Erosion – corrosion behavior of Metal Matrix Composites

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Abstract

The corrosion - erosion behavior AL5083 SiCp composites were investigated. Tests were performed in 3 wt. % NaCl solutions with and without sand particles using the rotating sample method at 1500 r.p.m., 2000 r.p.m., and 3000 r.p.m. In erosion- corrosion tests, the weight loss of cast Al 6061 dispersed with either 0 vol% SiCp, 5iCp and 15% SiCp were increased with test duration.
Also, the effect of velocity and the percentage content of silicon carbide particles in Al 5083 on the mechanism of erosion-corrosion. An analysis of the affected surfaces of typical specimens by SEM enabled the understanding of the operating erosion-corrosion mechanisms under specific test conditions.

1.Introduction:

Aluminum matrix composites (AMCs) that contain particle reinforcement have their advantages such as isotropic distribution of the particles to be used in the engineering applications. This distribution is generated during the fabrication processes by powder metallurgy, compo-casting, squeeze casting, pressure-less infiltration, hot rolled extrusion, etc. Another consideration of AMCs is the influence of reinforcement particles on the corrosion behavior. The high-strength, high-specific modulus and low-density aluminum alloy-based composites with silicon carbide reinforcement have guaranteed significant interest in the aerospace, defense and car industries. The combination of lightweight, environmental resistance and useful mechanical properties such as modulus strength, toughness and impact resistance, has made aluminum alloys well suited for use as matrix materials. Several previous studies on properties of aluminum matrix composite which have been reported in the literature were focusing on either comparative study between monolithic alloy and reinforced alloy in terms of influence of similar type of reinforcement [1], or comparative study between different reinforced alloys in terms of similar type of reinforcement [2].
Furthermore, several studies have focused on the properties of aluminum matrix composites from the same fabrication route such as casting [1, 3, 4] and powder metallurgy[2].

Aluminum, its alloys and composites represent an important category of materials due to their high technological value and wide range of applications, in aerospace industry, automobile industry and military applications [5,6]. The use of these materials in light weight applications is widespread and these usages expose them to environments that could be acidic or alkaline [4]. Pitting attack is reported to be the major form of corrosion in 6061 Al alloy–15 vol. % SiC metal matrix composites [7]
Zaki Ahmed, C.Eng.[8] investigated the corrosion and pitting resistance of Al6061 and Al6013 silicon carbide composites in natural salt solution and seawater. This investigation is the first attempt to an in-depth understanding of the corrosion process involved in the two composites which would assist in creating a greater a wariness of the application potential of the alloy in corrosive environment. B.K. Prasad et al [9] have studied the erosion-corrosion abrasion characteristics in slurry of a zinc based alloy and its composite containing alumina particle dispersed. The slurry wear behavior of the specimen method. The specimens were fixed in a disc and rotated at a linear speed of 4.71 m/s using an electrical motor in a container containing the slurry. The influence of varying the sand concentration in the medium and the traversal distance on the response of the specimens has also been investigated were rate increased initially with traversal distance, attained a peak, and then decreased thereafter at longer traversal distance. This trend was much more pronounced when tests were conducted in a liquid only medium than in liquid sand.

The influence of environmental composition on the slurry erosion-corrosion of aluminum, carbon steel, copper and stainless steel was investigated[10-11]. The slurry erosion-corrosion rate of metals could be reduced by applying an electrochemical potential. The effect of changes in the surface oxide film due to the environmental composition and applied potential on the slurry erosion-corrosion of metal was also studied [12-18]. So from the last researches, there were few paper that investigated the behavior of erosion-corrosion of Al alloy /SiC composites in water and sodium chloride solutions containing sand particles by using the rotating sample method, therefore the present investigation is an attempt to understand the corrosion-erosion characteristics of Al alloy/SiCp composites with test duration at three speed of 1500 r.p.m., 2000 r.p.m., and 3000 r.p.m.

In erosion-corrosion tests, the weight loss of cast Al5083 dispersed with either 0 vol% SiCp, 5iCp and 15% SiCp were increased with test duration. Also, the effect of velocity and the percentage content of silicon carbide particles in Al 5083 on the mechanism of erosion-corrosion. An analysis of the affected surfaces of typical specimens by SEM enabled the understanding of the operating erosion-corrosion mechanisms under specific test conditions.

