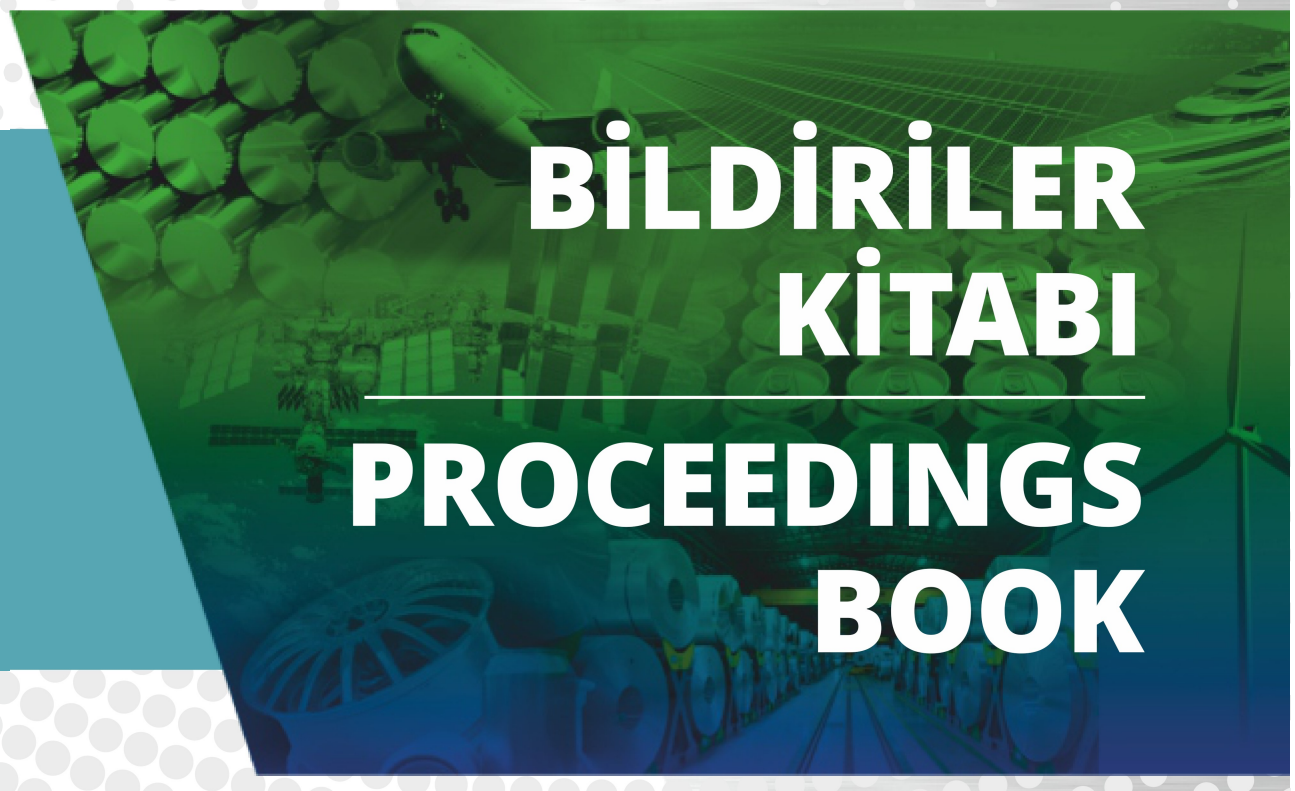
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# 10. Uluslararası ALÜMİNYUM SEMPOZYUMU

# 10th International ALUMINIUM SYMPOSIUM



# BİLDİRİLER KİTABI

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# SYMPOSIUM PROGRAM

## Heat Treatment / Isıl İşlem

*Session Chairman / Oturum Başkanı: ÇAĞLAR YÜKSEL*

16:50-17:10

### Al-Cu Alaşımlarının 0.1 K/S den 37000 K/S kadar Farklı Soğuma Hızlarında Katılaşması ve Mikroyapısının Tahmini

Solidification of Al-Cu Alloys in the Range of 0.1 K/S to 37000 K/S Cooling Rates and Prediction of Microstructures

