

EROSION-CORROSION BEHAVIOUR OF 6061 ALUMINIUM ALLOY

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Abstract:

Corrosion and erosion-corrosion behavior of Al-6061 was investigated. Tests were performed in 3 wt. % NaCl solutions with and without sand particles using the rotating sample method at 5.65 and 11.3 m/sec. Both the tests showed an increased weight loss with test duration. In erosion-corrosion tests, weight loss of the samples was accelerated by the impingement of the electrolyte at corroded sites leading to easy removal of corrosion products from the surface. The presence of sand particles in the electrolyte accelerates the process of material removal due to rapid formation of pits and craters. The effect of velocity and heat treatment on the mechanism of erosion-corrosion was investigated. An analysis of the affected surfaces of typical specimens by SEM enabled the understanding of the operating wear mechanisms under specific test condition.

تم دراسة سلوك التآكل الميكانيكي والكيميائي لسبيكة الألومنيوم 6061. أجريت الاختبارات في محلول ملحي فقط بتركيز 3% بالوزن وكذلك في وجود حبيبات رمل باستخدام طريقة تعتمد على دوران العينات في الوسط (slurry) عند سرعات 5.65 و 11.3 م/ث. من التجارب لوحظ أنه في جميع الحالات أن الوزن المفقود يزداد مع زيادة زمن التجربة. وقد أدى وجود الرمل في المحلول الملحي إلى تعجيل الزيادة في الوزن المفقود نتيجة لاصطدام حبيبات الرمل بسطح العينة وإزالة نواتج التآكل الكيميائي المتكونة على السطح وكذلك لتكون النقر والحفر على السطح. تم أيضا دراسة تأثير المعالجة الحرارية وكذلك تأثير السرعة على التآكل الميكانيكي والكيميائي لهذه السبيكة. وقد استخدم الميكروسكوب الإلكتروني لتفسير الظواهر التي صاحبت عملية التآكل.

Keywords: Erosion-corrosion, Slurry, Sand, Water, Sodium chloride.

1-INTRODUCTION

Wastage of alloys due to the combined effects of erosion and corrosion is a serious problem in many industrial processes. For example, erosion-corrosion of materials occurs in environments as diverse as catalytic cracking systems in oil and gas separation, combined cycle coal conversion systems such as pressurized fluidized bed combustion, and on the turbine blades of jet engines where the erosive component may be caused by the injection of particulate material or the accumulation of such material as a result of the corrosion process. The diversity of such environments in which erosion-corrosion problems are encountered has led to more investigation in the area and patterns of the effects of the main erosion-corrosion.

The effective use of any material depends on the assessment of its response to conditions representing specific applications; the more accurate the simulation of conditions, the more realistic the assessment.

Slurry erosion-corrosion of materials can be a major problem in many of the materials processing industries. In such cases, erosion may cause loss of adhesion of protective films which inhibit corrosion, or in severe cases, cause damage to the substrate material. A common approach to tackling erosion problems in such conditions is to modify the

properties of the particles, in many cases; particle size may be the only parameter which may vary readily.

Aluminum and its alloys have found a wide spread application spectrum because of their physicochemical and metallurgical characteristics. The vast applicability of this metal has attracted a large number of investigations on its electrochemical behavior in aggressive environments [1]. The effect of the erodent particle size on the erosion rate was investigated. The erosion is found to be independent of particle size above a critical value (usually observed between (100-200 μ m) [2].

A model for erosion caused by solid particles was studied and equation based upon the relationship between dynamic indentation and the hardness of the material was proposed. The equation was established by the relationship between the surface hardness and the erosion damage to the material [3]

Steady state erosion rates were measured for pure aluminum and an Al-12wt. % Si eutectic alloy at an impact angle of 30°. The erosion rates of the Al-Si alloy can be significantly higher than those of pure aluminum under identical conditions. Since the indentation hardness of the alloy is about a factor of 3 greater than that of pure aluminum, this implies that the hardness, or flow stress, is itself insufficient as a measure of erosion resistance [4].

An interpretation of the variation in material loss of aluminum specimens in sea water immersion at 14 different locations world wide was described [5]. Careful examination of the conditions under which aluminum corroded in very low velocity sea water has shown that the only significant variables are temperature and aeration. It is found that corrosion tends to be generally low expected at temperature around about 10 °C and in the region 20- 27 °C with a local peak at about 23 °C.

