Study the Effect of Erosion-Corrosion of Al-Mg-Si Alloy in Marine Environment

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ABSTRACT

Erosion–corrosion of Al-Mg-Si aluminum alloy in NaCl–water solutions were studied by weight-loss measurements through an impingement jet system. The effect of sand concentration and fluid impingement angle, were investigated. The sand used is Iraqi silica sand from Al-ardhimah .

The result showed that, increasing erosion time, will increase the erosion rate of alloy samples for all sand concentration and impact angels. When the sand concentration is increased the erosion-corrosion rate of alloy samples will increase, and the maximum value of erosion –corrosion rates occur when the impact angle is about(45◦).The surface morphologies of eroded surface after abrasive water-jetting, show that erosion rather than corrosion, controls the total Erosion-Corrosion rate of Al-Mg-Si alloy in sand-containing NaCl–water solutions.

Key words: erosion, erosion-corrosion, Al alloy.

دراسة تأثير التآكل بالتعرية لسبيكة المنيوم - مغنسيوم - سيليكون في الأوساط البحرية

محلول مائي يحتوي على كلوريد الصوديوم باستخدام حسابات الفقدان في الوزن باستخدام منظومة القذف أو الأرتطام . في هذا البحث استخدمت حبيبات من رمل السيليكا من منطقة ارضمه في العراق وتم دراسة تأثير تركيز الرمل و زاوية الأرتطام على معدل التعرية ومعدل التآكل بالتعرية .

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أظهرت النتائج إن زيادة زمن التعرية سوف يؤدي الى زيادة معدل التعرية في العينات عند جميع تراكيز الرمل كذلك زوايا الأرتطام . عند زيادة تركيز الرمل في المحلول يزداد معدل التآكل بالتعرية لعينات السبيكة المستخدمة.

تم الحصول على أعلى معدل تآكل بالتعرية عند أستخدام زاوية أرتطام 45° .إن هيئة السطح للتراكيب التي حدث فيها تعرية بعد القذف بالمحاليل الحاوية على الرمال أظهرت إن التعرية لها تأثير أكثر من التآكل وهو الذي يسيطر على معدل التآكل بالتعرية لسبيكة المنيوم – مغنسيوم – سيليكون عند أستخدام محلول حاوي على كلوريد الصوديوم .

INTRODUCTION

According to a recent survey, erosion corrosion was rated in the top 5 most prevalent forms of corrosion damage in the oil , gas production and cause significant economic loss [1]. Aluminum alloys, such as Al5052, Al 5054, Al 6061 and Al 6063, remained the focus of attention in the late 1970s and early 1980s for seawater applications because of their good combination of mechanical strength, formability, corrosion resistance and cost advantages. Furthermore , due to their low density and high thermal conductivity as well as excellent formability, Aluminum alloys have been extensively used as automotive radiators and heat exchangers . However, coolant the automotive heat exchanger is always contaminated with chloride ions. Moreover, sand particles that are mainly from the combusting dusts and corrosion scale are also present in the cooling system.[2]

Al alloy in pure water exhibits significant resistance to corrosion because of the natural protection from its oxide film. However, the oxide film is not stable in the presence of common water contaminants such as chlorides; therefore, Al alloys are prone to flow-assisted corrosion (FAC) and erosion–corrosion [3].

Generally, the total weight-loss of materials during erosion–corrosion is much higher than those caused by corrosion or erosion individually. Various methods, such as jet impingement rig, loop impingement system, rotating cylinder electrode, have been used for erosion and erosion-corrosion research [4-7]. In this work, an impingement water jet system was used to study erosion–corrosion of Al-Mg-Si alloy in salt–water solution. Parametric effects, such as sand concentration and fluid impingement angle, were investigated.