**Altan TÜRKELİ** *Marmara Üniversitesi, Türkiye*

17:10-17:30

### Recrystallization Behavior of Cold Rolled Twin-Roll Cast 3003 Aluminum Alloy

İkiz Merdane Sürekli Döküm Tekniği ile Üretilen Soğuk Haddelenmiş 3003 Alüminyum Alaşımının Yeniden Kristalleşme Davranışı

**Elif ÖNER SHBEH, Onur MEYDANOĞLU**
*ASSAN Alüminyum San. ve Tic. A.Ş., Türkiye*

17:30-17:50

### Krojenik Isıl İşlemin AA 2024 Boru Profillerin Mekanik Özelliklerine olan Etkisinin İncelenmesi

Investigation of The Effect of Cryogenic Heat Treatment on Mechanical Properties of AA 2024 Tubular Profiles

**Özkan TUNÇ[2], Ali KALKANLI[1], İbrahim KILINÇ[2], Funda KUYUMCU[2], Bukle Pelin BAYMUŞ[2]**
*[1]Orta Doğu Teknik Üniversitesi, [2]Ditaş Doğan Yedek Parça İmalat ve Teknik A.Ş., Türkiye*

17:50-18:10

### Effect of Aging Conditions of AA6063 and AA6061 Alloys on Corrosion Behavior

AA6063 ve AA6061 Alaşımlarının Yaşlandırma Koşullarının Korozyon Davranışına Etkisi

**Murat DOĞAN[1,2], İbrahim TÜTÜK[1], Serhat ACAR[1], Kubilay ÖZTÜRK[1], Kerem Altuğ GÜLER[1]**
*[1]Yıldız Technical University, [2]Sistem Teknik Endüstriyel Fırınlar Ltd. Türkiye*

18:10-18:30

### The Effect of Homogenization Treatment on the Microstructure of Secondary AA6063 Aluminium Billets

Homojenizasyon Isıl işleminin Eşit Boyutlardaki İkincil AA6063 Alüminyum Kütüklerin Mikroyapısına Etkisi

**Ferhat SAYDAM[1], Kerem Can DİZDAR[2], Alptekin KISASÖZ[3], Çağlar YÜKSEL[4]**
*[1]Biser Alüminyum, [2]İstanbul Technical University, [3]Kırklareli University, [4]Atatürk University, Türkiye*

# Effect of Aging Conditions of AA6063 and AA6061 Alloys on Corrosion Behavior

## AA 6082 yerine AA 6061 olacak "AA6063 ve AA6061 Alaşımlarının Yaşlandırma Koşullarının Korozyon Davranışına Etkisi

Murat DOĞAN[1,2], İbrahim TÜTÜK[1], Serhat ACAR[1], Kubilay ÖZTÜRK[1], Kerem Altuğ GÜLER[1]

[1] Yıldız Technical University, Türkiye
[2] Sistem Teknik Endüstriyel Fırınlar Ltd. Türkiye

**Abstract**

In this paper, the corrosion behavior of Al-Mg-Si-Cu (AA6063) and (AA6061) alloys were investigated in naturally aged, over-aged, under-aged, and peak-aged conditions. The solution heat-treated samples were aged at 180 °C for 4 hours, 8 hours, and 24 hours. Potentiodynamic polarization tests were applied in NaCl solution to investigate the corrosion behavior of the alloys. The results were discussed based on hardness measurements, microstructural investigations, and electrochemical corrosion outcomes. The results show that the formation of precipitates in the structure has a positive effect on the corrosion behavior and the pitting susceptibility increased with increasing aging time.

