Studying Corrosion Behavior of Recrystallization Treatment of AA 5083 and AA 5085 Aluminium Alloys in Tigris and Shatt Al Arab

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Abstract. In this study, the corrosion behaviour of both AA 5083 and AA 5086 aluminium alloys in the marine environment was investigated in the Tigris and Shatt Al Arab water media before and after recrystallization annealing at room temperature (23^0 C). The corrosion resistance of AA 5083 marine aluminium alloy shows an improvement after recrystallization at a temperature of 350^0 C for 15 minutes from (708.5×10^{-6}) to (513×10^{-6} mmpy) in Tigris, while in Shat Al Arab the improvement was from (1.84×10^{-5}) to (217.7×10^{-6} mmpy) using the Tafel test. While the corrosion resistance in AA5086 decreased in both Shat Al Arab and Tigris River, in Tigris the decreasing was from (1.259×10^{-3}) to (7.418×10^{-3} mmpy), while in Shat Al Arab the decreasing was from (28.25×10^{-6}) to (305×10^{-6} mmpy). Both alloys suffered from uniform corrosion in the Tigris River. In Shat Al Arab both alloys suffered from pitting corrosion. Hardness for both alloys shows decreasing after recrystallization annealing.

Keywords: marine aluminium alloys; Tigris River; Shatt Al Arab River; corrosion behaviour; Tafel test.

1 Introduction

Al-Mg alloys are considered as non-heat treatable alloys with moderate strength. They can be strengthened either by solid solution[1] or by cold work strain hardening [2]. Al-Mg alloys are used in many applications such as trailers, cryogenic tanks and especially in building various parts in ships and boats [3, 4], because of their low density, high corrosion resistance and good mechanical properties [5-9]. The corrosion resistance of Al-Mg alloys is owed to oxide film formation as this layer under atmospheric condition will improve [10]. This layer is thin, non-coherent and non-uniform. Some factors like the film type that has been formed, the existence of aggressive anion and some unknown factor [11] will affect the film growth rate or it will affect the film quality that plays an important role in the breakdown of the film. The breakdown of this layer will result in pitting and crevice corrosion [12, 13]. Al-Mg alloys have a heterogeneous microstructure so these alloys will undergo pitting corrosion [14, 15].

Pitting corrosion is formed in the aluminium alloy in saltwater because of the existence of precipitate. These precipitates will lead to ions transformation and this will result in the formation

IMDC-SDSP 2020, June 28-30, Cyberspace

DOI 10.4108/eai.28-6-2020.2297942

of a weak oxidation layer [16]. Temperature, Cl concentration and PH concentration of the solution will also initiate pitting formation [17, 18]. Resistance to pitting corrosion of AL-Mg alloys tends to increase or decrease by the presence of alloying elements in aluminium alloys [19, 20]. Al-Mg alloys with more than 3% Mg are supersaturated alloys at room temperature. Solute atoms in Mg tend to be precipitated as β phase (Al_3 Mg_2) spreads along the grain boundary of Al-Mg alloy at room temperature, during ageing, or during the exposure to high temperature (65-2000 C) [21-23], so Al-Mg alloy like 5083 and 5085 will become sensitized and will be susceptible to corrosion.
In this study, the corrosive behaviour of both AA 5083 and AA 5086 marine aluminium alloys have been studied by using the Tafel test. This study was conducted in the Tigris and Shatt Al Arab Rivers, at a room temperature of 23^0 C. Additionally, the effect of recrystallization annealing on the corrosion behaviour of both AA 5083 and AA 5086 marine aluminium alloys has been studied. The effect of recrystallization annealing on the hardness of AA 5083 and AA 5086 alloys have been also studied.

2 Experimental Work

2.1 Aluminium alloys

Aluminium alloy grade AA 5083 and AA 5086 have been utilized in this work to investigate their corrosive behaviour in the Tigris and Shat Al Arab Rivers. The chemical composition of aluminium alloys was analyzed by using Spectro max and the results are listed in Table 1 which is fitted to the standard value in reference [24] and reference [25]. The samples with a thickness of 25mm were cut using the water jet method. These samples were cut into this thickness to fit the specimen holder dimensions that have been conducted specially for this study. The specimen holder was made of Teflon because Teflon is a slippy material, resists high temperatures and is resistant to almost all chemicals and solvents. The design and dimensions of this specimen holder are shown in **figure 1**.