EXPERIMENTAL PROCEDURE

Materials and solutions

Test material was Al-Mg-Si alloy. The area of each substrate specimen is of (7) mm^2 and the chemical composition of the alloy is shown in Table (1). Before tests, the work surface of samples was abraded with silicon carbide abrasive paper down to 1000 grit, rinsed with de ionized water and degreased in acetone. The testing solution for the slurry preparation was of (3.5%NaCl +H_2O), and the pH was fixed at 8.4 by adjustment with HCl solution. Various amount of Iraqi silica sand from Al-ardhimah region (0.5,1 , 1.5)% ,were added into the solution. The sand particle size were 0.29 mm ,and the specific gravity of sand particle is 2560.

Impingement Jet System

Figure (1) schematically illustrates the impingement water jet system set up used in the experiments. The experimental apparatus consisted of a plastic tank used as a reservoir, a high pressure pump, a flow velocity controller, a sand concentration controller, a stirrer, and valves. When the fluid entered the ejector at a high speed, it produced a partial vacuum due to the venturing effect. The sands underneath the valve could be mixed with the flowing fluid by means of suction. A stirrer was used to ensure the homogeneity of sands in fluid. The impact angle of the impinging fluid to Al alloy sample, which was defined as the angle between the surface of the specimen and the flow direction of fluid, can be adjusted conveniently by rotating the sample in special fixture. compressed air supply was maintained at 1bar with, flow rate 36liter per minute All experiments were conducted at 25-27^{o}C.

Weight-loss& Erosion-Corrosion Testing

Weight loss studies were conducted in accordance with ASTM standard G31-72 [8]**.** Two different set of experiments were used: erosion test and erosion-corrosion test. In the erosion testing, erosion time, impingement angle, sand concentration, were change using water solution. In erosion-corrosion erosion time , impingement angle and concentration of sand were change . The solution is(3.5% NaCl +water).

After the abrasive water-jetting, the weight of the samples was then measured using an electronic balance with a precision of 0.1 mg. The specimens are weighed before and after erosion by abrasive water-jetting, then calculate the weight loss.

After erosion-corrosion test, the corrosion product on sample surface was carefully removed, and weighed then calculate the weight loss and erosion rate E according to following equation:[9]

$$E=w_1-w_2/A .t \quad \quad …… (1)$$

t: is the time of erosion process,
$\mathbf{W_1}$**-**$\mathbf{W_2}$ is the weight loss, $\mathbf{W_1}$ is the original weight.
A: is the area of substrate.

Microstructure Examination

The microstructures of samples after erosion test and erosion- corrosion test, were examined using the Carl Zeiss optical microscope.

RESULTS AND DISCUSSION

The relationship between the erosion rate and exposed time at different impact angle and sand concentration is illustrated in Figur (2-4). It is seen that, with the increase of exposed time, the erosion rate of samples is increased. Furthermore the erosion rate is increased with increases sand concentration.Figure (2-4) showed that the erosion rate is small in samples impingement with angel (0^{o}) and increased with increasing impact angle, the maximum value of erosion rates occur when the impingement angle is about (45◦),then decrease when impact angel reached (90^{o}) . This result may be attributed to the combined effect of shear stress and normal stress (normal impact) exerting on Al sample by sand-containing solution. The maximum erosion rates do not take place at 90◦ because the shear stress (perpendicular to the normal stress) is equal to zero when the impingement angle is 90◦. [10]

Figures (5-7) The relationship between the erosion-corrosion rate and erosion time at different show impact angle and sand concentration. The result showed that the erosion-corrosion rate increased with increasing exposed time and sand concentration. On the other hand the erosion-corrosion rate is increased with increasing impact angle, the maximum value of erosion-corrosion rates occur when the impingement angle is about (45◦),then decrease when impact angel reached(90^o). Figure (8) shows the dependences of erosion and total erosion-corrosion rate on sand concentration in the solution after exposed time(2hr.)and impact angel 45^o. It is seen that, with the increase of sand concentration, the total erosion-corrosion rate of alloy sample increased significantly. Furthermore, When solution contains sands with a low concentration, the impingement effect on sample is slight and an oxide film on the surface would provide protection to the sample.

