Comparison of Ceramic and Polymer Crevice Formers on the Crevice Corrosion Behavior of Ni-Cr-Mo Alloy C-22

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Abstract:

  The effect of the crevice former material on the evolution of localized corrosion-damage is determined in this study. A standard crevice corrosion test method is modified by the use of ceramic or polymer materials as the crevice former. The focus is on the post initiation stage of crevice corrosion and addresses factors that may limit the initiation of localized corrosion and also slow or stop the continued propagation of corrosion. Controlled crevice corrosion tests are performed under aggressive, accelerated conditions on Ni-Cr-Mo alloy C-22 and the less corrosion resistant 316 stainless steel (SS316). Under identical conditions in high temperature, concentrated chloride brines, the PTFE tape covered ceramic is the most active crevice former on alloy C22 while solid polymer crevice formers (PTFE or Kel-F) are less active and ceramic crevice formers cause no crevice corrosion. The affects are important to the determination of the penetration rate and extent of corrosion damage by localized corrosion.

Key words: Alloy C-22, 316 stainless steel, crevice, initiation, stifling, localized corrosion

Introduction

Crevice corrosion is an important degradation mode to be evaluated for corrosion performance of passive metals exposed to high temperature brines over long exposure periods. A necessary condition for crevice corrosion is that a crevice former creates a sufficiently tight, restricted geometry on the metal surface to support the development of critical crevice chemistry. Crevice geometry factors, e.g. height, gap and length affect the initiation, propagation and stifling and arrest of crevice corrosion.

Both modeling and experimental work has been performed on the effect of the crevice geometry on the initiation and propagation of crevice corrosion [3-5]. Heppner [3] coupled a transport model and an ionic interaction model to simulate the effect of a crevice gap on the initiation of crevice corrosion. The results showed that decreasing the crevice gap will increase the electrical potential along the crevice, increase the electrical conductivity of the solution and increase the severity of the crevice solution composition. As the gap size decreases, the charge density throughout the crevice solution and the severity of crevice increase [3].

Akashi [6] studied the effect of applied torque on the crevice repassivation potential of 304 stainless steel in NaCl solution. As the applied torque increased, the repassivation potential decreased, i.e. more severe corrosion with a tighter crevice. When the applied potential was above a certain value, the repassivation potential was stable and no longer decreased when the applied torque was increased [6]. Factors that affected the crevice geometry could affect the crevice corrosion. Surface roughness and the mechanical properties of the crevice former could also affect the severity of crevice corrosion.

Localized corrosion of alloy C-22 has been examined by a number of researchers [7-11]. Different crevice formers were used to characterize the localized corrosion performance of alloy C-22. A PTFE tape covered ceramic [12] and PTFE Teflon [7, 13, 14] were used as crevice formers. These crevice formers have different mechanical properties, and in turn the resulting crevice geometry can be affected. The objective of this work was to determine the effect of the crevice formers on the evolution of corrosion damage: initiation, propagation, stifling and arrest. The crevice formers studied were PTFE tape supported with ceramic, bulk polymer (PTFE, Kel-F) and bulk ceramic (Al_2O_3).

Experiment methods

The alloy C-22 (N06022) Multiple Crevice Assembly (MCA) [15] specimens used in this study were fabricated from ~ 2mm thick wrought plate, which was obtained from Haynes International, Inc. The chemical composition is shown in table 1. The shape and dimension of the MCA specimen are shown in figure 1a. The crevice formers used in this study were: obtained from Metal Sample Inc., PTFE Teflon crevice former, Kel-F (PCTFE) crevice former and PTFE Teflon tape covered ceramic crevice former. The shape and dimensions of the crevice formers are shown in figure 1b after specification ASTM G48 [15].

The working surfaces of the MCA metal specimen were finished with 600 grit, wet silicon carbide (SiC) grinding paper before the test. Spot welding was used to attach a 0.8mm diameter alloy c-22 wire to the specimen. This provided stability in holding the assembly in the test solution and also provided electrical contact for the sample during the test. The specimen was then ultrasonically cleaned with methanol for a period of 10

minutes. The ceramic crevice formers were used in the as-fabricated condition, while the

Kel-F and PTFE Teflon crevice formers were ground with 1200 grit SiC sand paper. The

crevice formers were also cleaned with methanol. After grinding and cleaning, the

specimen and two crevice formers were assembled together with grade 2 titanium bolts,

nuts and washers that were electrically isolated from the metal specimen. Figure 1c shows

the MCA assembly of SS316 with two crevice formers.

Two crevice formers made from different materials were used on each assembly for the

potentiostatic test. Thus, the two crevice formers were tested under identical environment

conditions and a head-to-head comparison of the effects of crevice formers were made.

Two crevice formers made from the same materials were used in the assembly. The

applied torque was 70 in-lb for assemblies with ceramic and Kel-F crevice formers. The

initial applied torque for assembly with PTFE crevice formers was 2.5 in-lb. The applied

torque was increased to 14 in-lb and 25 in-lb during the tests.

The test solution used for alloy C-22 was 4M NaCl (20wt%), with a temperature of

100°C. The test solution used for SS316 was 0.5M NaCl at room temperature. In all the

tests, the test solutions were prepared with American Chemical Society (ACS) certified

grade NaCl obtained from Fisher Scientific Inc. The solution used for the potentiostatic

test, was open to the air through a water-cooled condenser while the solution used for the

cyclic potentiodynamic polarization test was purged with Ar before and during the test.