Table 1. Chemical composition of (AA 5083 and AA 5086) aluminium alloys in %

Alloy	Si %	Fe %	Cu %	Mn %	Mg %	Cr %	Ni %	Ti %	Zn %	Pb %	Al %
5083	0.15	0.368	0.022	0.417	3.8	0.140	0.002	0.019	0.010	0.019	95
5086	0.06	0.28	0.001	0.20	3.11	0.074	0.010	0.011	0.006	0.033	96

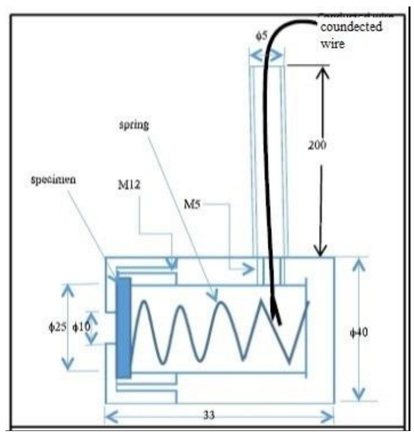

Figure 1. Design and dimensions of the specimen holder. All dimensions are in mm.

2.2 Water media

The corrosive behaviour of AA 5083 and AA 5086 marine aluminium alloys was investigated in both Tigris and Shatt Al Arab water media. Tigris is a River in Iraq that rising in Turkey and flow through Baghdad to the Euphrates in the south-east of Iraq. The two Rivers meet in southern Iraq, forming the Shatt Al Arab which flows into the Gulf.

This study investigates the corrosive behaviour of marine aluminium alloys in the Tigris and Shat Al Arab River at a temperature of (23^0 C) and salinity of (625 mg/L) and (3254 mg/L) respectively. The chemical analysis of the Tigris and Shat Al Arab Rivers are listed in Table 2.

Table 2. Chemical analysis of Tigris and Shat Al Arab

Water media	PH	EC	T.D.S (Mg/l)	CO_3 (Mg/l)	HCO_3 (Mg/l)	Ca (Mg/l)	Mg (Mg/l)	Cl (Mg/l)	NO_3 (Mg/l)	Na (Mg/l)	K (Mg/l)
Tigris River	7.3	955	625	0.0	366	47	19	142	1.1	115	2
Shat Al Arab	7.48	4625	3254	0.0	86	280	126.68	980	5.27	348	161

2.3 Heat treatment

In this study, AA 5083 and AA 5086 marine aluminium alloys were annealed by recrystallization annealing to study the effect of heat treatment on the corrosion behaviour of these alloys. Recrystallization annealing is a heat treatment process that has been used to change the properties of cold-worked metals and alloys. For recrystallization annealing, the samples were placed in the lab furnace at a temperature of (350^0 C) for 15 min and then they were cooled down in the air of the furnace.

2.4 Corrosion test

The Tafel test has been utilized to study the corrosive behaviour of 5083 and 5086 marine aluminium alloys before and after heat treatment. Before the Tafel test, all samples were ground using emery papers with different grades (300, 500, 1000 and 1500) and then polished by using alumina solution (5 µ) with a rotation speed of 250 rpm till all the scratches were removed from the surface. The samples were then washed by using water and then etched by using a killer solution (the killer solution is a mixture of hydrofluoric acid, hydrochloric acid and nitric acid that is used to etch aluminium alloys). Samples with 0.78 cm^2 exposure surface area were exposed to both the Tigris and the Shat Al Arab Rivers before and after recrystallization annealing. The experimental work was carried out in three-electrode corrosion cells with working electrodes, graphite counter electrodes and calomel reference electrodes.

2.5 Optical microscope

In this study, optical microscopes (100X) have been used to identify the microstructure of 5083 and 5086 marine aluminium alloys and the type of corrosion that occurs in these alloys before and after recrystallization annealing.

3 Results and Dissections

3.1 Effect of recrystallization annealing on the microstructure.

Figure 2 shows the microstructure of both AA 5083 and AA 5086 before and after recrystallization annealing at a temperature of 350^0C for 15 mins. **Figure 2a and figure 2b** show the microstructure of AA 5083 alloys before and after recrystallization annealing respectively. The microstructure of recrystallized annealed specimens has a larger second precipitate phase than before. Both figures clarify that they are in the same phases. While **figures 2c and 2d** show the microstructures of AA 5086 alloy before and after recrystallization annealing respectively. The microstructure of the recrystallized annealed specimen has a higher amount of second precipitate phase than before. The difference in the microstructure of these alloys is not very large, but the alloying elements in AA 5083 alloy are higher than AA 5086. These alloying elements will affect the mechanical properties after heat treatment more than their effect on the microstructure of AA 5083 and this may result in fine grains.

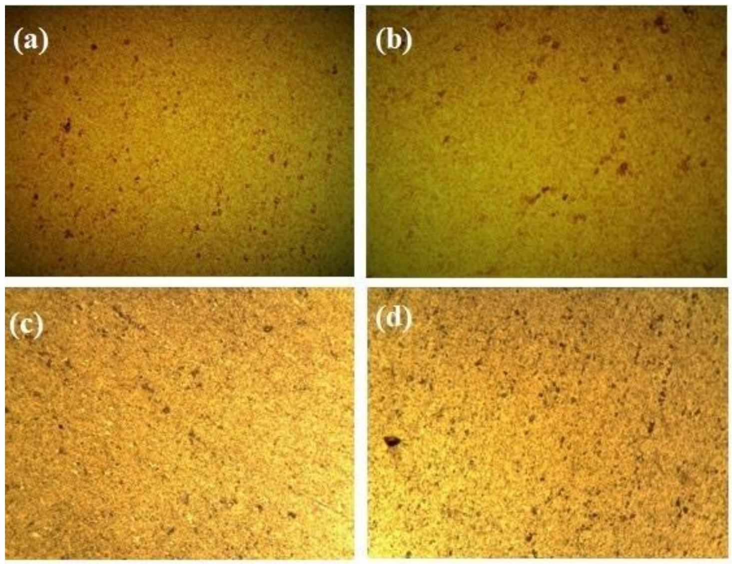

Figure 2. An optical microscope of AA 5083 and AA 5086 marine aluminium alloys: a) AA 5083 as received; b) AA 5083 after recrystallization annealing; c) AA 5086 as received; d) AA 5086 after recrystallization annealing

3.2 Micro-hardness test

Table 3 shows the micro-hardness for both marine aluminium alloys before and after recrystallization annealing. The hardness of 5083 alloy shows a decrease in hardness from 84 to 79 VHN. This decreasing is due to stress relief which occurs during recrystallization annealing [26]. For 5086 alloy it shows the same behaviour when decreasing hardness from 105 to 98 VHN. This is also due to stress relief [27].

Table 3. Microhardness of AA 5083 and AA 5086 marine

Marine alloy	As received	Recrystallization annealing
AA 5083	84 VHN	79 VHN
AA 5086	105 VHN	98 VHN

3.3 Effect of recrystallization annealing on corrosion behaviour of 5083 and 5086 alloys in Tigris River.

The Tafel test results for both AA 5083 and AA 5086 alloys before and after recrystallization in the Tigris River are shown in **figure 3.** In **figure 3a** and Table 4, it is clear that AA 5083 marine aluminium alloy will resist uniform corrosion better than AA 5086 due to the percentage of Mg in AA 5083 (3.8 %) which is higher than Mg value in AA 5086 (3.11 %). The corrosion rate of AA 5083 alloy will decrease as a result of recrystallization annealing as shown in **figure 3b** and Table 5, due to annealing in the range of 230-350^0 C which will improve AA 5083 sensitization [28]. In AA 5086 the corrosion rate will increase due to β (Al_3 Mg_2) precipitate along the grain boundary of AA 5086 during the fabrication of the plate [29] which will result in intergranular corrosion, and the disappearance of Ti from the microstructure of AA 5086.

The microstructure of both AA 5083 and AA 5086 after the Tafel test in Tigris are shown in **Figure 4.** In this figure, both AA 5083 and AA 5086 will suffer from uniform corrosion. Uniform corrosion results from a decrease in thickness over the alloy's surface. The rate of uniform corrosion can range from some microns per year to many microns per hour. This rate depends on the environment and the type of acid in water. Due to low salinity of Tigris River, pitting corrosion does not occur in these alloys.

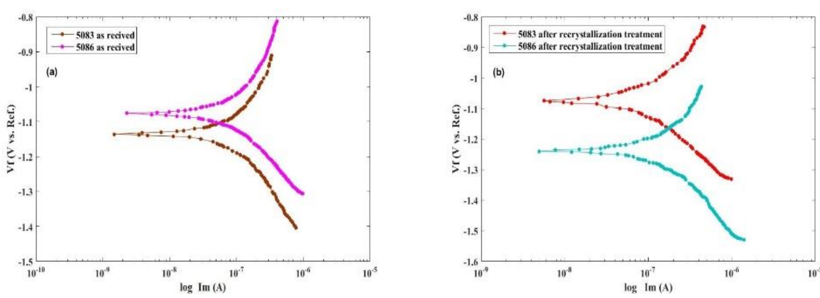

Figure 3. The Tafel test results; a) AA 5083 and AA 5086 alloys as received in Tigris; b) AA 5083 and AA 5086 alloys after recrystallization

Table 4. Data for AA 5083 and AA 5086 in Tigris before recrystallization

materials	β_a (V/ decade)	β_c (v/ decade)	E_{corr} (v)	I_{corr} (nA)	CR (mmpy)
AA5083	165.7×10^{-3}	160.7×10^{-3}	-1.140	61	708.5×10^{-6}
AA5086	337.4×10^{-3}	216.8×10^{-3}	-1.080	108	1.259×10^{-3}

Table 5. Data for AA 5083 and AA 5086 in Tigris after recrystallization

Materials	β_a (v/ decade)	β_c (v/ decade)	E_{corr} (v)	I_{corr} (nA)	CR (mmpy)
AA5083	156.7×10^{-3}	119.7×10^{-3}	-1.070	44.4	513.3×10^{-6}
AA5086	12.43×10^{-3}	541.6×10^{-3}	-1.240	639	7.418×10^{-3}

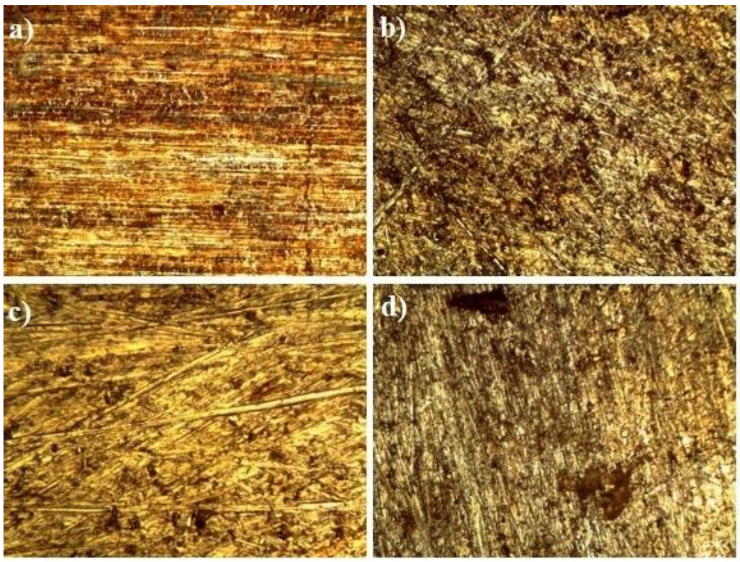

Figure 4. The microstructure of both AA 5083 and AA 5086 after the Tafel test in Tigris; a) AA 5083 alloy as received after the Tafel test; b) AA 5086 alloy as received after the Tafel test; c) AA 5083 alloy after recrystallization and the Tafel test; d) AA 5086 alloy after recrystallization and the Tafel test

3.4 Effect of recrystallization annealing on corrosive behaviour in Shat Al Arab.

The Tafel test results for both AA 5083 and AA 5086 alloys before and after recrystallization in Shat Al Arab are shown in **figure 5** from **figure 6, 5a** and Table 6. Both alloys will suffer from uniform corrosion as well as pitting corrosion, but AA 5086 alloy will resist pitting corrosion better than AA 5083, due to different characteristics for intermetallic particles in these alloys [5]. After recrystallization, the pitting resistance of AA 5083 had been improved as shown in **figure 5, 6b** and Table 7. Pitting corrosion resistance for AA 5086 had been also decreased after recrystallization.
The microstructure of both AA 5083 and AA 5086 after the Tafel test in Shat Al Arab is shown in **Figure 6.** In this figure, both AA 5083 and AA 5086 will suffer from pitting corrosion due to the

high salinity of Shat Al Arab in addition to uniform corrosion. The diameter and the depth of this pitting will depend on many factors like alloy type, environments, salt concentration etc.

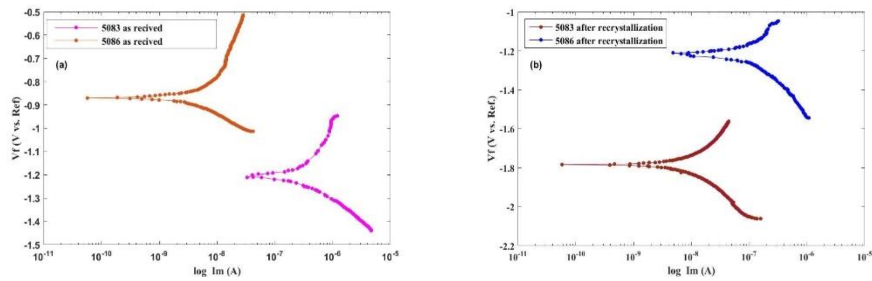

Figure 5. The Tafel test result; a) AA 5083 and AA 5086 alloys as received in Shat Al Arab; b) AA 5083 and AA 5086 alloys after recrystallization in Shat Al Arab.

Table 6. Data for 5083 and 5086 in Shat Al Arab

materials	β_a (v/ decade)	β_c (v/ decade)	E_{corr} (v)	I_{corr} (nA)	CR (mmpy)
AA5083	147×10^{-3}	100.4×10^{-3}	-1.210	158	1.84×10^{-3}
AA5086	91.2×10^{-3}	97.3×10^{-3}	-0.868	2.43	28.25×10^{-6}

Tabel 7. Data for AA 5083 and AA 5086 in Shat Al Arab after recrystallization

materials	β_a (v/ decade)	β_c (v/ decade)	E_{corr} (v)	I_{corr} (nA)	CR (mmpy)
AA5083	443.6×10^{-3}	396.6×10^{-3}	-1.780	18.8	217.7×10^{-6}
AA5086	83.5×10^{-3}	78.50×10^{-3}	-1.22	26.3	305×10^{-6}

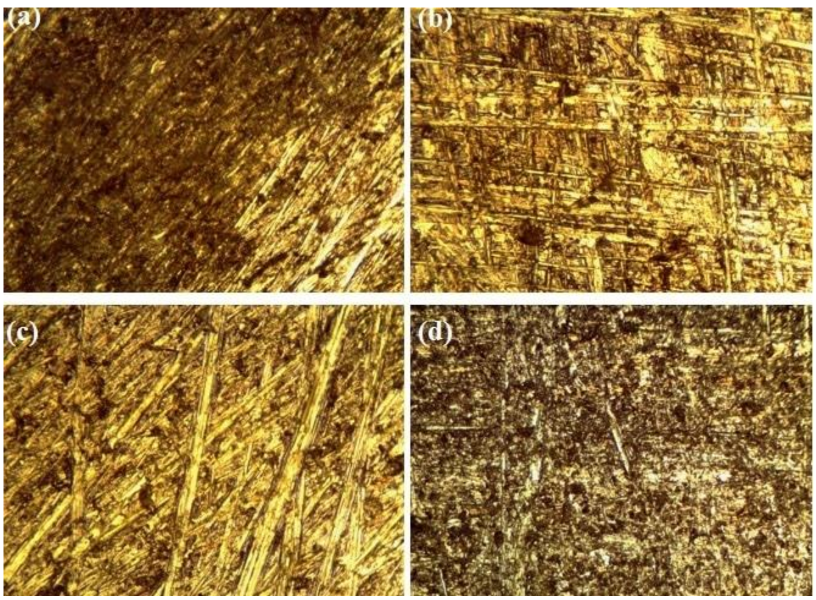

Figure 6. The microstructure of both AA 5083 and AA 5086 after Tafel test in Shat Al Arab; a) AA 5083 alloy as received after the Tafel test; b) AA 5086 alloy as received after the Tafel test; c) AA 5083 alloy after recrystallization and the Tafel test; AA 5086 alloy after recrystallization and the Tafel test

3.5 cycle polarization in Shat Al Arab

The AA5083 and AA 5086 cycle polarization curve in Shat Al Arab at room temperature (25^0 C) are shown in **figure 7.** The presented plots show that the properties of the curves are similar to a large degree. This indicates the same reaction on the surface of alloys. In the anodic region, the passive region can be seen in both alloys. This region is formed as a result of the oxide layer on both alloys. The oxide layer decreases the rate of dissolution and acts as a barrier.

The difference in cathodic reaction of AA 5083 and AA 5086 is due to the difference in the amount of dissolved oxygen [30]. The values of i_{cor} and the rate of corrosion are listed in table 6. They were obtained by using the Tafel test. It can be seen that AA 5083 exhibit higher i_{cor} as compared to AA 5086. The dominating type of corrosion of AA 5083 and AA 5086 in saltwater is pitting corrosion. To get more information about pitting potential, cycle polarisation is plotted **in figure 7.**

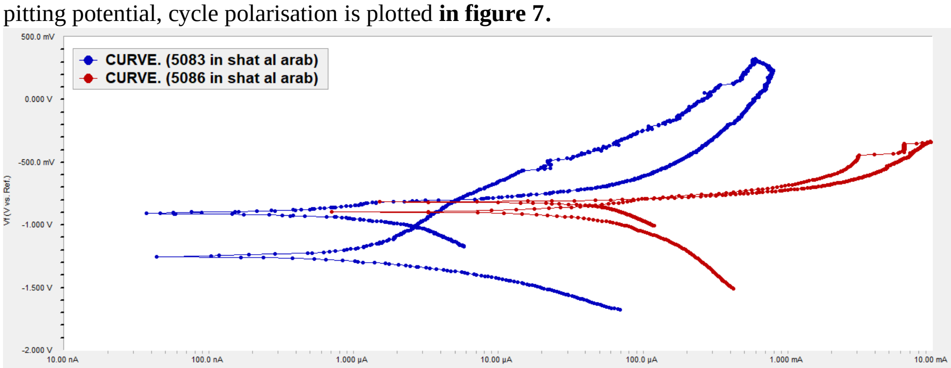

Figure 7. shows the cycle polarization test of AA 5083 and AA 5086 in Shat Al Arab

4. Conclusion

1- The Tafel test reveals that both 5083 and 5086 alloys will suffer from uniform corrosion in the Tigris River at room temperature (23^0 C) with better corrosion resistance for 5083 alloys.

2- After recrystallization at a temperature of 350^0 C for 15 minutes, the results from the Tafel test show an improvement in corrosion resistance of 5083 alloys while the corrosion resistance of 5086 decreased in both Tigris and Shat Al Arab River.

3- In Shat Al Arab River the Tafel test reveals that both 5083 and 5086 alloys will suffer from pitting corrosion at room temperature (23^0 C) with better corrosion resistance for 5086 alloys.

Acknowledgements

The authors would like to thank the staff of Mustansiriyah University (www.upomustansiriyah.edu.iq) Baghdad-Iraq, for their support in the present work.

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