However, when the sand concentration increase, the impact effect of sands on sample is sufficiently significant to damage the oxide film and increased corrosion rate. Apparently, erosion, rather than corrosion, controls the total weight-loss of Al alloy in sand-containing salt–water solutions..

The effect of impact angle on Al alloy erosion-corrosion in salt–water solution is shown in Figure (9), it is clear from the results that the erosion- corrosion rate is small in samples impingement with small angel (0^o) and increased with increasing impact angle, then decrease when impact angel reached (90^o). The surface morphologies of eroded surface after abrasive water-jetting may explain these results. From Figure (10) It is seen that, before water-jetting, surface layer have no cracks as shown in Fig(10- a).After erosion When the impact angle is(0^o) , It is seen that there is wear deformation and no crack on the eroded surfaces as shown in Figure (10-d). When the impact angle is 90o there is some discrete cracks in the eroded surface as shown in Figure (10-b). When the impact angle is (45^o) there are many interconnected cracks in the eroded surface, further more there were small percentages of corrosion component on the surface as shown in Figure (10-c).These results may be explain as follow: When a normal stress is applied, i.e., the fluid impacts the sample at 90^o, the surface film on sample is broken and damaged, but still remains on the sample surface, providing somewhat protection. When the impact angle is 0^o, stress plays an essential role in thinning oxide film. An impact of fluid at 45^o involves a combined effect of shear stress and normal stress, resulting in both physical damage and removal of surface film. Therefore, the highest erosion-corrosion rate was observed at 45^o.

Two mechanisms have been proposed for illustration of the synergism of corrosion and erosion. One is the corrosion-enhanced erosion which is related to the degradation of surface hardness or strength of materials. The role of corrosion is to roughen the material surface, which in turn greatly increases the erosion rate. Another is the erosion-enhanced corrosion which is caused by the retardation of formation of a protective film on metal surface. As a consequence, corrosion proceeds at a high rate in the absence of such protective films [11].

CONCLUSIONS

- For all sand concentration and impact angels, increasing erosion time, will increase the erosion rate of Al alloy samples**.**

- When the sand concentration is increased the erosion-corrosion rate of Al alloy samples will increase.
- The maximum value of erosion –corrosion rates occur when the impact angle is about(45◦),then decrease when impact angel reached (0^o).
- The surface morphologies of eroded surface after impingement water-jetting, show that erosion rather than corrosion, controls the total E-C rate of Al alloy in sand-containing NaCl–water solutions.

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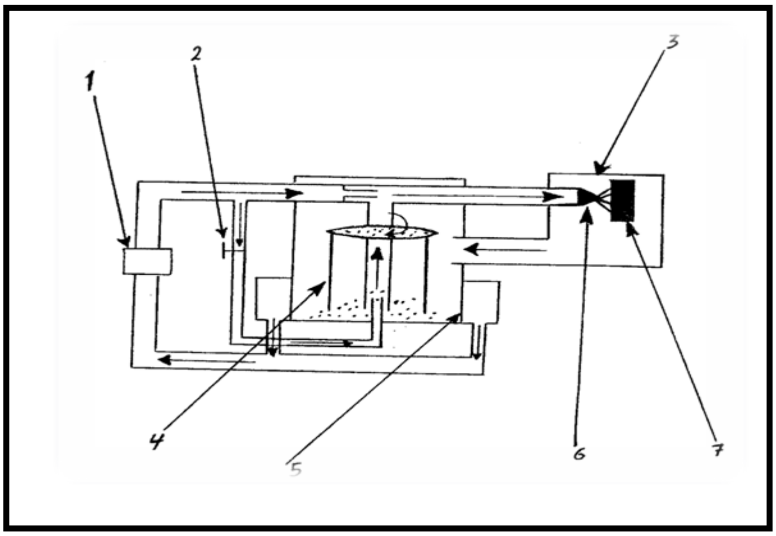
Table (1) Nominal chemical composition of the alloy.

element	Si	Fe	Cu	Mn	Zn	Ti	Cr	Mg	Al
Wt%	0.8	0.5	0.6	0.2	0.18	0.12	0.09	1.1	Balance

(a)erosion-corrosion device.