Electrochemical tests were conducted in standard three electrode glass test cells with a

capacity of 1000 cm^3. The volume of solution used was approximately 900 ml. A rarte-

earth metal coated titanium wire obtained from Eltech System Corp. was used as the

counter electrode in each test, and was separated from the sample compartment of the test cell with a fritted tube. A Saturated Calomel Electrode (SCE) was the reference electrode, and was connected to the test cell through a salt bridge to an external chamber.

The cyclic potentiodynamic polarization tests were performed with a Solartron 1287 potentiostat. When the open circuit potential of the specimen E_{corr} reached a stable value, the cyclic potentiodynamic polarization test was performed. Typically, hold times were 12 to 24 hours at the open circuit potential of alloy C-22 to reach equilibrium. Cyclic potentiodynamic polarization was started from 50 mV below E_{corr} and continued until the current density reached 5mA/cm^2. The scan direction was then reversed., The scan rate was 0.1667mV/sec during both the forward and reverse scan.

The potentiostatic tests were performed on a Solartron 1480 multi-channel potentiostat, which has the capability of controlling up to 8 test cells simultaneously. The applied potential was more positive than the repassivation potential for the alloy in the test environment, e.g. the applied potential was -0.150 V-SCE, which is less than 100 mV above the repassivation potential of alloy C-22 in 4M NaCl solution [9, 16] at 100°C. The controlling software used for both Solartron 1480 and Solartron 1287 was CorrWare® from Scribner Associates.

The specimens were rinsed with de-ionized water and methanol, and examined with a stereo-microscope to complete each test. The SEM analyses were performed on a FEI/Philips XL-30 Environmental Scanning Electron Microscope (ESEM). The corrosion depth profiles and surface roughness were measured with an InfiniteFocus® Microscope

(IFM) made by Alicona Imaging GmbH. The IFM is an optical device for 3D surface measurement and analysis.

Results

Cyclic potentiodynamic polarization

Figure 2 shows the cyclic potentiodynamic polarization curves of alloy C-22 with (a) PTFE tape covered ceramic crevice formers and (b) ceramic crevice formers in de-aerated 4M NaCl at 100°C. In the forward scan, these two samples showed similar behavior. Both samples had a corrosion potential of -0.629 V-SCE and a breakdown potential at +0.240 V-SCE. The crevice formers had no effect on the corrosion and breakdown potentials of alloy C-22. While in the reverse scan, there is a difference in the curves obtained with these two crevice formers. There is a large hysteresis loop during the reverse scan of the sample with PTFE tape covered ceramic crevice formers. The repassivation potential for the sample with PTFE tape covered crevice formers was -0.182 V-SCE. This value is in fair agreement with the -0.195 V-SCE result obtained by Ilevbare [9]. A potential of -0.150 V-SCE was applied in the potentiostatic tests, i.e. a potential 30 to 50 mV more positive than the repassivation potential.

Crevice corrosion and corrosion products were found under the crevice feet of the PTFE tape covered ceramic crevice formers sample. During the reverse scan of the sample with the ceramic crevice formers, the sample repassivated easily, and no crevice corrosion or corrosion products were found under the crevice feet. These results indicate that the crevice corrosion, where observed, initiated after the specimen was polarized beyond the

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breakdown potential and the corrosion damage occurred from the initiation event and continued until the specimen repassivated during the reverse polarization scan.

Severity of crevice corrosion with different crevice formers

Figures 3a and 3b show the potentiostatic test results of alloy C-22 in 4M NaCl at 100°C with ceramic crevice former and PTFE tape covered ceramic crevice former. The charge of the sample during the 67 hour test was 10 coulombs. The test protocol was to initiate crevice corrosion and to stop the test after 10 coulombs of corrosion current, and for this test 10 C was reached after 67 hours exposure. This was one of a series of tests to examine the crevice corrosion damage after controlled amounts of total coulombs had passed. Figure 3a shows the morphology on the side with the ceramic crevice former, while figure 3b shows the morphology on the side with PTFE tape covered ceramic former. Localized corrosion and corrosion products were not observed under the ceramic crevice former feet however superficial mechanical damage was observed. The damage was attributed to the high torque during assembly.

, Green-black corrosion products were observed outside the crevice former on the side with PTFE tape covered ceramic crevice former during the test. The crevice former was removed at the end of the test, and crevice corrosion was found under the crevice former feet. Black, loose corrosion products were found in the corroded regions of the crevice.

A total of 7 samples with ceramic and PTFE tape covered ceramic crevice formers were tested potentiostatically in 4M NaCl at 100°C. All 7 samples showed crevice corrosion on the side with PTFE tape covered ceramic crevice former, while corrosion was not found on

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the side with ceramic crevice former. The results showed that PTFE tape covered ceramic is the most severe crevice former. Identical test conditions showed ceramic crevice formers caused no localized corrosion.

The torque with ceramic/PTFE tape covered ceramic remained high at about 55 to 60 in-lb after the test. Relaxation of torque was observed for the tests with bulk polymer crevice formers. Decrease in torque can be due to flow of the polymer and/or crevice corrosion increasing the gap between the crevice former and the metal.

Similar results were obtained on SS316 as for alloy C22. Figures 3c and 3d show the morphology of the SS316 specimen after being tested with ceramic crevice former and PTFE tape covered ceramic crevice former on each side of the specimen. The specimen was held under +0.100 V-SCE in 0.5M NaCl solution for 2.5 hours at room temperature. Severe corrosion with a depth up to 200 μm was found under the crevice former on the side with PTFE tape covered ceramic, while on the side with ceramic crevice former, only mechanical damage caused by the compression of the ceramic crevice former was found.