The corrosion behavior of 6056-T6 aluminum alloy was investigated in 1 M NaCl solution. Pitting and intergranular corrosion were found to be dependent on each other since intergranular corrosion nucleated on pit walls and spread from them [6].

Erosion-corrosion by either solid particle or liquid impact occurs in a wide variety of industrial environments which range from coal conversion process to steam turbines in nuclear power generation. The effects of erosion-corrosion depend on properties of the particles, the target and the nature of the corrosion environment. Various regimes of erosion- corrosion interaction have been identified, ranging from "erosion-dominated" (erosion of the substrate) to "corrosion -dominated "(erosion of the corrosion product) [7]. An experimental study was conducted on the erosion-corrosion behavior of three alloys in sea water- sand slurries. The idea explored was to select a steel, copper alloy, and a titanium alloy, which should have good resistance to abrasive wear because of high hardness (within their alloy classes) [8].

The influence of environmental composition and applied potential on the slurry erosion-corrosion of aluminum in various aqueous solutions was studied [9, 10]. The slurry erosion-corrosion rate of metals could be reduced by applying an electrochemical potential.

The effect of heat treatment on the electrochemical properties of bare metal samples of aluminum alloy 3005 in an acidified sodium chloride was investigated [11]. Annealing at increasing temperatures in the range 150-500°C causes negative potential transients of increasing magnitude and longevity for samples exposed at open circuit. Electrochemical characterization shows the potential transients to be caused by an increased anodic reaction rate of the annealed material surfaces as compared to the cold, hard temper substrate. It is suggested that this increased anodic activity during short time exposure of the bare metal samples may be attributed to changes in the protective properties of the surface oxide as a result of the high temperature heat treatment.

The present investigation is an attempt to understand the erosion- corrosion characteristics of 6061 aluminum alloy in slurries of 3% NaCl (aqueous) electrolyte and 3% NaCl plus 40wt% sand. The influence of heat treatment (To-T6), duration time and speed on the behavior of erosion- corrosion were studied. Analysis of the affected surfaces of typical specimens by SEM was carried out to understand the wear mechanisms under specific test condition.

2. EXPERIMENTAL PROCEDURE AND MATERIAL:

2.1. Materials and specimens preparation.

Specimens of 6061 Al alloy of nominal composition shown in table 1. were used.

Table1: Chemical composition of Al 6061 alloy (wt%).

Mg	Si	Cu	Cr
1.0	0.6	0.25	0.25
Zr	Fe	Ti	Al
0.25	0.7	0.15	Bal.

The specimens were prepared in sizes of 20x12x6 mm³ from a hot rolled sheet. The specimens were polished with 1000 grade emery paper and were degreased in acetone, rinsed with deionised water and dried in air.

2.2 Slurry wear test.

The slurry wear behavior of the specimens was studied using a rotating specimen method. A schematic representation of the wear test apparatus is shown in Fig. 1. The samples were fixed on a disc of a non- conducting material with 75 mm radius (corresponding to a linear speed 5.65 ms⁻¹). The disc assembly containing the specimens was rotated about its vertical axis in a tank containing the slurry by using an electric motor. The erosion-corrosion tests were conducted in 3 %NaCl solution and 3% NaCl solution + 40 wt% sand (150 µm) at 5.65 and 11.3 ms⁻¹ speed. The studies were made over a wide (40hrs)of duration time of tests. After each test the specimens were removed from the slurry tank and cleaned with running water.

This was followed by chemical cleaning by dipping in concentrated (about 70%) nitric acid at room temperature for 20 second, scrubs lightly in a stream of water with a rubber stopper or a bristle brush to clean them from impurities and sand. After cleaning, the specimens were dried in air. The weight losses of specimens were measured using Electronic digital balance (1702 MP8) with a sensitivity of 10⁻⁴ gram. The weight loss of erosion-corrosion was calculated by:

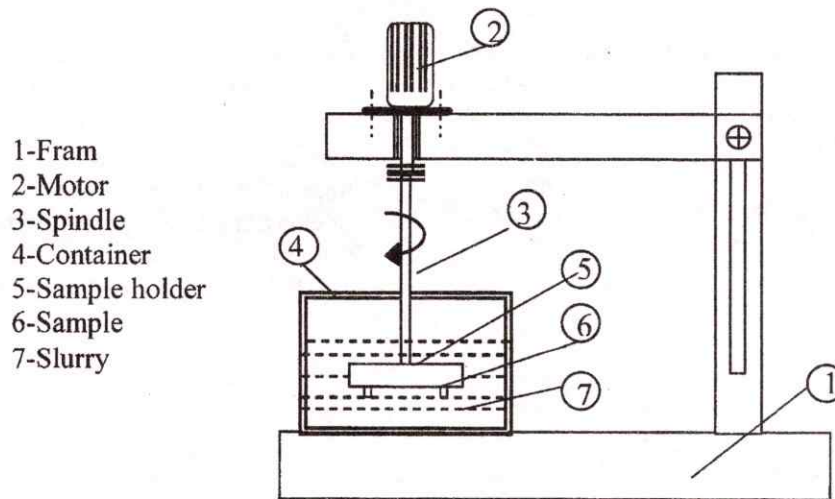


Fig.1 Schematic view of erosion-corrosion rig

$$\text{Erosion-corrosion loss (Kg/m}^2\text{)} = \frac{\Delta W}{A} \text{ and}$$

$$\text{Erosion-corrosion rate (Kg/h.m}^2\text{)} = \frac{\Delta W}{A.t}$$

Where ΔW is the weight loss in each time interval in kg, t is the time interval in hours and A is the surface area of the specimen in m^2 .

Analysis of the affected surfaces of typical specimens was made by SEM model Philips XL30 attached with EDX unit

3. RESULTS AND DISCUSSION

The mechanical properties of 6061 aluminum alloy as received in this study are given in table 2.

Table.2. Typical mechanical properties of Al 6061 alloy.

Alloy	U.T.S (MPa)	σ_y (MPa)	ΔL %	H.B
6061-To	125	55	25	30
6061-T6	310	275	12	95

Figure 2.shows the weight loss plotted as a function of the duration time in 3 %NaCl solution only and 3 % NaCl solution plus 40 wt% sand slurry for Al 6061-To and Al 6061- T6 at speed 5.65 ms^{-1} . It is evident from the figure that, in general, material loss of the specimens increased with test duration. Initially, a slow increase in material loss was observed, beyond this which, the weight loss of the specimens increased rapidly. Finally, at longer duration times a steady state weight loss was noticed for Al 6061-T6, while the Al 6061-T0 revealed still increasing weight loss. This trend is attributed to the incubation period required for corrosion attack by the electrolyte. It is known that in the case of aluminum

alloys, an oxide layer inherently envelops the exposed surface and a certain period is required for the breaking down of the weight loss in the layer by chloride ions; so that the weight loss in the initial time is not significant in the case of NaCl solution.

After the incubation period, a large area becomes available for corrosion attack where pitting starts taking place to a considerable extent. This caused a sharp increase in weight loss of the alloy. The rate of corrosion loss was slowed down due to the retarding corrosion reaction as a result of accumulation of the corrosion products Al^{+++} , inducing a passivity effect.

As the slurry contains suspended solid particles (sand) in a liquid so their impingement on the specimen surface enhances the degree of material loss. Associated with this, the corrosion action of the liquid part of the slurry is further aggravates the situation. The combined action of corrosion by NaCl and mechanical damage (erosion) by sand particles in NaCl + sand slurry resulted in the formation of impact craters and the occurrence of localized corrosion. Accordingly, the weight loss of the specimens was higher in the case of NaCl + sand slurry than in NaCl solution only.

Figure (3) shows erosion-corrosion rate vs. duration time, and the trend can be divided into four stages as follows:

- i) An incubation period, (from 0 to5 hrs in NaCl solution and 0 to3 hrs in NaCl solution plus sand) during which, deformation of the surface occurs accompanied by little or no material loss because of the stability of the oxide layer.
- ii) An accumulation or transition period (from 5to 12 hrs in NaCl solution and from 3 to 8 hrs in NaCl solution plus sand) in which the erosion – corrosion rate increases to a maximum level because a large area becomes available for

corrosion attack where pitting starts after the break of the oxide layer(Fig4.a,b.c and d). In this period erosion and corrosion expands over the whole area of the specimens.

