Damaging Profile of SS-304 Crevice Corrosion in Chloride Environments

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Abstract: *Type 304 stainless steel (SS-304) has wide industrial applications due to its weldability and resistance to corrosion. However, it suffers crevice corrosion especially in chloride environments. The damaging profiles of its crevice corrosion in chloride environments were evaluated. The crevice assembly used for this study comprised of coupon (SS-304), polytetrafluoroethylene (crevice former) and fasteners (titanium bolt, nut and washers) designed in three configurations with crevice scaling factor of 8, 16 and 24, respectively. The configurations had 40 crevice sites and immersed in various chloride solution concentrations of 1.5, 3.0 and 4.5 w/w % simulating environmental conditions A, B, and C respectively for 45 days in full immersion test. ASTM G-78 was used to estimate the value of % area attacked over time. The obtained results showed that the highest percentage of creviced area was attacked in marine environment followed by brackish and freshwater in that order. The damaging profile confirms the severity of chloride environment and the possible control by reducing the possible percentage of chloride in creviced area of process assembly.*

Keywords: *chloride environments, crevice corrosion, damaging profiles, ss-304.*

1. INTRODUCTION

The Crevice corrosion is a localized form of attack that occurs at shielded areas on the metal surfaces exposed to certain specific corrosive environments [1]. This type of corrosion occurs very frequently in engineering structures particularly with threaded or rivetted joints, gasket fittings, welded lap joints and coiled or stacked sheets [2]. The crevice corrosion susceptibility of a metal is dependent on the geometry of the crevice, chemical environment and the metallurgical state of the material. Austenitic stainless steels have excellent uniform corrosion resistance but are highly susceptible to localized corrosion like pitting, crevice corrosion and stress corrosion cracking [3].

AISI-304 is an austenitic stainless steel designed for maximum resistance to general corrosion but highly susceptible to crevice corrosion in chloride environment. The presence of a crevice on a stainless steel surface, as might be caused by biofouling or a gasket, greatly reduces resistance to chlorides [4]. It is difficult to avoid crevices in construction and operation, although good design and conscientious maintenance help in high-chloride environments. Examples of High-chloride environments are brackish water, seawater, pulp mill bleach plants, and other high-chloride process streams [5].

Crevice corrosion cause significant problems across industries, yet they have not been receiving the deserved attention. Maintenance professionals often focus on other types of corrosion, such as stress-corrosion cracking (SCC) and microbiological-influenced corrosion (MIC). But because crevice corrosion is extremely damaging, it's important to understand what causes this form of attack, where to find them and what corrective actions to apply most especially in specific environments [6]. In discussing the performance of stainless steels in strong acid environments, it is important to recognize that a very small concentration of chloride can greatly accelerate general corrosion. Accurate characterization of such environments is not always possible because the material may witness substantial variations of the temperature and chemical conditions during the operating and maintenance cycle [5].

The total-immersion corrosion test is most adaptable to rigorous control of the important factors that influence results. This control may be achieved in different ways and it is unnecessary and undesirable to seek a standardized method or apparatus for universal use. All that is required is recognition of what is essential, as covered, for example, by the ASTM procedure. As far as tests for crevice corrosion are concerned, all that is required is a geometrical configuration that simulates a crevice, which may be achieved in a variety of ways using either the metal itself or the metal and a non-metallic material [7].

In this study, experimental design and fabrication of crevice corrosion system in chloride environments were considered to evaluate effects of chloride concentration, crevice scaling factor and immersion time on the occurrence of crevice corrosion of SS-304 in chloride containing environments for the purpose of understanding the nature of its damaging profiles in the projected environments.

2. MATERIALS AND METHODS

2.1 Material Preparation

Samples of stainless (304) were obtained for testing. The coupons (Figure 1) used for crevice corrosion and fraction of sites damaged testing were 50 mm X 50 mm X 3 mm (Type A), 50 X 40 mm X 3 mm (Type B), or 50 mm X 30 mm X 3mm (Type C) plates dimensioned with a 600 grit finish. Teflon crevices (Figure 2) were prepared as the crevice former on the coupon for crevice corrosion tests. All samples were degreased with acetone in an ultrasonic cleaner prior to assembly and testing. The aqueous simulant used for this study were prepared at 1.5, 3.0 and 4.5 NaCl w/w, to simulate fresh, brackish and marine water environments respectively. The creviced assembly (Figure 3) remained immersed in solution between and during testing.