The results of a series of tests with different combinations of crevice formers run with alloy C-22 in 4M NaCl at 100°C and at a constant potential of -0.150 V-SCE are summarized in table 2. Three tests compared the crevice corrosion severity caused by PTFE tape covered ceramic and Kel-F crevice formers. Crevice corrosion occurred on the side with PTFE tape covered ceramic crevice former, and black corrosion products were found under the crevice formers on all three specimens. Localized corrosion or the corrosion products were not found under the Kel-F crevice former. There was no mechanical damage on the Kel-F side., The maximum corrosion depth was about 25 μm on

the side with PTFE tape covered ceramic crevice former after a total flow of 10 coulombs of charge. Corrosion was not found on the freely exposed areas (no crevice) on all of the samples. The results showed that the PTFE tape covered ceramic crevice former was a more severe crevice former than Kel-F bulk polymer.

The combination of ceramic crevice former and Kel-F crevice former was also tested in 4M NaCl at 100°C under anodic potential -0.150 V-SCE. Five specimens were tested with this crevice former combination. Only one specimen corroded under the Kel-F crevice former. The other samples, which were tested for up to 10 days, showed no corrosion on either the Kel-F side or the ceramic crevice former side. Only superficial mechanical markings were found near the edges of the crevice feet on the ceramic crevice former side, as in the combination of ceramic/PTFE tape covered ceramic crevice formers. Crevice corrosion was found under all 12 feet on the side with Kel-F crevice former of the single specimen that corroded. Black corrosion products were found in the corroded sites. The test was stopped when the charge reached 10 coulombs, and the maximum corrosion depth was 18 μm.

Combinations of PTFE crevice former with ceramic crevice former, PTFE tape covered ceramic crevice former, and Kel-F crevice former were also tested for 35 days under potentiostatic condition in 4M NaCl at 100°C. The initial applied torque was 2.5 in-lb as specified in ASTM G48 [15]. There was no indication of crevice corrosion for the three crevice former combinations after 15 days of testing. When the specimens from the test cells were removed, it was found that there was almost no torque remaining with the assemblies due to the flow and relaxation of PTFE crevice formers at 100°C. The MCA

assemblies were re-tightened to 14 in-lbs, and the samples were tested for another 10 days. During the test period there was still no indication of crevice corrosion. After 10 days, the assemblies were re-tightened to 25 in-lbs, the highest torque that could be applied. The re-torqued assemblies were put into the solutions and the tests were restarted. After another 10 day period, there was no indication of crevice corrosion on the three crevice former combinations with PTFE crevice former. The assemblies were loose after the test period. Post examinations of the samples with a stereo microscope showed that no crevice corrosion formed on either side of the samples.

Morphology of crevice corrosion

Corrosion depth profiles after the tests measure the amount and distribution of the corrosion damage. Figure 4a shows a corrosion site beneath a contact foot of the crevice former on the alloy C-22, PTFE tape covered ceramic specimen shown in figure 3b. Figure 4b shows the corrosion depth profile across the damaged area along the line in figure 4a. Note the dimensional scale on the depth of the penetration scale is nearly 1000 times that of the width. The horizontal penetration is about 770 μm wide and the maximum depth is about 25 μm. Based on the depth of damage profile, the corroded area can be divided into three regions. The penetration is observed near the edge of the crevice foot, then there is a deeper corrosion region that has the maximum corrosion depth. The corrosion depth profile changes faster in this deeper corrosion region than in the other regions. Following the deeper corrosion region there is a plateau region, where the corrosion depth is shallower and the depth of penetration decreases slowly. Next is a stained region between the corroded and uncorroded areas. In the stained region, the surface is covered with a thin

layer of tenacious corrosion products. The central region of the crevice foot contact is uncorroded.

Crevice corrosion on alloy C-22 and SS316 was not found on the side with ceramic crevice former, and only superficial mechanical damage under the ceramic crevice formers was found as shown in figures 3a and 3c. To confirm that the damage on the ceramic crevice former side is mechanical damage, a 20 day test using two ceramic crevice formers was performed on alloy C-22 under -0.150 V-SCE potential in the 4M NaCl solution at 100°C. Post test examination with SEM shows no crevice corrosion under the crevice former. Figures 5a and 5b show SEM pictures of the alloy C-22 sample after 20 days of testing with two ceramic crevice formers. For comparison, a sample assembled with two ceramic crevice formers in air to the same torque and held for 2 hours without any corrosion exposure was also prepared and examined with SEM. The morphology under the crevice former is shown in figures 5c and 5d. No apparent differences can be found between the morphologies obtained under these two conditions. The damage depths of these two samples are similar at less than 3 µm. A similar result was obtained on SS316. The depth of the damage in figure 3c is less than 3 µm, and the morphology is similar to the one without corrosion exposure testing. The conclusion is that the damages under the ceramic crevice former in figures 3a and 3c are mechanical damages caused by the compression of the ceramic crevice former. Localized corrosion did not occur.

Current vs. time changes during potentiostatic crevice test

The magnitude of the corrosion current during the constant potential exposure is an indication of the corrosion rate during the test. Figure 6 shows the current vs. time changes

during the test with two ceramic crevice formers. Overall the corrosion current decreases with increasing test time. The initial current of about 3µA decreased to 1 µA after 30 minutes. The corrosion current decreased further to approximately 0.1 µA after about 100 hours. The final corrosion current was 0.04 µA after 20 days of testing. The total surface area of the specimen was 10cm^2, and the corrosion current density was 0.004µA/cm^2 based on the total specimen area. The corrosion current showed no initiation of crevice corrosion, and the alloy stayed in the passive state during the whole test period. This is further substantiation that the damages under the ceramic crevice former in figure 3a are mechanical damages caused by the compression of the ceramic crevice former.

