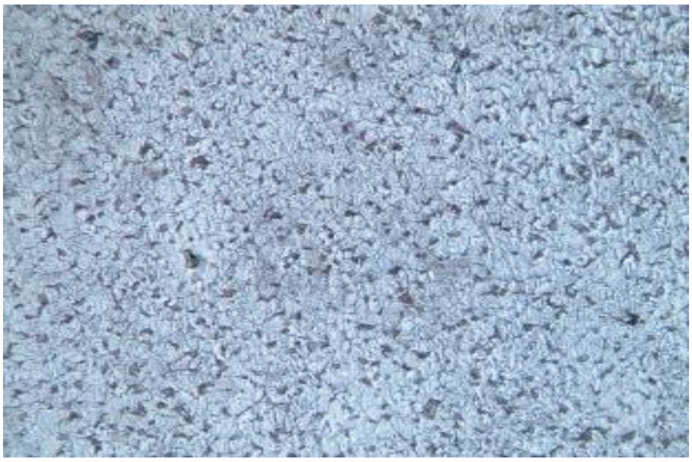


Figure 4: The microstructure of low carbon steel specimen showing ferrite (light region) and pearlite (dark region) (× 200 magnification)

Generally, low carbon steel contains pearlite and ferrite. The amount of pearlite is small due to the low carbon content. An increased in the carbon content will subsequently increase the amount of pearlite. Low carbon steel often suffers from corrosion due to its low corrosion resistance and does not contain the alloying elements to form protective oxide on its surface when exposed to corrosive environment [5-8].

3.3 Visual Inspection on The Test Specimen

After each SCC test was completed, the specimen was taken out from the solution chamber for visual inspection to observe any physical changes. Similarly, the specimens tested in non-corrosive environment were removed from the machine after the test has been completed. The specimens which have been tested in air (without immersion in 3.5% NaCl solution). It was observed that there are no physical changes as illustrated in Figure 5. However, the change in appearance was seen on the specimens that had undergone the SCC test as shown in Figure 6. Corroded product in the form of brownish deposit was found on the surface of the specimens and when the deposit was removed, many pits were seen on the surfaces indicating that the corrosion has indeed occurred on the surface of the specimens as depicted in Figure 6.

(a) (b)

Figure 5: Test specimens after tensile test with constant load without corrosive environment (in air) for (a) round specimen and (b) plate specimen

(a) (b)

Figure 6: Test specimens after the SCC test for (a) round specimen and (b) plate specimen

3.4 Mechanical Properties of The Specimens

The mechanical properties determined for the specimens with and without the SCC tests were percentage of elongation based on tensile test under constant load and hardness. The percentage of elongation was determined from measurement of the specimen length before and after the tests and calculated as in Equation (1) [3]. The results are given in Tables 1 and 2.

$$\% \text{ Elongation} = (L_f - L_o)/L_o)\times 100 \quad (1)$$

where L_o is the original gage length before the test and L_f is the final length after the test.

Table 1: Percentage elongation of specimens before and after the tests

Specimen	Test	Test Duration (day)	Initial length, L_o (mm)	Final Length, L_f (mm)	% Elongation
Round	Tensile test (without 3.5% NaCl)	1	12.5	13.5	8
	SCC test (with 3.5% NaCl)	1	12.5	15.5	24
Plate	Tensile test (without 3.5% NaCl)	3	25.0	25.0	0
	SCC test (with 3.5% NaCl)	3	25.0	26.5	6

Table 2: Hardness of specimens before and after the tests

Specimen	Test	Hardness before test (Hv)	Hardness after test (Hv)	% Reduction in hardness
Round	Tensile test (without 3.5% NaCl)	147.9	146.2	1.15
	SCC test (with 3.5% NaCl)	147.9	111.7	24.48
Plate	Tensile test (without 3.5% NaCl)	147.9	143.5	2.97
	SCC test (with 3.5% NaCl)	147.9	139.9	5.41

It was found that the round specimen seems to elongate more (24%) when it underwent the tensile test with a constant load in 3.5% NaCl solution (SCC test) compared to the specimen tested in air without any solution. Also, the hardness is significantly reduced (24.48%) for the SCC specimens. It shows that the SCC specimen has experienced more deformation due to the combined effect of the stress and corrosive environment. The crack initiation sites may develop due to the loss of the metal regions by anodic dissolution [1]. Since the SCC and non-SCC tests were performed for a short period of time (one day for round specimen and three days for plate specimen), the time to cause failure could not be determined. It suffices to say that both the round and plate specimens are susceptible to SCC because they deformed more than those which were not exposed to the saline solution [5, 7-8].

4.0 CONCLUSION

Stress corrosion cracking (SCC) experimental setup was successfully designed and fabricated for both round and plate specimens by modifying the high temperature creep machine. The completed experimental setup was tested for its reliability in conducting an efficient SCC study. The test results in terms of elongation and hardness of the low carbon steel specimen after one and three days test duration show significant difference between the specimens which were exposed to 3.5% NaCl solution and those tested without immersing in the corrosive solution. It was found that SCC specimens deformed more than those without the salt solution due to the combined effects of the stress and corrosive environment which result in crack initiation and anodic dissolution.

ACKNOWLEDGMENTS

The authors would like to acknowledge the Ministry of Higher Education of Malaysia for providing the financial support under the Research University Grant (Vote No.: QJ130000.2524.18H99) and Universiti Teknologi Malaysia (UTM) for the research facilities.

REFERENCES

1. Yong L.Z., Liang Z.T., Ke L.R., Huan J.J., Wei D.C. and Gang L.X., 2016. Influence of Factors on Stress Corrosion Cracking of P110 Tubing Steel Under CO_2 Injection Well Annulus Environment, *Journal of Central South University*, 23(4): 757–764.
2. Heaver E.E., 1994. *Stress Corrosion Cracking of Steels in Industrial Process Environment*, PhD Thesis, University of Pretoria, Republic of South Africa.
3. Uhlig H.H. and Revie R.W.,1986. *Corrosion and Corrosion Control*, Riley New York.

4. Espinosa-Medina M.A., Sosa E., A´ngeles-Cha´vez C. and Contreras A., 2011. Assessment of pH and Temperature Effects on Stress Corrosion Cracking of 1018 Low Carbon, *Corrosion Engineering, Science and Technology*, 46(1): 32-41.
5. Hameed K., Jaafer H.I. and Ali A-K.M., 2016. Study the Stress Corrosion Cracking Susceptibility of Low Carbon Steel in 0.1M of Sulfuric Acid Solution Using U-Bend Test, *International Journal of Scientific & Engineering Research*, 7(8): 1790-1801.
6. Prawoto Y., Sumeru K. and Wan Nik W.B., 2012. Stress Corrosion Cracking of Steels and Aluminium in Sodium Hydroxide:Field Failure and Laboratory Test, *Advances in Materials Science and Engineering*, 2012: Article ID 235028.
7. Humpries M.J. and Parkins R.N., 1967. Stress Corrosion Cracking of Mild Steels in Sodium Hydroxide Solutions Containing Various Additional Substances, *Corrosion Science*, 7(11): 747-761.
8. Bulloch J.H., 1991. Stress Corrosion Cracking of Low Alloy Steel in Natural Seawater Environment-The Influence of Carbon Level, *Theoretical and Applied Fracture Mechanics*, 16(1): 1-17.