Figure 1: Cut and Polished corrosion test coupons of varied dimension

2.2 Crevice Assembly

The crevice test assembly (Figure 3) consisted of a bolt on which the following pieces were placed. First, a Teflon crevice washer dimension according to Table 1, a coupon, a shoulder washer and the nut to secure the pieces together. This assembly was then placed into a plastic specimen cup with 100 ml of the simulant solution and capped. The containers were swirled regularly during the work week in order to keep the solution mixed. Assemblies were taken apart once in 15 days and the areas under the spokes of the crevice washers were examined for depth of attack (crevice corrosion propagation). Samples were reassembled and placed back into the simulant solution. Surface visual analyses were achieved by using reflected optical microscope and digital camera.

Table 1: Detail Design Parameters of Creviced Assembly Types

Crevice Assembly Type	Parameters	Values
	Width of a single Crevice, w (mm)	1
	Length of a single Crevice, l (mm)	4
TYPE A	Depth of a Single Crevice, d (mm)	0.5
	Surface Area of a Single Crevice, a (mm^2)	2
	Total Crevice Area, A (mm^2)	80
	Width of a single Crevice, w (mm)	1.5
	Length of a single Crevice, l (mm)	8
TYPE B	Depth of a Single Crevice, d (mm)	0.5
	Surface Area of a Single Crevice, a (mm^2)	4
	Total Crevice Area, A (mm^2)	160
	Width of a single Crevice, w (mm)	2

Crevice Assembly Type	Parameters	Values
	Length of a single Crevice, l (mm)	12
TYPE C	Depth of a Single Crevice, d (mm)	0.5
	Surface Area of a Single Crevice, a (mm^2)	6
	Total Crevice Area, A (mm^2)	240

Figure 2: Fabricated Crevice former

Figure 3: Multiple Crevice Assembly for Crevice Corrosion Test according to ASTM G78.
Coupon Analyses

3. RESULTS AND DISCUSSION

3.1 Effect of Chloride Concentrations on Frequency of Attack in Different Creviced

3.1.1 Assembly Types

Effects of varied chloride concentrations which practically simulate the freshwater, brackish and marine conditions at 1.5 w/w %, 3 w/w % and 4.5 w/w % chloride concentration is considered in this section. The creviced assemblies used were of 8, 14 or 24 crevice scaling factors. The rate of crevice corrosion of SS-304 grade in three different simulated freshwater, brackish and marine environments was analysed in terms of % Area Corroded by immersion test. Freshwater, Brackish and marine environments of different concentration of sodium chloride (1.5 w/w%, 3 w/w% and 4.5 w/w %) content were used. Three types of creviced coupons were used at different crevice scaling factor (8, 16 and 24). The corrosion levels were measured at 15 days intervals.

3.1.1.1 Crevice coupons (type A)

The rate of crevice corrosion of stainless steel 304 grade in three Different simulated environments viz freshwater, brackish and marine environment were analysed in terms of percentage (%) area corroded by immersion test. Freshwater, Brackish and marine environment of different concentration of sodium chloride (1.5 %, 3 % and 4.5 % NaCl) Content were used. Three types of creviced coupons were used of different crevice scaling factor (8, 16 and 24).The corrosion level were measured after 15 days. The results for the creviced coupon A showed that crevice assembly in the simulated marine environment are the ones with the highest area percent of crevice corrosion at 85% of coverage and that those in freshwater environment are the ones with the least area percentage of corrosion at 32% coverage after 60days of immersion, while the brackish are in the intermediates. In Figures 4 and 5 the area percentage of rust inside the crevice is plotted against time. Photographs of the damaging profiles are presented in Tables 2, 3 and 4. Thus it is clear that the crevice corrosion process is predominantly under the marine condition in the presence of low crevice scaling factor.