The current vs. time curve for the test with PTFE crevice former/PTFE tape covered ceramic crevice former is shown in figure 7. The current vs. time curves for PTFE/ceramic and PTFE/Kel-F (not shown) combinations are similar. The current decreased to low values and remained low throughout the tests. The specimens stayed in passive states during the whole test period. No corrosion damage was observed after the tests were completed.

Three stages of initiation, propagation and stifling/arrest were observed in tests with PTFE tape covered ceramic where corrosion damage occurred. Transition in the initiation stage from passivity to active corrosion occured within the crevice region as an aggressive local chemistry was developed in the crevice region. During the propagation stage, the alloy actively corroded at selected areas within the crevice area. The corrosion penetrated deeper and further into the crevice with lateral growth a couple of orders of magnitude greater than penetration. In this study it was found that during the propagation stage,

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multiple propagation/arrest events occurred on the specimen and under individual crevice feet. Under many conditions, the creviced specimen exhibited stifling and arrest when the surface was repassivated. The multiple propagation/arrest events can correspond to the initiation of new crevice corrosion sites or arrest of an active crevice corrosion site.

Figure 8 shows the corrosion current vs. time curve for the test with ceramic crevice former vs. PTFE tape covered ceramic crevice former in 4M NaCl at 100°C. The test duration was 442.6 hours., Three different stages are shown on the corrosion current vs. time curve. During the initiation stage, the corrosion current was small and on the order of 0.13 µA. There was an increase in the corrosion current after about 71 hours, which corresponds to the initiation of the crevice corrosion. During the propagation stage, multiple initiation and arrest events were observed as serrations on the current vs. time curve. When the current reached a maximum value of about 200µA, the overall current started to decrease. When the total charge reached 118 coulombs, the current decreased to lower than 1µA, and the sample became repassivated. At the end of the test, the corrosion current was less than 0.3µA and showed a tendency to continue decreasing.

Other specimens where crevice corrosion initiated on the PTFE tape covered ceramic showed similar current vs. time behavior with multiple propagation, stifling and arrest events. Figures 9a, 9b and 9c show the current vs. time behavior of a sample with PTFE tape covered ceramic crevice former and Kel-F crevice former tested in 4M NaCl at 100°C. The crevice corrosion occurred on the side with PTFE tape covered ceramic crevice former during the test. In the incubation period, the corrosion current decreased

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with increasing exposure time, and the current was 0.13 μA before the initiation of the crevice corrosion. 26 hours into the incubation period, crevice corrosion initiated as indicated by the sharp increase of the corrosion current, and the crevice corrosion changed to the propagation period. During the propagation period, corrosion current initiation and arrest events occurred several times. After reaching a maximum current of 100 μA, the overall corrosion current started to decrease, and the sample gradually became repassivated. The sample stayed in the repassivation state for more than 100 hours until the test was stopped. No indication of the re-initiation of crevice corrosion was observed. The corrosion current was only 0.04μA at the end of the test.

Discussion

The test results show that crevice corrosion is least severe with the ceramic crevice former, while crevice corrosion is most severe with the PTFE tape covered ceramic crevice former. Kel-F also causes crevice corrosion under the test condition, but crevice corrosion is less severe than the ceramic crevice former covered with PTFE tape covered ceramic. Crevice corrosion with the PTFE crevice former is less severe than with the ceramic crevice former covered with PTFE tape.

When other factors are fixed, the crevice corrosion of an alloy is affected by the geometry of the crevice, and the crevice gap opening is a primary factor. With a tighter crevice gap, crevice corrosion initiates more readily. When the gap is larger than a critical value for the metal/environment condition, no crevice corrosion occurs.

The ceramic crevice former has a relatively rough surface finish. The average roughness Ra of the ceramic crevice former surface is 0.67 μm. This is close to the surface roughness

of alloy C-22 after grinding with 120grit SiC paper, where the average roughness Ra is about 0.66 µm. For comparison, alloy C-22 after grinding with 600 grit SiC paper has an average roughness Ra of about 0.23 µm. The surface roughness as related to the tightness of the crevice gap is likely to be a significant contributor to the severity of the crevice formed by the ceramic.

When the ceramic crevice former is covered with PTFE tape with initial thickness of 76 µm, the compressed tape can fill cavities both on the ceramic crevice former and the metal surface. This can greatly reduce the crevice opening and result in easier formation of crevice corrosion. Metal tends to increase the crevice opening and may stop the crevice corrosion when it is corroded under the crevice. Because the PTFE tape is backed with ceramic, which has a mechanical property that is not affected by the test temperature, the applied the toque can be kept without much loss during the test. The PTFE tape can fill up the new cavities formed by the crevice corrosion, and keep the crevice opening small. This favors propagation and retards the repassivation of the crevice corrosion.

Conclusion

This study examines the effect of the crevice former made of ceramic, polymer and polymer/ceramic combination on the likelihood and severity of crevice corrosion. The primary focus is on crevice corrosion of alloy C-22 in concentrated (4M NaCl, 20wt%) brines at an elevated temperature (100°C). Tests with SS316 in room temperature saline solution find similar rankings for the crevice formers.

- Ceramic crevice former in direct contact with the metal is the least severe, and no crevice corrosion is observed.

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- Ceramic/PTFE tape covered ceramic is the most severe crevice former.

- Solid polymer crevice formers (PTFE or Kel-F) are less severe than PTFE tape covered ceramic.

Where crevice corrosion is observed, three stages are identified: initiation, propagation and stifling/arrest.