2.Experimental procedures and material:

Materials and specimens preparation

Table 1 shows the chemical composition of Al 5083 alloy.

<table>
<thead>
<tr>
<th>Mn</th>
<th>Si</th>
<th>Cu</th>
<th>Cr</th>
<th>Zn</th>
<th>Fe</th>
<th>Mg</th>
<th>Alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>0.4</td>
<td>1.0</td>
<td>0.25</td>
<td>0.25</td>
<td>0.4</td>
<td>4.15</td>
<td>Al5083</td>
</tr>
</tbody>
</table>

The specimens were prepared in sizes of 25x14x8 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.

Experimental set up and procedure.

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...
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 at 5.65 and 11.3 ms⁻¹ speed. The studies were made over a wide range up to (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, scrub 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 analytical balance (1702 MP8) with a sensitivity of 10-4 gram.

The weight loss of erosion-corrosion was calculated by:

\[
\text{Erosion-corrosion loss (Kg/m2)} = \frac{\Delta W}{A} \quad \text{and} \quad \Delta W
\]

\[
\text{Erosion-corrosion rate (Kg/h.m2)} = \frac{\Delta W}{A t}
\]

Where \( \Delta W \) 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 m².

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

3. Results and Discussion:

Fig.(2:5) are showing the erosion-corrosion rate Vs duration time in 3wt%NaCl solution only and 3wt%NaCl solution+40wt% and slurry for Al5083, Al5083+5%SiCp), (Al5083+10%SiCp), (Al5083+15%SiCp). At three speed 1500r.p.m., 2000r.p.m., and 3000r.p.m.

These curves represent various stages of material removal. Each stage representing a specific operating mechanisms of material removal. Initially, the lower rate of increase in
erosion-corrosion rate corresponds to the incubation period (stage I) where the stability of the oxide layer is maintained. As subsequent increase in the slope of the plot with test duration indicates the breaking of the oxide layer which offers more potential sites for the erosive-corrosive action of the slurry.

The corrosive attack by NaCl was localized in nature and was more intensified around the dispersion phase. After impinging the suspended solid particles move along the surface of the rotating specimens producing channels and abrasion grooves. The homogeneous structure of the matrix produced by sand erosion around the dispersed phase provided sites for accelerated by pit nucleation by the NaCl electrolyte. Therefore in the NaCl+sand slurry, the attack become more severe at the dispersed matrix interfaces. The attack around dispersed also occurred because of the cathode nature of the SiCp and anodic nature of the aluminium matrix, resulting in the formation of galvanic cell.

Sea water contains about 3 wt% salt and it slightly alkaline, pH 8. It's a good electrolyte and can cause galvanic corrosion, crevice corrosion and localized corrosion while all the tests were conducted at laboratory temperature 25°C.

Figures (6:9) are showing the weight loss per unit area plotted as a function of the duration time in 3 wt% NaCl solution only and 3wt% NaCl solution + 40 wt% sand slurry for (Al5083), (Al5083+5 % SiCp), (Al5083 +10% SiCp) and (Al5083 + 15% SiCp) at three speeds 1500 r.p.m, 2000 r.p.m and 3000 r.p.m.

In general, it is evident from the figures (6-9) that, the material loss of the specified specimens increased with test duration. Initially, a slow increase in material loss was observed. Beyond this period, the weight loss of the specified specimens increased rapidly. When the test duration was further increased, the rate of material loss decreased and finally reached a steady state.

Also, we can note that, the composites attained greater weight loss that the corresponding matrix alloy Figures(10:13) are showing the corrosion-erosion rate vs. duration time in 3 wt% NaCl solution only and 3 wt% NaCl solution +40% sand for specified specimens at three speeds 1500 r.p.m, 2000 r.p.m and 3000 r.p.m.