(b)schematically illustrate of Impingement water jet system set up
1-pump,2-sand concentration controller,3- test chamber,4-stirrer,5-filter,6-nozel,7-sample.

Figure (1 a and b) illustrates photograph and schematically Erosion-corrosion device.

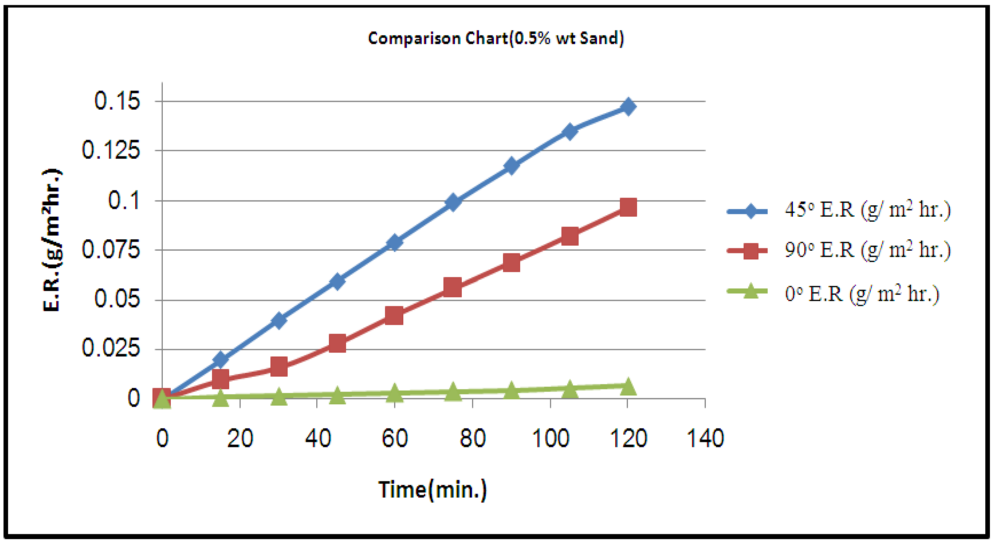


Figure (2) Variation of erosion rate of Al alloy with time (Different impact angle, 0.5%sand).

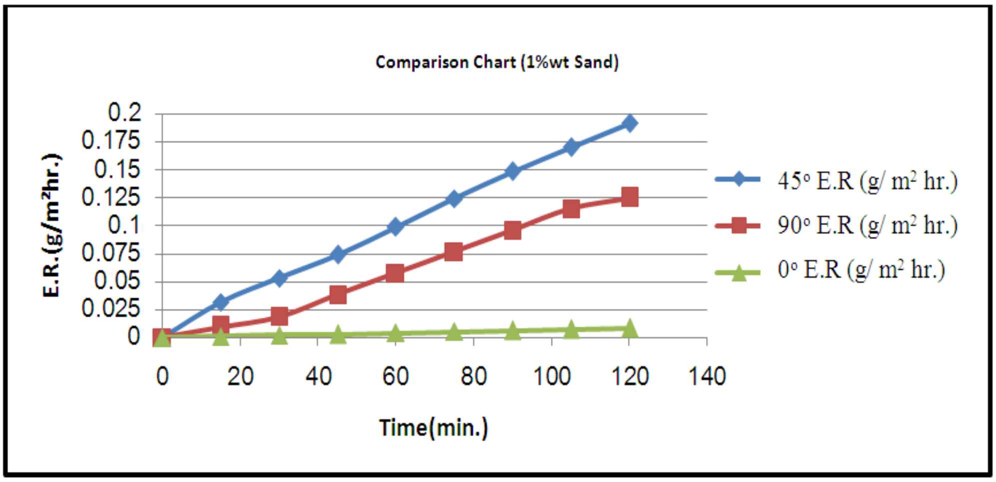


Figure (3) Variation of erosion rate of Al alloy with time (Different impact angle, 1%sand).