- Polarization current throughout the test indicates a magnitude of corrosion and initiation/arrest/re-initiation events.

- After initiation, multiple initiation/arrest events are observed during the propagation stage.

- After stifling/arrest, the polarization current returns to passive metal levels.

Acknowledgement and Disclaimer

References

[1] John Wengle, Office of Science and Technology and International Annual Report 2005, DOE/RW-0581, Las Vegas, Nevada (2006)

[2] D. C. Agarwal, Materials and Corrosion 48 (1997): p. 542-548.

[3] K. L. Heppner, Corrosion 60 (2004): p. 718-728.

[4] J. S. Lee, M. L. Reed, R. G. Kelly, J. Electrochem. Soc. 151 (2004): p. B423-B433.

[5] M. Vankeerberghen, Corrosion 60 (2004): p. 707.

[6] M. Akashi, G. Nakayama, "Initiation Criteria for Crevice Corrosion of titanium Alloys Used for HLNW Disposal Overpack", CORROSION / 96, paper 158, (Houston, TX: NACE, 1996).

[7] D. S. Dunn, Corrosion 61 (2005): p. 1078.

[8] D. S. Dunn, Corrosion 62 (2006): p. 3.

[9] G. O. Ilevbare, Corrosion 62 (2006): p. 340.

[10] K. J. Evans, JOM 57 (2005): p. 56.

[11] B. A. Kehler, Corrosion 57 (2001): p. 1042.

[12] G. O. Ilevbare, J. Electrochem. Soc. 152 (2005): p. B547.

[13] X. He, "Crevice corrosion Penetreation Ratesof Alloy 22 in choloride Containing Water", CORROSION / 2006, paper 06618 (Houston, TX: NACE, 2006).

[14] F. Hua, Corrosion 60 (2004): p. 764.

[15] ASTM G48-03, "Standard Test Methods for Pitting and Crevice Corrosion Resistance of Stainless Steels and Related Alloys by Use of Ferric Chloride Solution", ASTM International, West Conshohocken, PA (2005)

[16] R. B. Rebak, "Factors affecting the crevice corrosion susceptibility of Alloy 22", CORROSION / 2005, paper 05610 (Houston, TX: NACE, 2006).

[17] H. W. Pickering, Corrosion 42 (1986): p. 125-140.

[18] H. W. Pickering, J. Electrochem. Soc. 150 (2003): p. K1-K13.

[19] Y. Xu, H. W. Pickering, J. Electrochem. Soc. 140 (1993): p. 658-668.

[20] H. W. Pickering, Mater. Sci. Eng. A 198 (1995): p. 213-223.

[21] M. I. Abdulsalam, H. W. Pickering, J. Electrochem. Soc. 145 (1998): p. 2276-2284.

[22] J. W. Oldfield, "Development of a mathematical model of crevice corrosion propagation on nickel base alloys in natural and chlorinated sea water", Report (1994), (Order No. AD-A284715), 73 pp.

Table 1 Alloy C-22 composition used in the test

Cr	Mo	Fe	W	Co	Mn	V	Si	S	P	C	Ni
21	13.1	3.8	2.8	2.1	0.25	0.011	0.024	0.005	0.006	0.0052	BAL

Table 2 Summary of crevice corrosion test results for alloy C-22 in 4M NaCl at 100°C

Crevice former		Observation	Comments
C (0/7)	TC (7/7)	PTFE tape covered ceramic (TC) side always corroded. No crevice corrosion on ceramic side (C). The remaining torque after test is about 55 to 60 in-lb compared to initial 70 in-lb.	Most aggressive crevice formers combination.
C (0/5)	K (1/5)	One of five samples corroded on Kel-F side (K), the remaining samples no corrosion beneath the crevice formers, i.e. K or C. The remaining torque after test is less than 5 in-lb.	Kel-F deforms/relaxes under high temperature (100°C)
TC (3/3)	K (0/3)	TC side always got corroded, no crevice corrosion on Kel-F side. The remaining torque after test is less than 5 in-lb.	Kel-F deforms/relaxes under high temperature (100°C)
C (0/1)	T (0/1)	Tested for 35 days. Initial torque was 2.5 in-lb and tested for 15 days. Re-torqued to 14 in-lb at RT and tested for another 10 days. Followed by another re-torque of 25 in-lb at RT and tested for another 10 days. No corrosion was found on either side. The remaining torque is less than 5 in-lb.	PTFE deforms/relaxes under high temperature (100°C), not as aggressive crevices as with ceramic support
TC (0/1)	T (0/1)	Same re-torque schedule as the C/T crevice formers combination.	Same as the previous one
K (0/1)	T (0/1)	Same re-torque schedule as the C/T crevice formers combination.	Same as the previous one
C (0/1)	C (0/1)	Tested for 20 days, no corrosion.	For verification