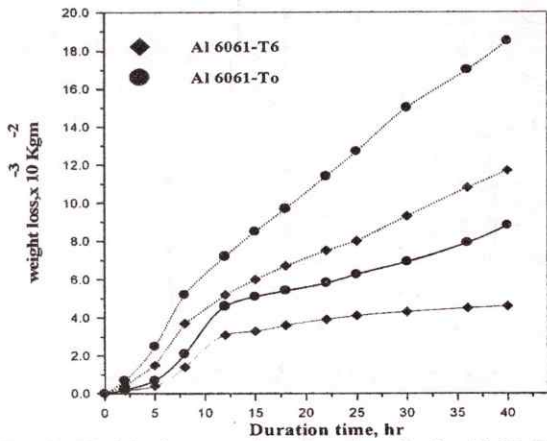


Fig. 2. Weight loss vs. duration time in 3wt% NaCl solution (solid line) and 3 wt% NaCl + 40 wt % sand (dotted line).

iii) An attenuation period (from 12 to 24 hrs in NaCl solution and from 8 to 32 hrs in NaCl solution and sand) in which the rate of weight loss decreases. It is due to the gas bubble generated during the process entrapped in the crater and thus would reduce the extent of direct contact of the media with the sample surface and with the cushioning effect of liquid trapped in the crater or pocket, or

the cushioning effect of diffused air in liquid. As a result the rate of the material loss goes down.

iv) Finally, a steady state rate of material loss was reached, (from 24 to 40 hrs in NaCl solution and from 32 to 40 hrs in NaCl solution plus sand) resulting in a balance between the material loss by crater formation and the entrapment of gas in craters causing a reduction in weight loss.

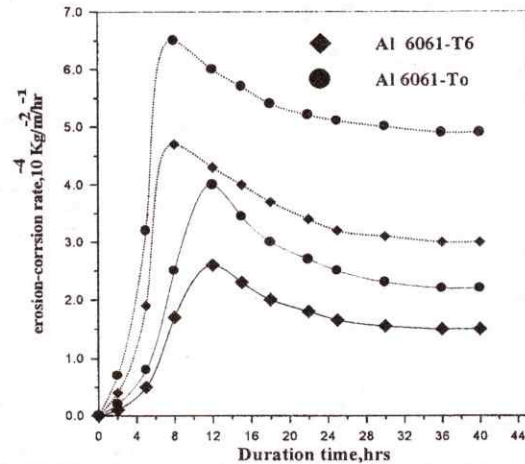
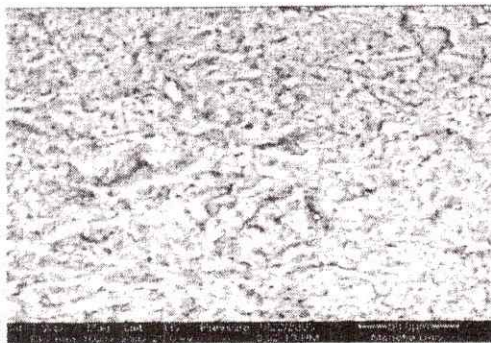
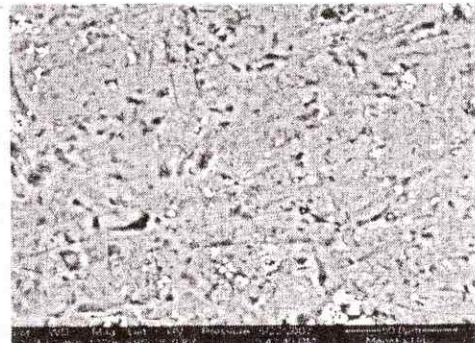


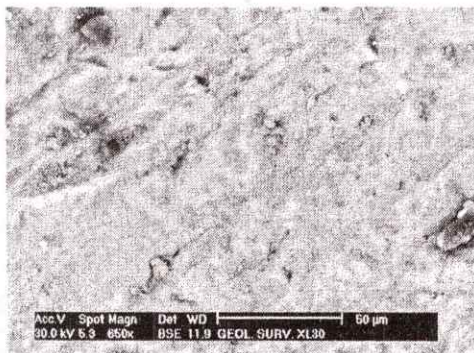
Fig.3. Erosion-corrosion rate vs. duration time in NaCl (solid line) and NaCl + 40% Sand (dotted line).



a) Al 6061- T6



b) Al 6061-T0



c) Al 6061 -T6



d) Al6061 -T0

Fig.4. Eroded-corrode surface of the alloy exposed to NaCl (a and b) and NaCl plus sand (b and c)

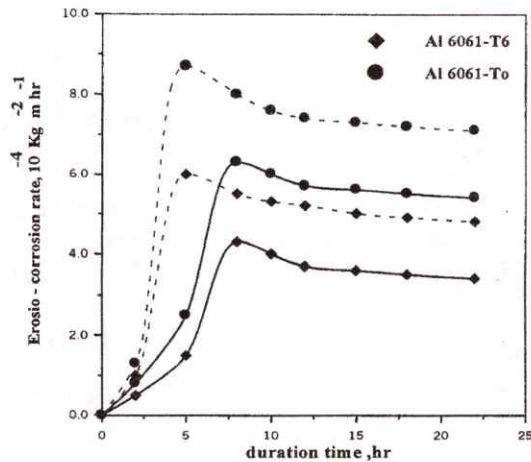


Fig. 5. Erosion-corrosion rate vs. duration time in NaCl (solid line) and NaCl plus sand (dotted line) at 11.2 m/ sec

The effect of velocity of the solution or of the metal on the rate and form of corrosion is shown in Fig (5). Generally, an increase in velocity accelerated the erosion- corrosion loss [11, 12 ,13, and 14]. It is attributed to bringing the cathode reactant more rapidly to the surface of the metal thus decreasing cathode polarization, and by removing metal ions thus decreasing anodic polarization. The most significant effect of erosion- corrosion is the constant removal of protective films (which may range from thick visible films of corrosion products to the thin invisible films of corrosion products to the thin invisible passivity films) from the metal's surface, thus, resulting in localized attack at the areas at which the film is removed. This can be caused by movement at high- velocity, and will be particularly prone to occur in the slurry (solution contains sand) which have an abrasive action. In addition to the mechanical damage of the protective film, velocity or movement will also bring the cathode reactant more rapidly to the metal surface thus decreasing cathode polarization.

The behavior of the material in the high velocity is the same as at the low speed. Only (incubation period takes a little time one to two hours). The craters and pitting start after two hours (second period).and maximum erosion-corrosion peak take place at 5 hours. The reason for increases the increase in erosion-corrosion rate with velocity seems to depend essentially on the rise in number of impacts per unit time.

Figure (6) shows the damaged surface during erosion – corrosion in NaCl solution plus sand after 20 hours at 11.3 m /s where impact craters and localized corrosion were observed.

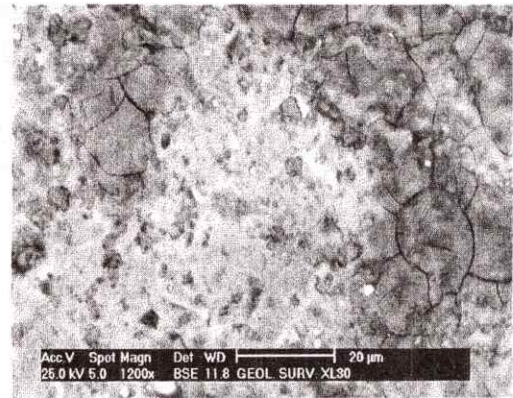


Fig. 6 Damaged surface of AL6061-T6 during erosion – corrosion test in NaCl solution plus sand after 22 hrs at 11.3 m/sec

4. CONCLUSIONS

- 1) Weight loss of Al 6061-To be significantly higher than Al 6061-T6 in the NaCl solution and in the NaCl solution plus sand slurry.
- 2) The presence of sand particles in the electrolyte further accelerated the process of material removal.
- 3) The rate of corrosion loss was slowed down due to the retarding corrosion reaction as a result of accumulation of the corrosion products, inducing a passive effect after 12 hours in NaCl solution only and after 8 hours in NaCl plus sand slurry.
- 4) Increasing the velocity of rotating disc accelerates the erosion-corrosion rate in the NaCl solution and in NaCl plus sand slurry due to the impingement of electrolyte.
- 5) Scanning electron micrographs have shown that pits (formed as a result of localized corrosion as well as due to the damage caused by solid particle impacts) were numerous, small and rather shallow. Following the formation of pits, crack initiation and growth extended from the pit. After a short time, these cracks connected and caused up lifting of the surface.

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