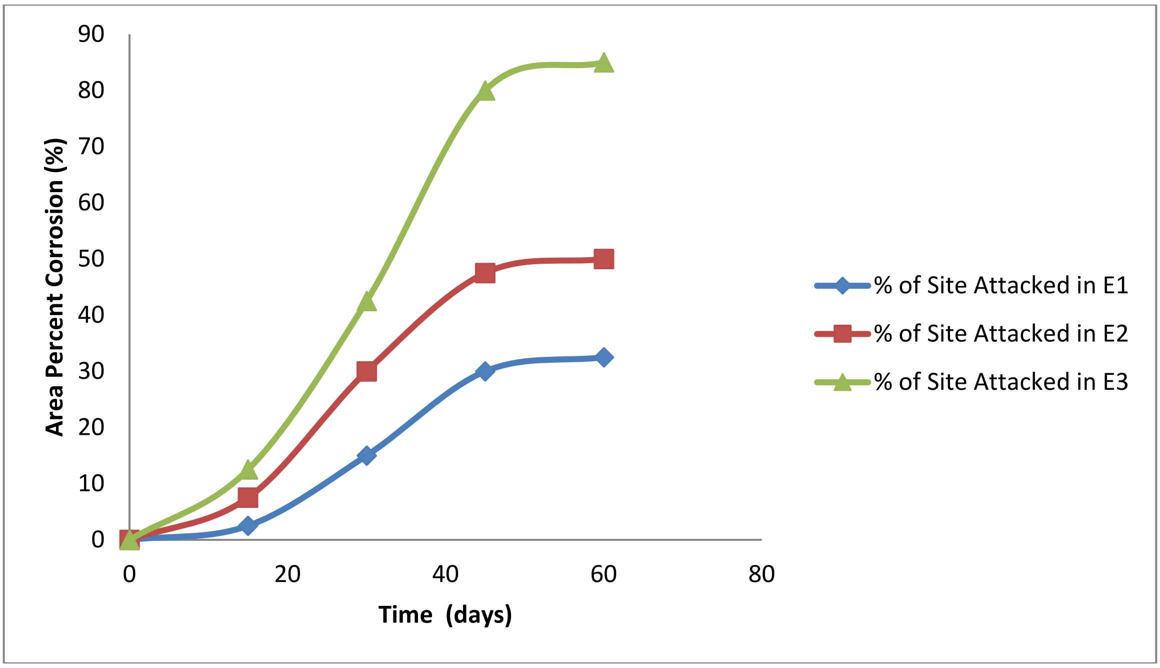


Figure 4: Effect of Varied Salinity on Frequency of Attack in Coupon Type A

3.1.1.2 Crevice coupons (Type B)

In Figure 5, it is seen that the SS-304 surface had 37.5% coverage of crevice corrosion products after 60 days of exposure in marine environment, while those in brackish water conditions had approximately 30% coverage. The one with the least area percentage of corrosion was the assembly in freshwater condition. These clearly establish that the crevice scaling parameter can be adjusted in case of unavoidable crevice to control cases of crevice corrosion in SS-304 in marine related industries.

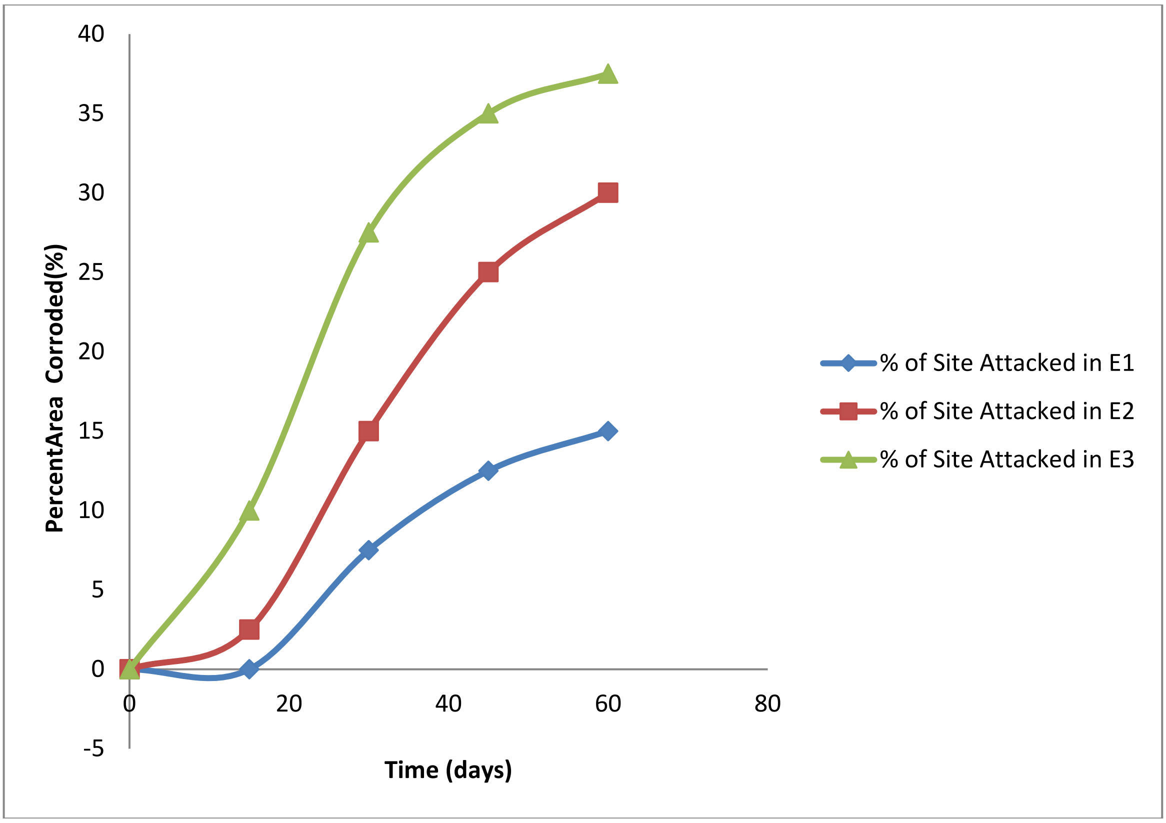


Figure 5: Effect of Varied Salinity on Frequency of Attack in Coupon Type B

3.1.1.3 Crevice coupons (Type C)

The results from image analysis from this group show unequivocally that the crevice scaling parameter observed in this coupon type gives the best crevice corrosion protection. In this crevice configuration, the highest coverage of attack observed was 25% in 60 days of immersion in marine environment, 20% in brackish condition and 7.5% in freshwater condition. This further confirms that the higher the crevice scaling factor, the better the creviced corrosion are put under control.

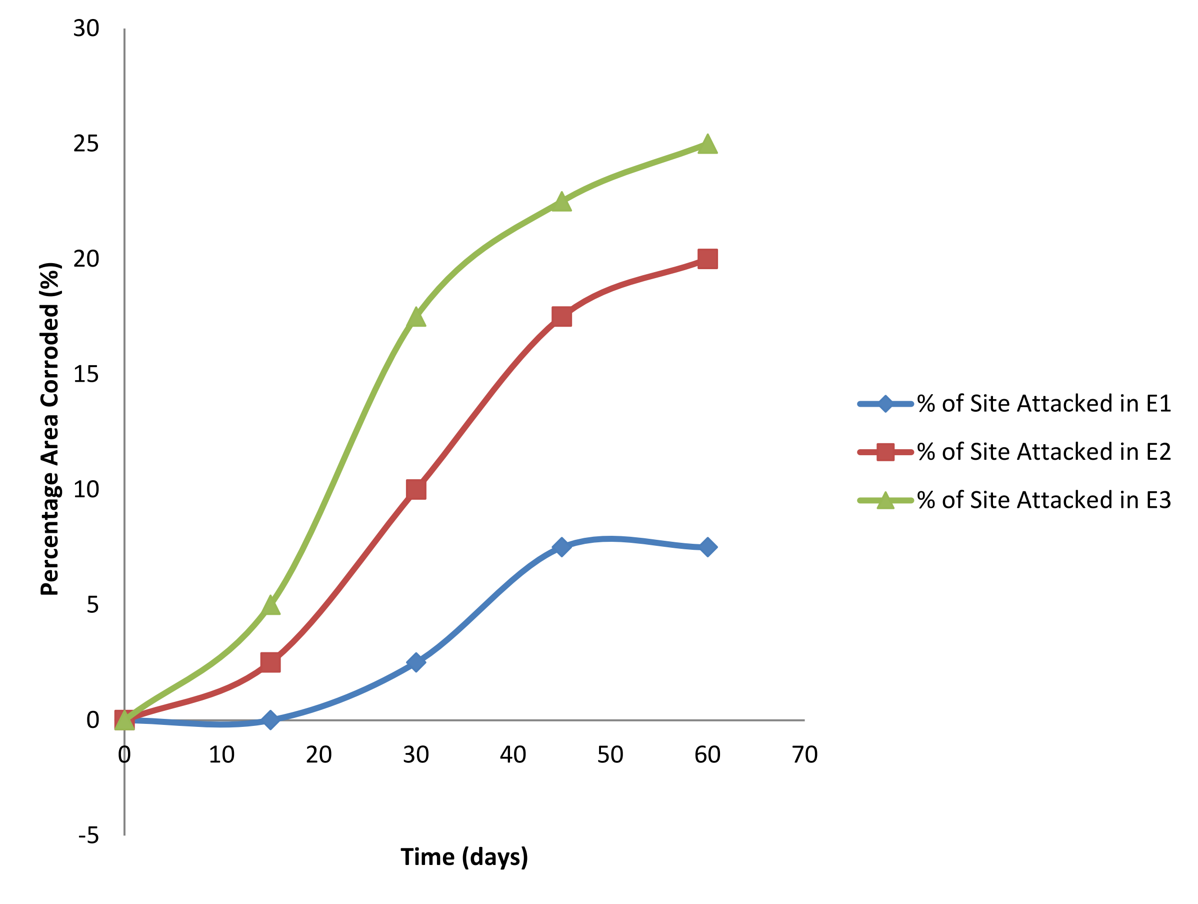


Figure 6: Effect of Varied Salinity on Frequency of Attack in Coupon Type C

3.2 Micro-structural Studies of ss-304 in different Chloride Containing Environments

3.2.1 Morphological Studies of SS-304 in Different Chloride Containing Environments

Figure 7 shows the surface morphological picture of the as-received SS-304 samples respectively at X200 magnifications. The SS-304 sample appears to be a homogeneous, fine grained microstructure with randomly spaced inclusions. Also, the surface morphological conditions of corroded surfaces in simulated freshwater, brackish and marine environments were also presented at different time interval to evaluate the effect of time on the rate of propagation of crevice corrosion in different simulated environments. These are presented in Tables 1, 2 and 3. Comparing the morphological details in each of the environments with the as received (Figure 7) component shows different levels of damage across the environments, mostly severe in marine environments. Some evidence of localized attack such as micro-pits was detected at the metal-resin boundary in each simulated chloride containing environment. These pits are believed to occur as a result of certain inclusions in the metal matrix [8]. During immersion tests under static conditions, the SS-304 in fresh water condition did not show much appreciable damage even after immersion for a period of 45 days, but the rate of damage are much more severe in brackish condition and mostly severe in marine conditions.

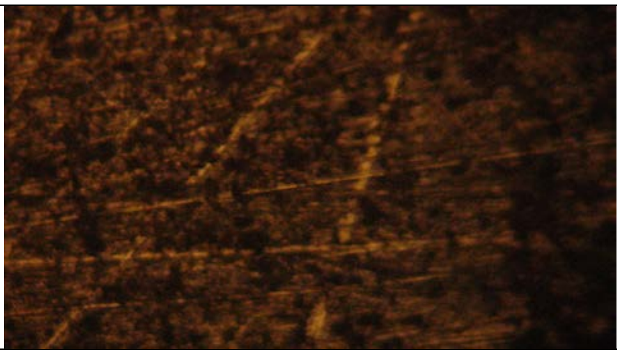
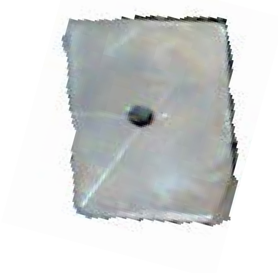
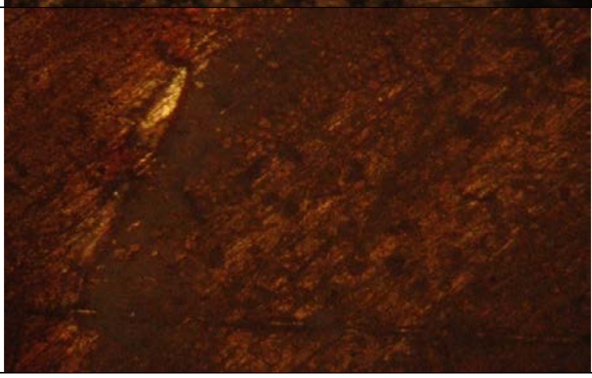
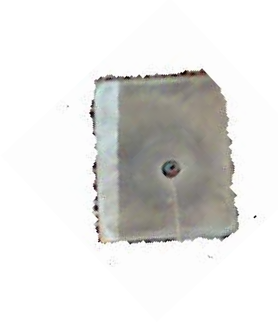
While comparing these conditions with as received conditions shown in Figure 7**,** it is further confirmed that there are possibility of repassivation of the SS-304 surface in use at freshwater conditions of test, while the rate of crevice corrosion propagation is faster in brackish conditions and fastest in marine condition. This was in appreciable agreement with the other research works [9, 10].

In comparing morphological details in each of the simulated environments, it is observable that damages in marine are more pronounced as evident in Table 4.3, even at 15 days of immersion. The morphological damages in freshwater is minimal when compared to the brackish condition. This is basically because of the concentration of chloride solutions available in the crevices over the period of time. Therefore, the changes in the surface conditions occur much more rapidly in marine condition than in the case of freshwater and brackish conditions. For this reason, the general compromise is that crevice corrosion of SS-304 is more detrimental in marine environment [9,10].

The distributions of pits observed at positions observed in each chloride containing environments are different from each other. The pits presented in the figures put in Tables 2 and 3 are shallower than those in Table 4. These shallow pits correspond with the low corrosion rate observed in environment with lower concentration of chloride, this explains the fact that crevice corrosion nucleates by the formation of pits in the crevice region at the initiation of crevice corrosion. Similar observations have been previously reported [11].


Figure 7: Optical micrographs of the as-received 304 austenitic stainless steel sample

Table 2: micrographs of corroded surfaces in simulated freshwater

Days of immersion	**Optical Micrographs of ss-304 in Freshwater (X200)**	
15 days		
30 days		

45 days		

Table 3: micrographs of corroded surfaces in simulated Brackish-water

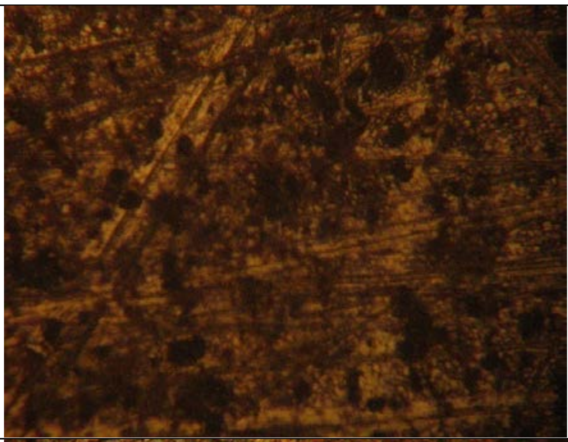
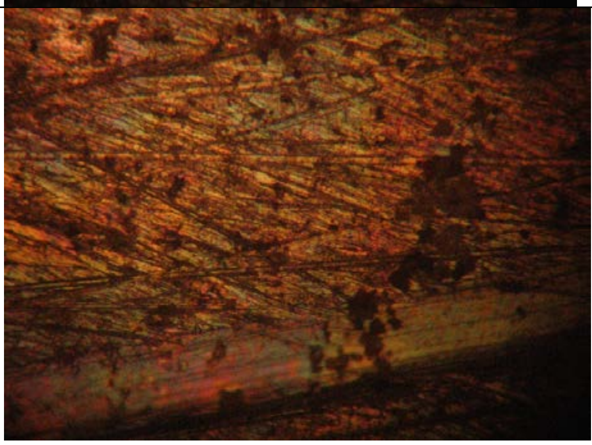
Days of immersion	**Optical Micrographs of ss-304 in Brackish Water (X200)**	
15 days		
30 days		
45 days		

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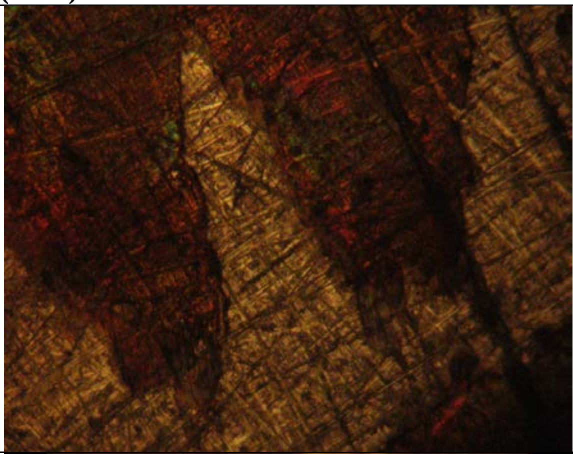
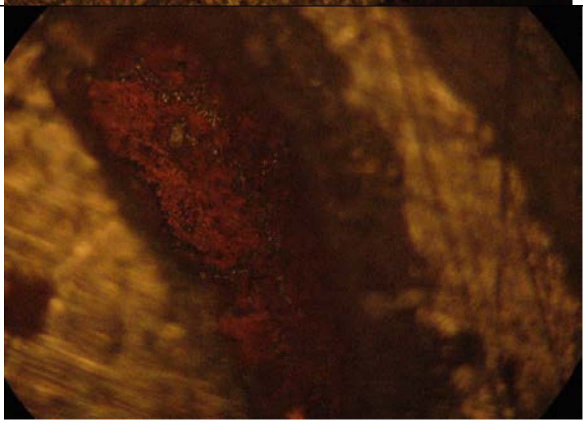
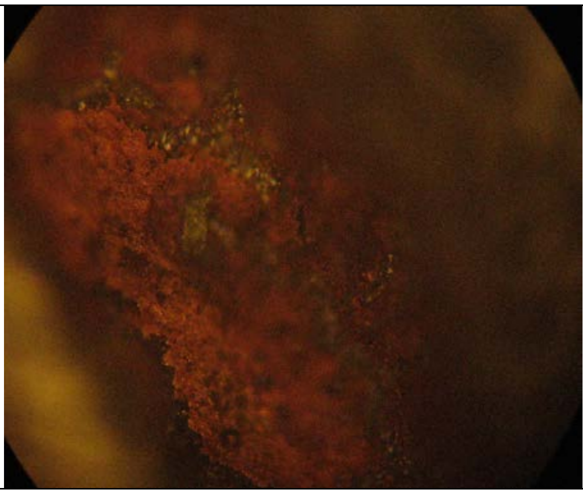
Table 4: micrographs of corroded surfaces in simulated Marine water

Days of immersion	**Optical Micrographs of ss-304 in Marine Water (X200)**	
15 days		
30 days		
45 days		

4. CONCLUSIONS

The damaging profiles of ss304 crevice corrosion in different chloride environment were evaluated. It was found that the crevice corrosion was mostly severe in marine environment followed by brackish and freshwater respectively. This experiment was successful in demonstrating how crevice corrosion monitoring in a laboratory can provide information on the use of related metal assemblies for real-life applications.

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REFERENCES

[1] Engelhardt, G. and Macdonald D.D. (2004): Unification of the deterministic and statistical approaches for predicting localized corrosion damage. I. Theoretical foundation; Corrosion Science (46): 2755– 2780

[2] Heppner K.L., Evitts R.W., and Postlethwaite, J. (2002): Prediction of the crevice corrosion incubation period of

passive metals at elevated temperatures. Part I. Mathematical model, *Can. J. Chem. Eng.* 1(8): 849–856.

[3] Aoki, S.Yakuwa, H Miyasaka, M. Sakai, J. (2011). Dissolution Behavior of α and γ Phases and Preferential Dissolution Mechanism of a Duplex Stainless Steel in a Simulated Crevice Solution. Volume 60 (7) 328-332.

[4] He, X.; Brettmann, B. and Jung, H. (2009): Effects of test methods on crevice corrosion repassivation potential measurements of alloy 22, *Corrosion* 6(5): 449–460.

[5] Dawson, J.L. and Ferreira, M.G.S. (1986): Crevice corrosion on 316 stainless steel in 3% sodium chloride solution, *Corrosion Science*. (26): 1027–1040

[6] Goyal R.K,; Rajesh K.; and Pravin G. (2006): *Proceedings of the 67th Annual Convention of STAI.* Ahmadabad.

[7] DeJong, L.A. and Kelly, R.G., (1999): The Demonstration of the Microfabrication of Rigorously Defined Crevices for the Investigation of Crevice Corrosion Scaling Laws", in Critical Factors in Localized Corrosion *III*, The *Electrochemical Society: Pennington, NJ*. p. 678-688

[8] Alkire, R. C and Lott, S. E (1985): The Initiation of Crevice Corrosion on Grade 304, Stainless steel, *The Electrochemical. Society*, 8(5) :17 – 19.

[9] Tarja L.; (2000): Localized corrosion of stainless steel in chloride, sulfate and thiosulfate containing environments; *Corrosion Science* (42) 421-441

[10] Aniekan E, (2009): Electrochemical Measurement of Crevice Corrosion of Type AISI 304 Stainless Steel; *Thesis.*

[11] Stewart, K. C. (1999): Intermediate Attack in Crevice Corrosion by Cathodic Focusing; a PhD thesis for Doctor of Philosophy in Materials Science and Engineering.pp102-111.