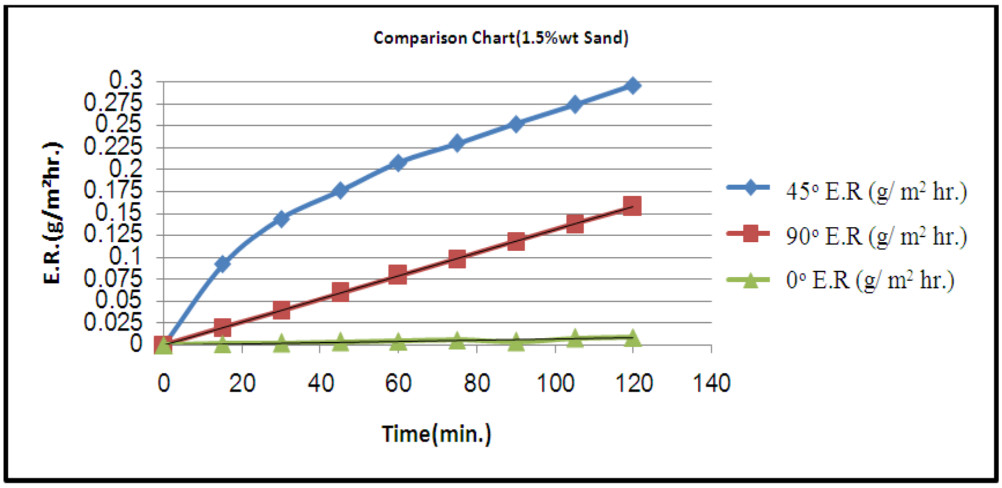


Figure (4) Variation of erosion rate of Al alloy with time (Different impact angle, 1.5%sand).

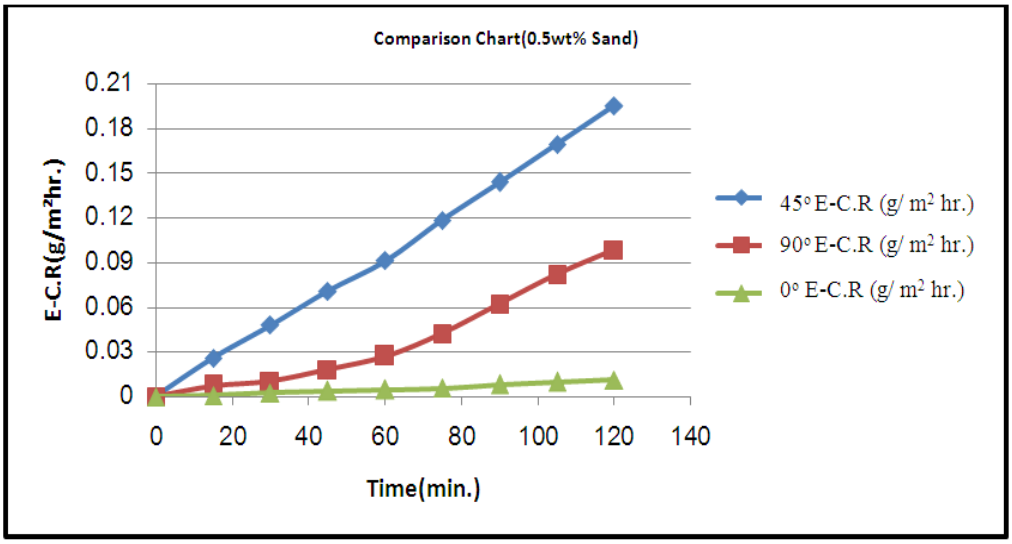


Figure (5) Variation of erosion-corrosion rate of Al alloy with time (Different impact angle, 0.5%sand).