These curves represent various stages of material removal. Each stage representing a specific (combination of) operating mechanisms of material removal. Initially, the lower rate of increase in erosion-corrosion rate corresponds to the incubation period (stage I) where the stability of the oxide layer is maintained. As subsequent increase in the slope of the plot with test duration indicates the breaking of the oxide layer which (stage II) peaks on the curves represent the appearance of the first deep crater on the specimen surface. A further increase in the test duration caused a decrease in the rate of material loss. (Stage III) owing to the entrapment of gas bubbles in the craters which reduced the extent of direct contact between the specimen surface and medium. The entrapment of sand particle in the crater also causes a reduction in material loss. The attainment of a steady state erosion-corrosion rate towards the final stage of material loss (stage IV) Could be due to the counter balancing effect of enhanced material loss due to crater formation and a reduction in wear loss owing to the resistance offered by the entrapped air bubbles, the entrainment of finer sand particles and work hardening of the sub-surface region.

Also, the weight loss and erosion-corrosion rate for all the specified specimens will be increase when the rotational speed (r.p.m) is increased at all times of the experiment as and this increasing in weight loss will be high in all cases than the case of (water + 3 wt% NaCl) in 12 hrs, 24 hrs, 36 hrs, 48 hrs and 72 hrs. This trend owing to a higher impinging action of a sand particles. The corrosive attack by NaCl was localized in nature and was more intensified around the dispersed phase. After impinging the suspended solid particles move along the surface of the rotating specimens producing channels and abrasion grooves.
as showing in figure (15). The homogenous structure of the matrix produced by sand erosion around the dispersoid phase provided sites for accelerated pit nucleation by the NaCl electrolyte.

Therefore in the (3 wt% NaCl + 40 wt% sand) slurry, the attack become more severe at the dispersoid / matrix interfaces. The attack a round dispersoids, also occurred because of the cathodic nature of the SiCp (dispersoid) and anodic nature of the aluminum matrix, resulting in the formation of galvanic cell. Figure (14) shows the un-corroded specified specimens, where the stability of the oxide layer is maintained. While in the transition period (stage II), 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. In this stage erosion and corrosion expands over the whole area of the specimens and you can note the formation of micro-cracks and craters on the surface of the specified specimens.

Generation of thermal stresses resulting from differential thermal expansion coefficient of the dispersoid and matrix further enhances the extent of the attack. This ultimately results in loosening of the dispersoid particles from the matrix and subsequent removal of the dispersoid during the process of sand erosion.

Material loss in a slurry medium takes place through the erosive action of the droplets of the liquid which are formed as a result of the relative motion between the slurry and the specimen. The corrosion behavior of an alloy strongly depends upon factors such as alloy composition, the mode of distribution and the electrochemical (anodic/cathodic), nature of various micro constituents and the nature of the corrosive environment, etc. The presence of dispersoid phases makes the process of corrosion more complex in the case of composites, furthermore, in the case of the composite, fracturing and subsequent removal of the dispersoid phase also take place owing to the combined action of erosion and corrosion, the shape and size of the dispersoid phase as well as the nature of the dispersoid/matrix interface greatly control the extent of this phenomenon. Around the Silicon carbide particles a layer is occasionally observed, which is estimated to be Al4C3. This layer has been observed earlier and has been regarded the result of the reaction of the SiCp with molten Al according to the following reaction.

$$4\text{Al} + 3\text{SiC} \rightarrow \text{Al}_4\text{C}_3 + 3\text{Si}$$

It seems also that the presence of the Al4C3 phase depends on the duration of stirring. As stirring increases, the amount of Al4C3 increases too but not to a great extent. In the case of (Al5083)/SiCp composites, the presence of SiCp on the material surface leads to an increase in the ratio of cathodic area and the formation of highly active galvanic couples which lead to an increase in the corrosion conditions, the oxide film passivity's the aluminium, but during erosion-corrosion it is disrupted by the impinging particles, after which fresh oxide grows immediately. The oxide formed on the aluminium surface is thin, and indentation by the impinging particles result in fracture and subsequent loss of the film. The metal substrate is heavily deformed to form craters.