Notes:
1) TC = PTFE tape covered ceramic; C = ceramic; K= solid Kel-F; T = solid PTFE
2) Numbers in parentheses indicate number of specimens corroded vs. number of specimens tested under each crevice former combination
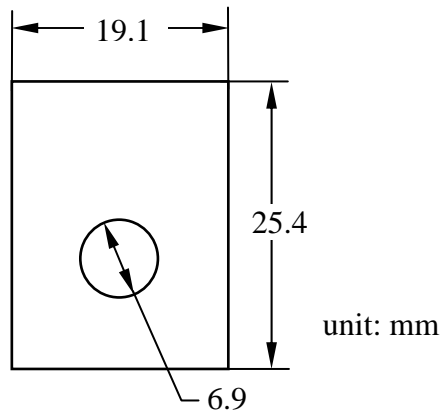
(a) test specimen
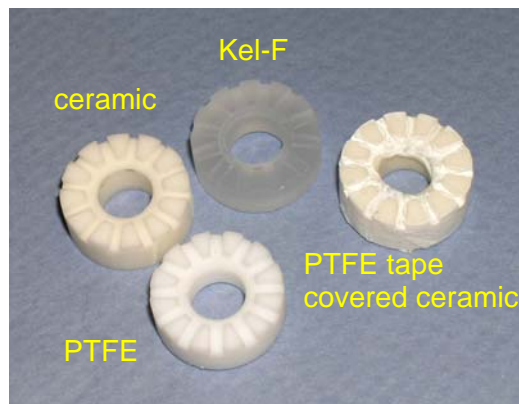
(b) crevice formers
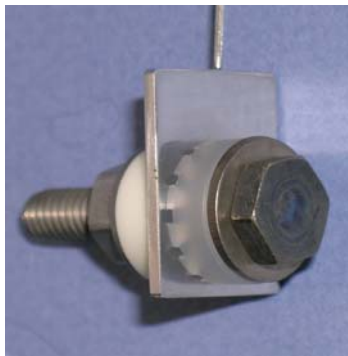
(c) MCA assembly with Kel-F and ceramic crevice formers

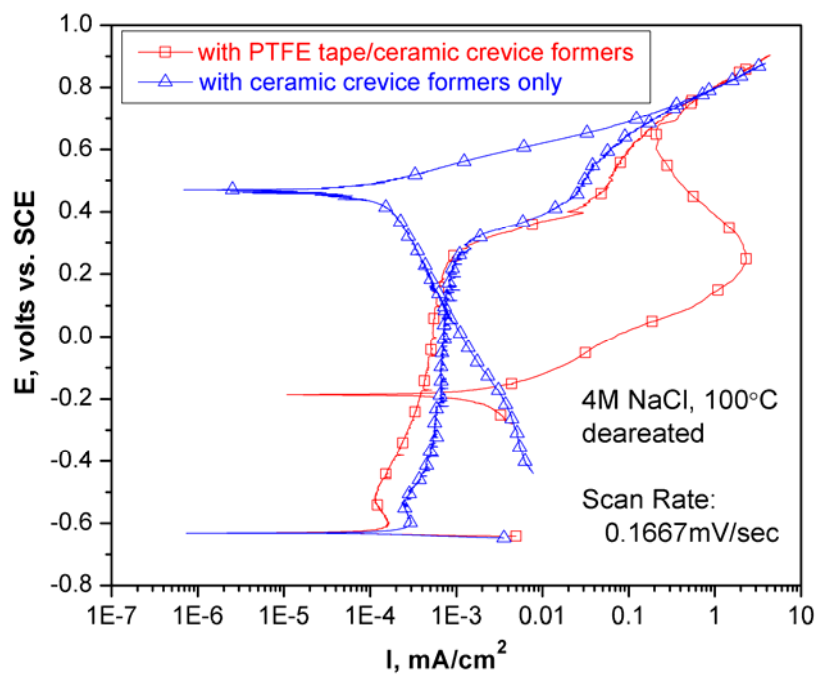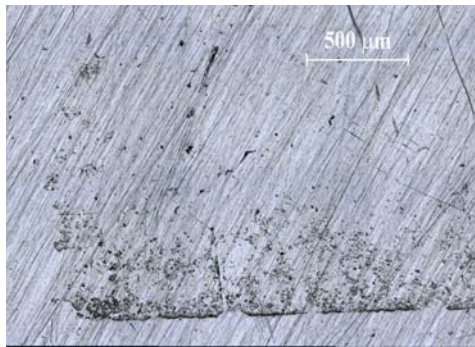Figure 1 MCA crevice test specimen

Figure 2 Cyclic polarization curves of alloy C-22 with PTFE tape covered ceramic crevice formers and ceramic crevice formers, 4M NaCl, 100°C, scan rate = 0.1667mV/sec
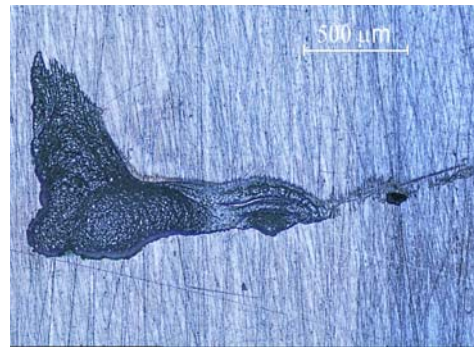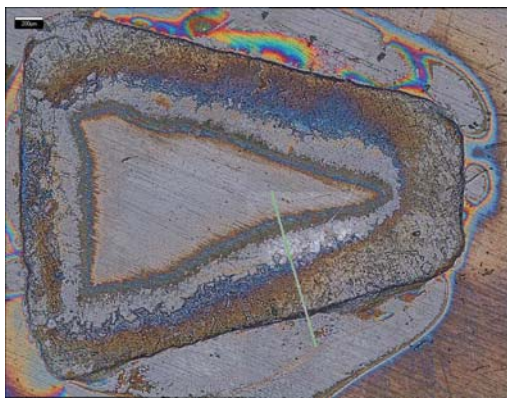
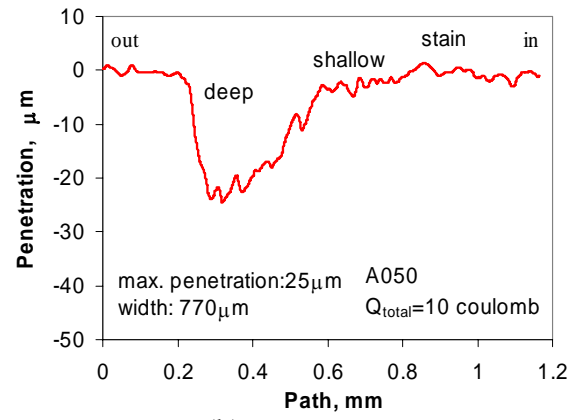(a)   (b)