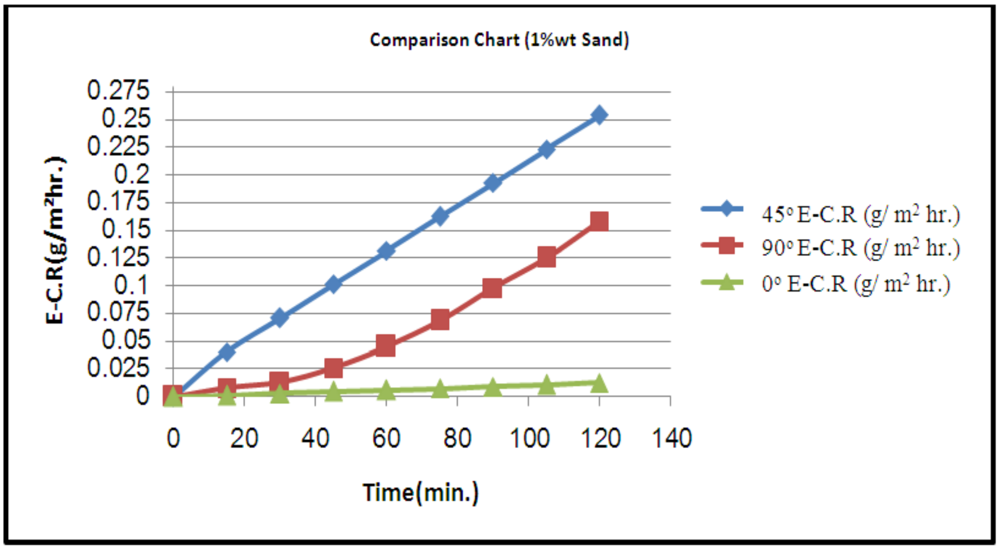


Figure (6) Variation of erosion-corrosion rate of Al alloy with time(different impact angle,1%sand).

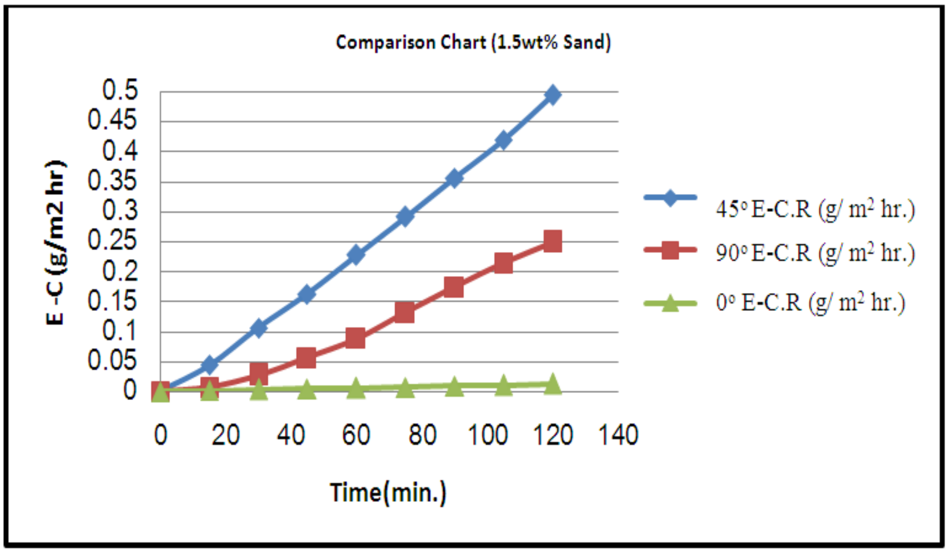


Figure (7) Variation of erosion-corrosion rate of Al alloy with time (different impact angle, 1.5%sand).