An increase in erosion-corrosion rate may at least partially result form the rapid growth and removal of this thicker oxide. The reason for increasing the erosion-corrosion rate with higher velocity seems to depend essentially on the rise in number of impacts per unit time. Micro-structural features of the un-corroded gravity cast Al- alloy(5083) reinforced with various volume fraction of SiC particles about (5%, 10%, 15%) and damaged surface during erosion-corrosion in NaCl solution plus sand after 72 hours where impact craters and localized corrosion were observed and showing in figures (26-27) respectively.
Fig. (2): Weight loss vs. duration time in 3 wt% NaCl solution (solid line) and 3 wt% NaCl + 40 wt% Sand (dotted line)

Fig. (3): Weight loss vs. duration time in 3 wt% NaCl solution (solid line) and 3 wt% NaCl + 40 wt% Sand (dotted line)
Fig. (4): Weight loss vs. duration time in 3 wt% NaCl solution (solid line) and 3 wt% NaCl + 40 wt% Sand (dotted line)

Fig. (5): Weight loss vs. duration time in 3 wt% NaCl solution (solid line) and 3 wt% NaCl + 40 wt% Sand (dotted line)
Fig. (6): Erosion-Corrosion rate vs. duration time in 3 wt% NaCl solution (solid line) and 3 wt% NaCl + 40 wt% Sand (dotted line)

Fig. (7): Erosion-Corrosion rate vs. duration time in 3 wt% NaCl solution (solid line) and 3 wt% NaCl + 40 wt% Sand (dotted line)
Fig. (8): Erosion-Corrosion rate vs. duration time in 3 wt% NaCl solution (solid line) and 3 wt% NaCl + 40 wt% Sand (dotted line)

Fig. (9): Erosion-Corrosion rate vs. duration time in 3 wt% NaCl solution (solid line) and 3 wt% NaCl + 40 wt% Sand (dotted line)
Light optical micrograph showing in corrosion attack for Al5083+5% SiCp at condition (water + 3wt% salt) at 3000 r.p.m, (500X)

Light optical micrograph showing in corrosion attack for Al5083 at condition (water + 3wt% salt) at 3000 r.p.m, (500X)
Light optical micrograph showing in corrosion attack for Al5083+15% SiCp at condition (water + 3wt% salt) at 3000 r.p.m, (500X)

Light optical micrograph showing in corrosion attack for Al5083+10% SiCp at condition (water + 3wt% salt) at 3000 r.p.m, (500X)
Light optical micrograph showing in corrosion attack for Al 5083, Al5083+5%SiCp, Al5083+10%SiCp, and Al5083+15%SiCp at condition (water+3wt% salt) at 3000 r.p.m., (500X).

4. Conclusions:

The analysis of the experimental results of the aluminum alloy (5083) and their corresponding composites [(Al5083)/SiCp] lead to the following conclusions.

The weight loss of cast aluminum alloys (5083) dispersed with either 0 vol.% SiCp, 5 vol.%SiCp, 10 vol.% SiCp, 15 vol.% SiCp in the NaCl solution was significantly lower than the weight loss of the same (Alalloy/SiCp) composites in the NaCl solution plus sand slurry.

The erosion-corrosion rate of cast aluminum alloys (5083) dispersed with either 0 vol.% SiCp, 5 vol.% SiCp, 10 vol.% SiCp and 15 vol.% SiCp in the NaCl solution plus sand slurry was significantly higher than the erosion-corrosion rate of the same composites in the NaCl solution.

Increasing the velocity of rotating disc accelerates the weight loss, and the erosion-corrosion rate in the 3 wt% NaCl solution and in (3 wt% NaCl solution plus Sand Slurry) due to the impingement of electrolyte and sand particles by the surface of the cast aluminum alloy (6061) and it is composites. The weight loss of Al5083 and its composites in the NaCl solution and in the NaCl solution plus sand slurry was increased by Increasing time, So time is necessary for salt precipitation in the pit.

The weight loss and erosion-corrosion rate of cast aluminum alloy (5083) dispersed with either 5 vol.% SiCp, 10 vol.% SiCp and 15 vol.% SiCp in the NaCl solution and NaCl solution plus sand slurry were significantly higher by about % then the weight loss and erosion-corrosion rate of cast aluminum alloy (5083).

5. References: