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Fatigue and Corrosion Fatigue Behavior of Nickel Alloys in Saline Solutions

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ABSTRACT : *Nickel based alloys have been developed as materials offering superior corrosion fatigue. The fatigue performance of IN600, IN601 and C22 was examined in increasing saline solution severity of 3.5% sodium chloride at pH = 6.8. Results of fatigue and corrosion fatigue tests indicate that the fatigue lives of IN600, IN601 and C22 tested in 3.5 % sodium chloride solution (NaCl) are essentially the same as for specimens tested in air. Fatigue fractures presented a ductile appearance in specimens tested in both air and in a saline solution, thus providing additional evidence of there being no effect of the 3.5% sodium solutions on fatigue strength.*

Keywords: *Air, C22, fatigue, IN600, IN601, solution.*

I. INTRODUCTION

Fatigue is the time-dependent growth of subcritical cracks under cyclic loading [1]. Fatigue cracking is one of the most common causes of failure of engineering structures, can go undetected, be unexpected, and can result in catastrophic failures.

Fatigue and fatigue damage in the presence of various corrosive media have been the subjects of sustained research in materials engineering technology for more than a century [2]. Metals and their alloys, when they are exposed to aggressive environments and cyclic stresses, can suffer a degradation of fatigue resistance. Even laboratory air containing some moisture has been shown to influence crack propagation rates of materials when compared with those obtained from tests in vacuum or in dehumidified inert gases. Measures to avoid such corrosion cracking include careful materials selection, heat treatment, and modifications of material/environment interactions through coating, controlled solution chemistry, inhibition, and applied potentials. Find better solutions are of extreme importance in several industries, including and especially in aerospace and power generation and offshore service.

Nnumerous studies have been carried out on the mechanical and chemical properties of nickel alloys [3-5]. Nickel alloys containing chromium and molybdenum are used in a wide variety of environments involving corrosive media because these elements significantly improve corrosion properties [6-8].

Understanding the processes of fatigue cracking of these nickel alloys in corrosive environments is key to developing processes for the addition of alloying elements and for materials and manufacturing process selection. For example, fatigue crack initiation in materials used in environments containing corrosive media has been attributed to various factors such as the presence of pitting corrosion sites. Increased corrosion fatigue enhanced deformation was proposed to explain the apparent intensification of intrusions and extrusions in materials [6-10].

The current study was conducted to determine and to compare the effect of alloying elements on the fatigue and corrosion fatigue behavior of the nickel-based alloys, IN600, IN601 and C22.

II. EXPERIMENTAL PROGRAM

2.1 Material

The IN600, IN601 and C22 alloys were chosen because of the possibility that chloride ions (Cl), could severely disorder passive film and then damage the oxide film. In addition, chloride ions can be found in dry and wet atmospheric conditions. The chemical composition (wt. %) of these alloys is reported in [11]. For the tests reported in this study, standard fatigue specimens with dimensions shown in Figure 1 were machined from the as-received material.

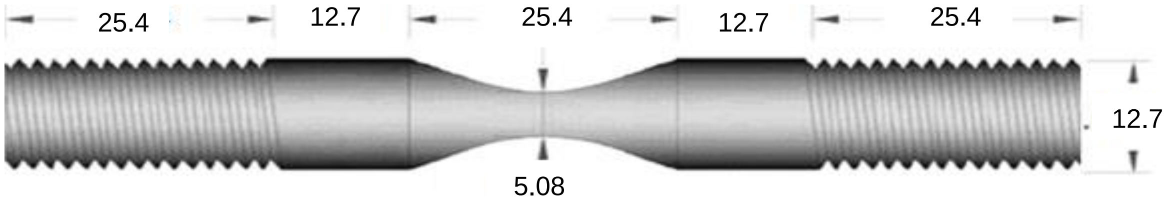

Figure 1Dimensions of fatigue specimen in (mm)

2.2 Fatigue Test Equipment

Fatigue tests were conducted on annealed specimens of the three alloys at a constant frequency of 10 Hz under axial tension-tension load in two environments - air and 3.5 % sodium chloride (NaCl) solution and were conducted on an Instron 1337 testing machine, connected to an Instron 8500 programmable control unit. The Instron 1337 unit has a load cell with a full load scale of 1000 kg/1V. The servo-hydraulic test unit applies a load through a hydraulic actuator, while a computer-controlled servomechanism controls the oil flow to the actuator. The specimen is mounted on the test unit between the actuator and the load cell by screwing it into the test fixture as shown in Figure 2. The Instron 8500 programmable control unit was used to set up all the testing parameters. Furthermore, the control unit also received data from the displacement gauge and the load cell throughout each test. The data were processed in real time by the computer and, based on the programmed test parameters, feedback sent to the servo valve to control the hydraulic actuator.

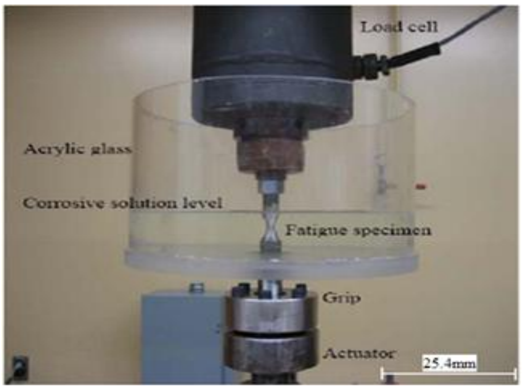

Figure 2 Photograph of Instron testing machine and corrosion cell

Fatigue tests in corrosive solutions were performed by enclosing the specimen within an “O” ring sealed, acrylic glass cylinder, as shown in Figure 3. An O-ring was installed at the bottom of the cell to permit the transfer of load to the specimen while preventing leakage of the saline solution (Figure 3).

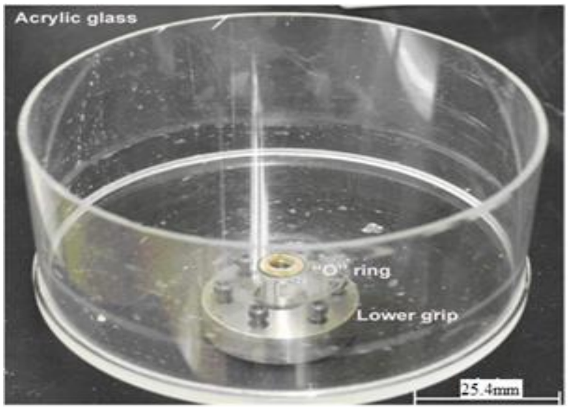

Figure 3 Micrograph showing corrosion cell connected to the grip from the bottom

III. RESULTS AND DISCUSSION

Fatigue tests were first conducted in air to provide a baseline for comparing with results in aqueous solutions of 3.5 % NaCl solution at pH = 6.8. The results of the fatigue testing are presented in the form of stress to cycle to failure curves (Figures 4-6).

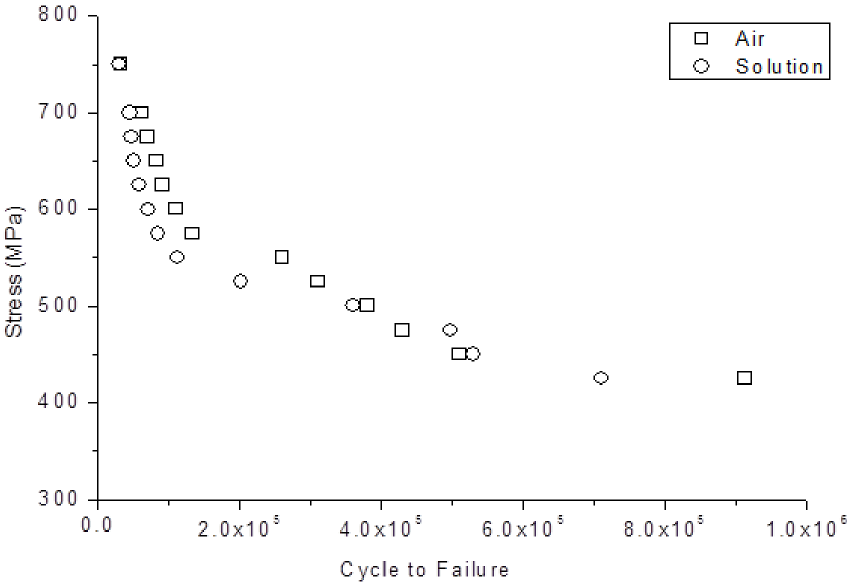

Figure 4 Fatigue test curves of IN600 in air and in 3.5%NaCl at pH = 6.8

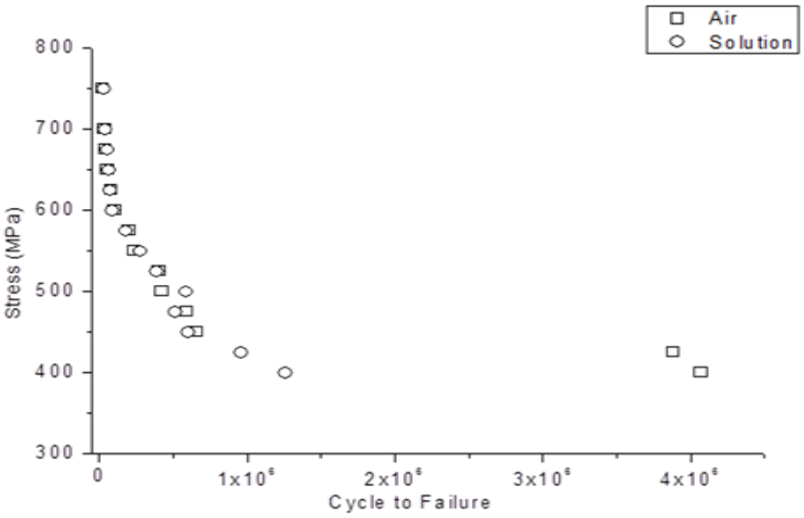

Figure 5 Fatigue test curves of IN601in air and in 3.5%NaCl at pH = 6.8

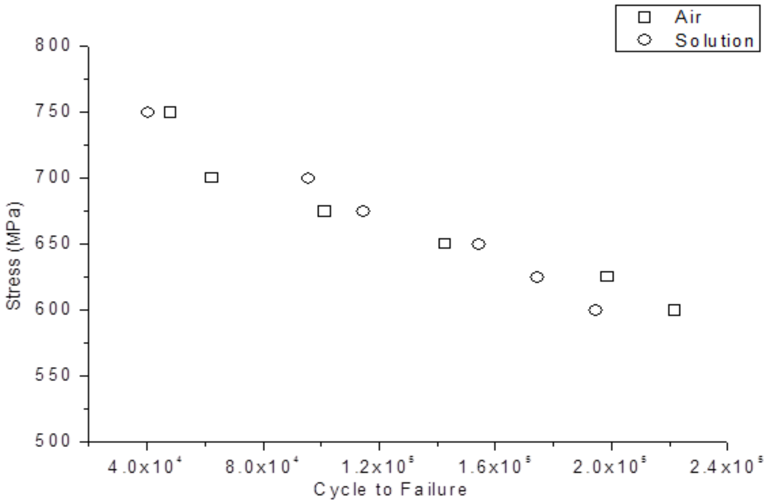

Figure 6 Fatigue test curves of C22 in air and in 3.5%NaCl at pH = 6.8

Test data show that fatigue in 3.5 %. NaCl solution had little effect and difference not statistically significant and hence, essentially the same on the fatigue strength of any of the alloys as the fatigue test curves are similar to those for specimens tested in air (Figs 4-6).

The test data are supported by scanning electron microscopy (SEM) which shows similar fracture surfaces for specimens tested in air and those tested in 3.5% NaCl solution (Figs. 7-9). In both cases, the fracture surfaces have a ductile character with fatigue striations. There is no evidence for corrosion or cleavage fracture. It was therefore concluded that all three alloys had excellent corrosion resistance in 3.5 % NaCl solution.

Appearance of striations is evidence that the fracture was definitely caused by fatigue. However, if striations do not appear, this does not necessarily mean the fracture is not due to fatigue. Typical striations were observed in a number of specimens of C22 alloy as shown in Figure 10.

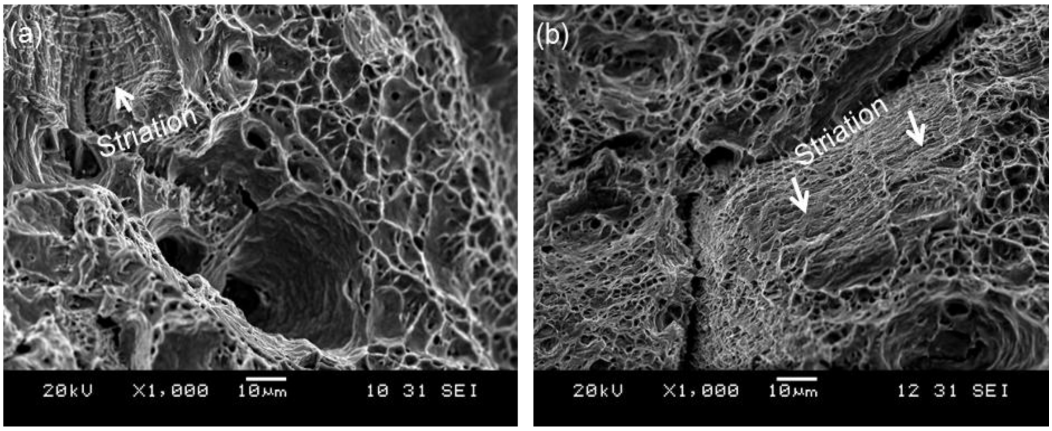

Figure 7 Fatigue fracture surface of IN600 (a) in air, and (b) in 3.5%NaCl solution at pH 6.8

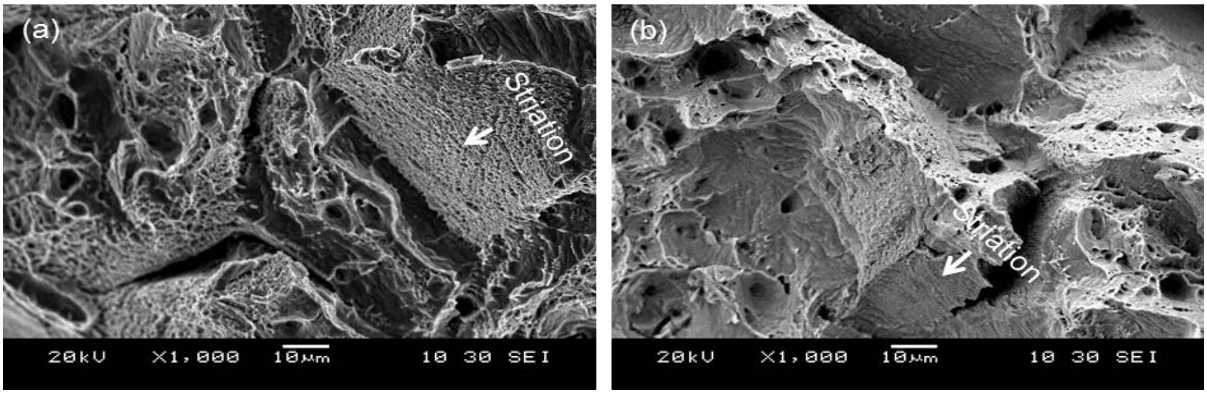

Figure 8 Fatigue fracture surface of IN601 (a) in air, and (b) in 3.5%NaCl solution at pH = 6.8

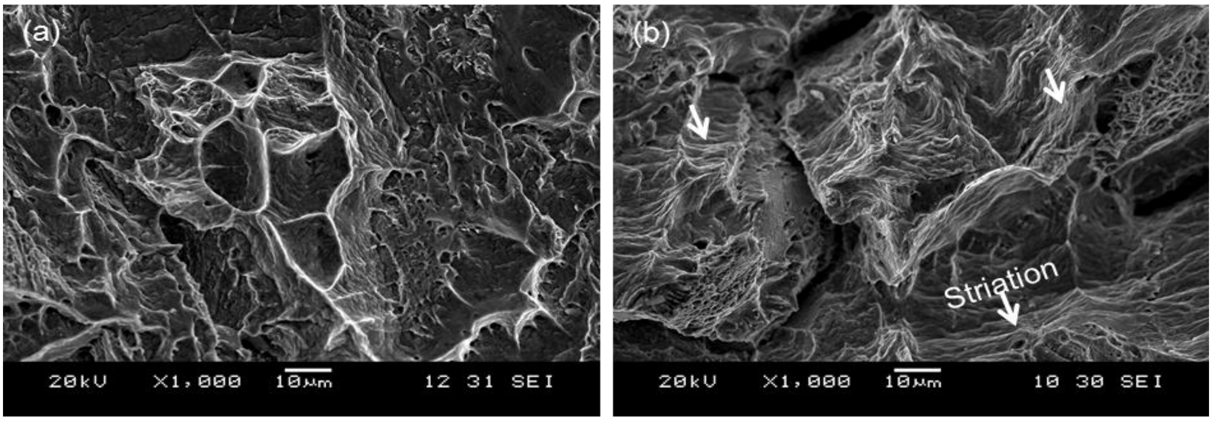

Figure 9 Fatigue fracture surfaces of C22 (a) in air, and (b) in 3.5%NaCl solution at pH = 6.8

A similar study of corrosion fatigue on annealed type 316 stainless steel showed the maximum stress level for failure in 0.5 M sodium chloride aqueous solution at pH = 4.2 was one-third lower than in air after a similar number of cycles [12].

Microscopic examination showed crack initiation resulting from pit formation, and crack coalescence was suggested as an explanation for the decrease in the maximum stress level for corrosion fatigue. The nickel alloys used in the study reported here has a greater resistance to corrosion pitting than type 316 stainless steel and therefore a comparatively greater resistance to crevice corrosion and degradation of fatigue strength [12].

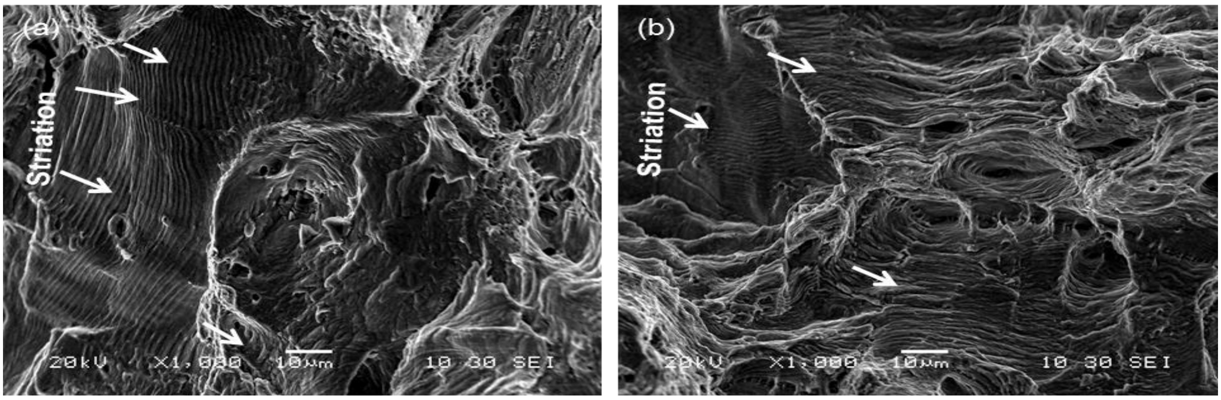

Figure 10 Typical striations observed on fatigue fracture surface of alloy C22 (a) and (b)

IV. CONCLUSION

The 3.5% NaCl solution at pH 6.8 had no effect on the fatigue life of any of the three alloys tested. Fracture surfaces for specimens tested in air showed no differences to those in specimens tested in 3.5% NaCl solution. Hence, all three alloys had excellent corrosion resistance in 3.5 % NaCl solution.

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