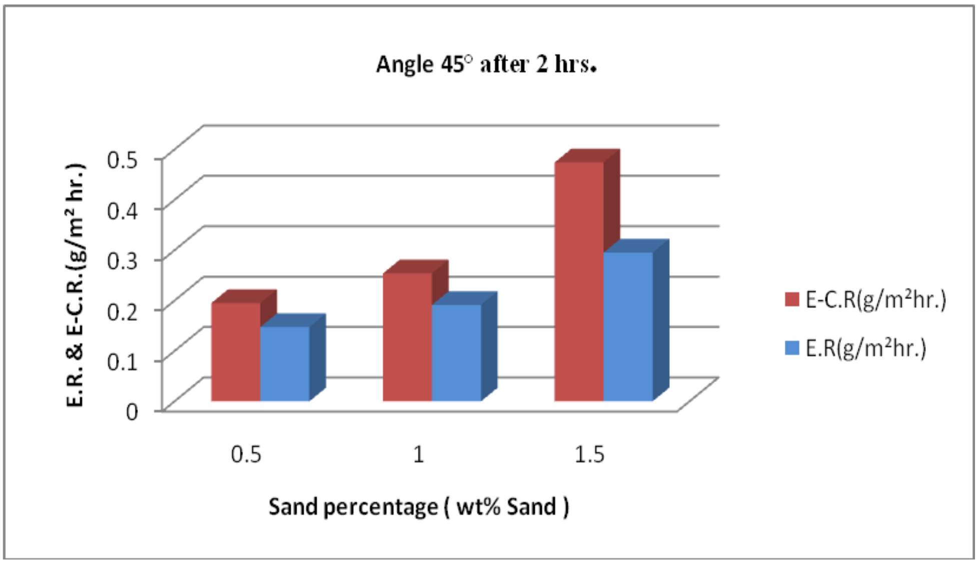


Figure (8) Effect of sand concentration on erosion – corrosion and erosion rate (at 45°, after 2hr.).

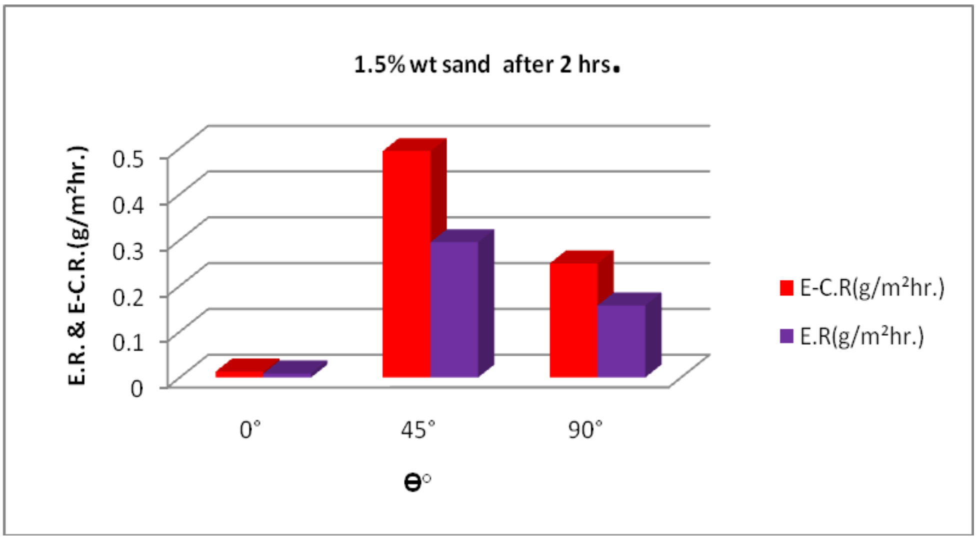
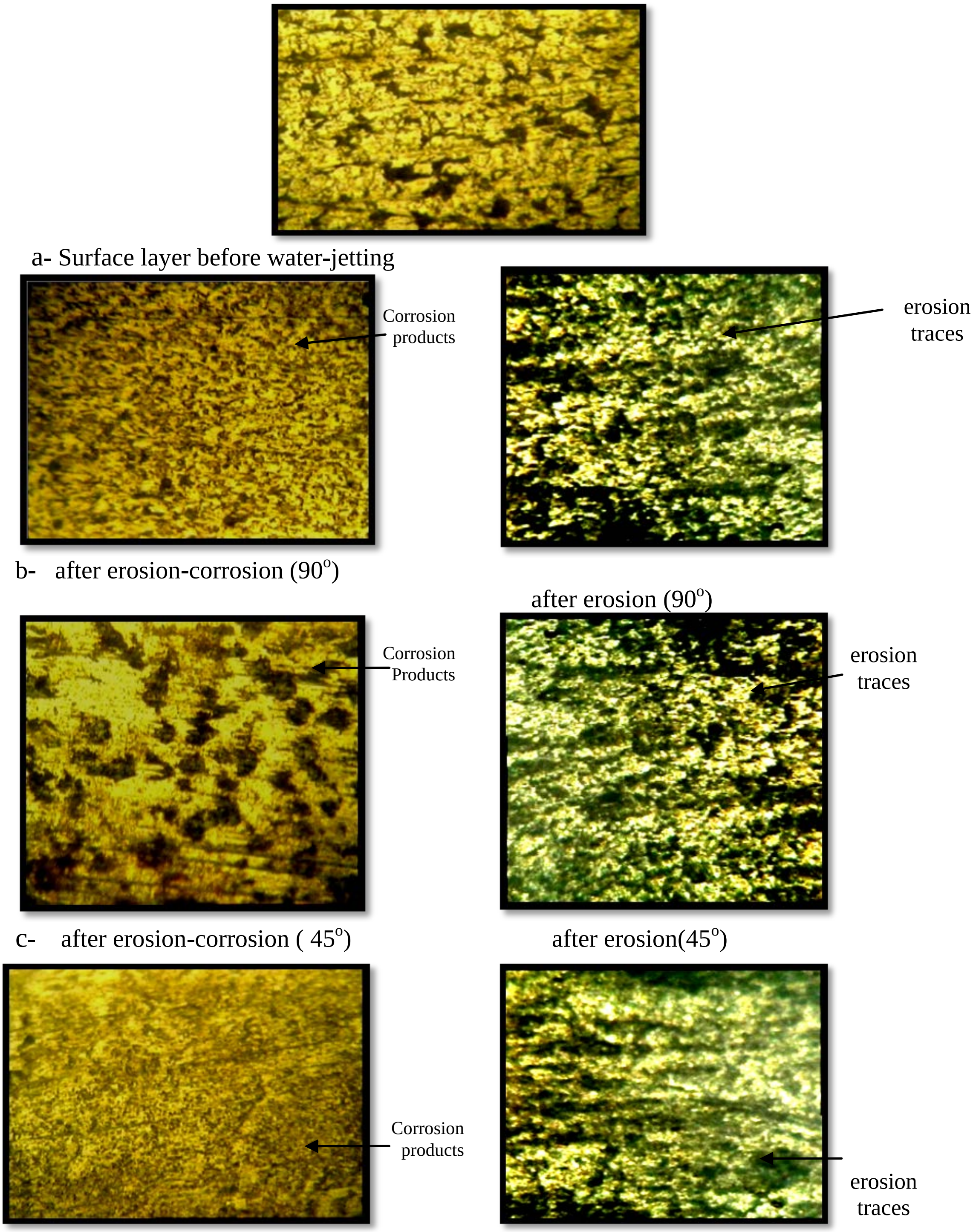


Figure (9) Effect of impingement angle on erosion-corrosion rate. (1.5%sand,after 2hr.).



a- Surface layer before water-jetting

b- after erosion-corrosion (90^o) | after erosion (90^o)

c- after erosion-corrosion (45^o) | after erosion(45^o)

d- after erosion-corrosion (0^o) | after erosion(0^o)

Figure (10) Optical microscope images of Al alloy after erosion – corrosion and erosion tests at different impact angles.