(c)   (d)

Figure 3 Crevice corrosion morphology with ceramic crevice former and PTFE tape covered ceramic crevice former on alloy C-22 and SS316, (a) alloy C-22, ceramic side (b) alloy C-22, PTFE tape covered ceramic side (c) SS316, ceramic side (d) SS316 PTFE tape covered ceramic side

(a)

(b)

Figure 4 Corrosion morphology of alloy C-22 under PTFE tape covered ceramic crevice former, Q=10 coulomb, number of feet corroded = 10

low magnification   high magnification

(a) tested for 20 days

low magnification   high magnification
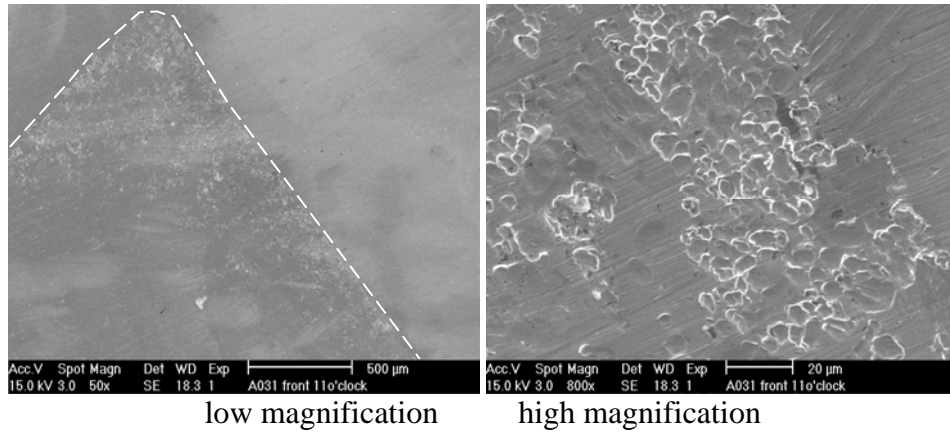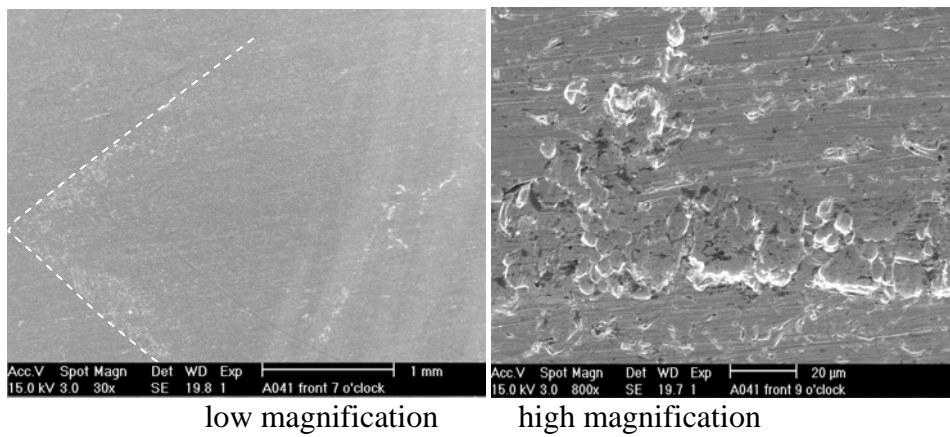
(b) assembly only sample without test

Figure 5 Damage morphology of alloy C-22 under ceramic crevice former, the dash line shows the outline of the crevice former foot
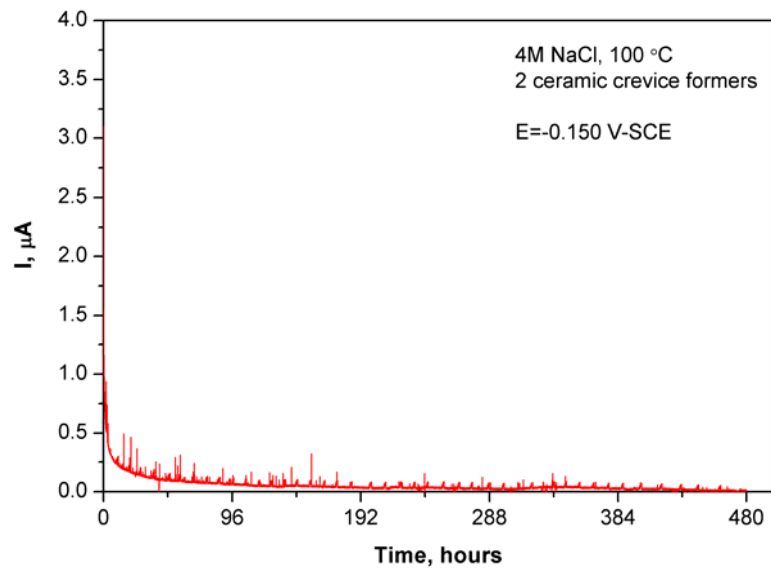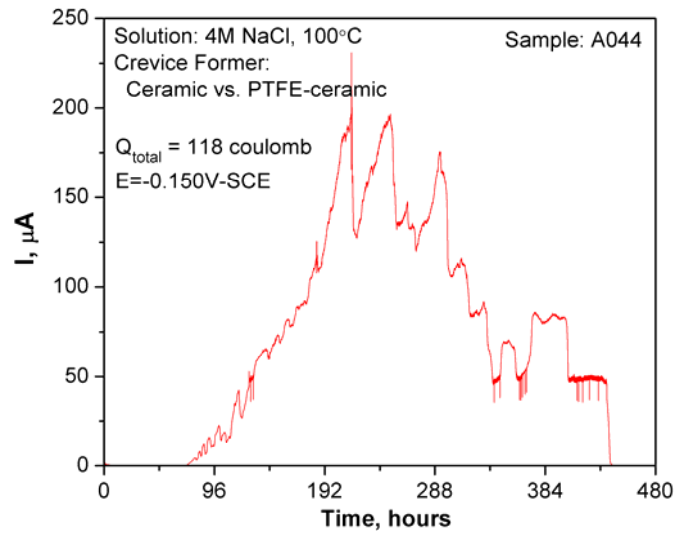
Figure 6 Current vs. time changes of alloy C-22 during the test with two ceramic
crevice formers, 4M NaCl, 100°C, E=-0.150 V-SCE
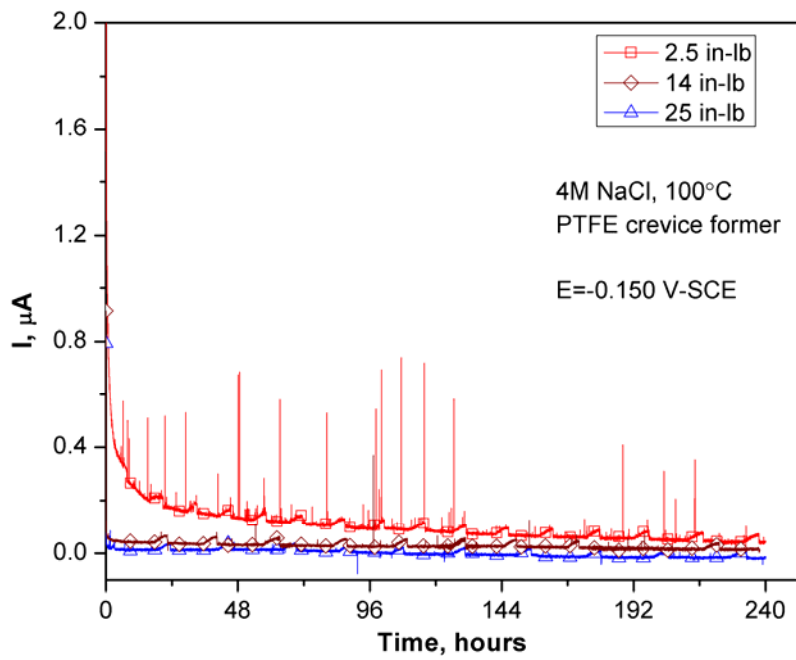
Figure 7 Current vs. time changes during the test of alloy C-22 with ceramic crevice former and PTFE crevice former, 4M NaCl, 100°C, E=-0.150 V-SCE
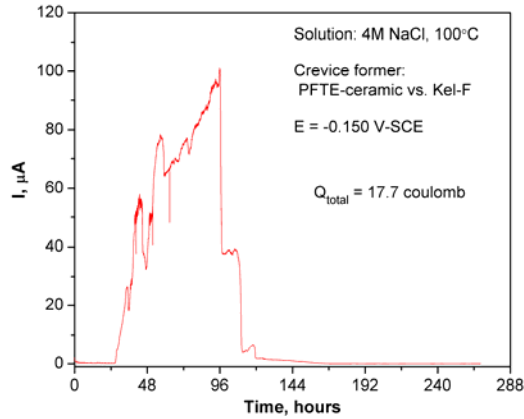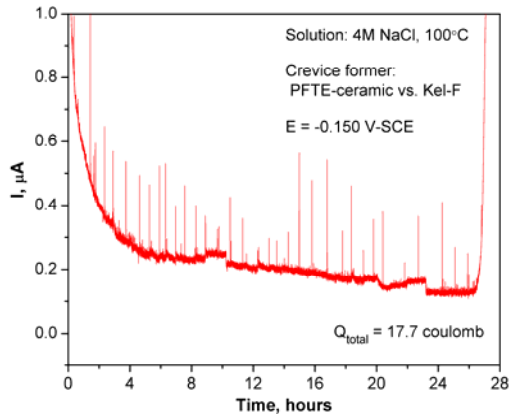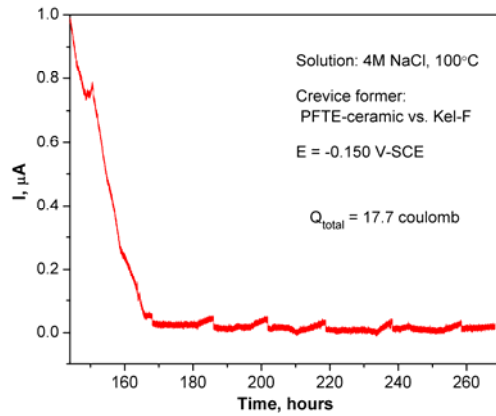
Figure 8 Current vs. time changes of alloy C-22 for test with PTFE tape covered ceramic crevice former, total feet corroded = 9, Q = 118 coulomb

(a) Current vs. time

(b) initiation

(c) repassivation

Figure 9 Initiation and repassivation events in the crevice corrosion process of alloy C-22, PTFE tape covered ceramic/Kel-F, feet corroded = 10, Q= 37 coulomb