### 1. Introduction

Aluminium has high resistance to corrosion with an oxide film. Aluminum should be used in neutral environments because this oxide film is stable in the 4 to 9 Ph range only. Aluminium can protect itself with oxide film from further oxidation because this oxide film forms instantly with the aluminium surface of exposing to the atmosphere. Magnesium and silicon are the main alloying elements of 6xxx alloys. These heat-treatable alloys are commonly used for architectural extrusions, automotive industry, marine, and machinery [1-3]. AA6063 is commonly used for architectural extrusions because AA6063 has excellent formability. AA6061 has good mechanical properties with its medium strength. Mechanical and corrosion properties can be changed as a function of time at room temperature with natural aging. Temperature and holding time are important values of understanding the degree of precipitation hardening. $Mg_2Si$ is the main precipitation compound for 6xxx alloys and can be improved mechanical properties. $Mg_2Si$ is cathodic compared to the Al-alloy matrix. During aging, peak aged has a maximum value for the duration aging time of $t$ [4]. Under-aged temper needs to be a treatment time shorter than $t$. The over-aged temper needs to be a treatment time longer than $t$. Direct chill casted billets are the raw material of the extrusion products. Liquid metal is poured into a water-cooled mold. This mold has a graphite ring and mold lube system. The skin of the billets becomes solid with this graphite ring and lubricant. Further cooling of billets is achieving by using dual water jets. Wrought aluminium alloy billets are usually subjected to a homogenization heat treatment after DC casting [5].

El-Menshawy et al. [6] reported that under-aged specimens of AA6061 showed susceptibility to intergranular corrosion but the over-aged specimens showed maximum susceptibility to IGC, while pitting was the dominant corrosion behavior for the over-aged tempers. The solution heat-treated specimens showed the highest resistance to pitting or IGC and exhibited uniform corrosion. Aging temperature and aging time were reported to be important depending on the dominant corrosion behavior. Another important aspect reported for all aged specimens is the shift in the corrosion potential towards more noble values compared to the solution-treated condition. The maximum Icorr values correspond to the peak-aged condition. Corrosion current density values Icorr decrease in the over-aged condition. Decreasing the cathodic area on the specimen surface with over-aging is expected to cause shift in Ecorr back towards more negative values in the direction to the solution heat-treated condition.

In a series of works, Svenningsen et al. [7-10] reported that lower Cu specimens of 6xxx series alloy showed resistance to IGC. The susceptibility to IGC was reduced significantly as a result of artificial aging to peak aging. Over-aging revealed pitting susceptibility. High Cu samples exhibited significant IGC. IGC susceptibility was the result of micro galvanic coupling between grain boundary precipitates and the adjacent depleted zone. Specimens were susceptible to IGC in naturally aged conditions. To sum up, Cu content as low as 0.12 wt. % could cause IGC, while the low Cu alloy was resistant.

Liang et al. [11] reported that $E_{pit}$ shifts towards more noble values with high Cu samples. $E_{pit}$ shifts towards more negative values with increasing aging time. The effect of aging time on $E_{corr}$ is not important. The precipitation of $Mg_2Si$ could cause to decrease in $E_{pit}$. The naturally aged conditions showed that the lowest $i_{corr}$. $i_{corr}$ values increased with increasing aging time. Artificial aging reveals the higher $i_{corr}$ values. $E_{corr}$ shifts towards slightly more noble values with high Cu samples. $E_{corr}$ shifts more noble values with excess Si. These Si particles are cathodic compared to

the aluminum matrix. The electrochemical test results showed that the naturally aged samples reveal the least corrosion [12].

In this paper, the corrosion behavior of AA6061 and AA6063 alloys was investigated at different aging conditions by using the electrochemical corrosion method. The aim of the present work is to understand the effect of Cu and heat treatment on the corrosion behavior of the 6xxx alloys.

## 2. Experimental Procedure

### 2.1. Materials

The chemical composition of these two 6xxx alloys is shown in Table 1. The chemical composition of alloys was determined using Thermo Scientific ARL 3460 optical emission spectrometer. The alloys were provided as DC cast billets. The billets were homogenised after DC casting at 585 °C.

**Table 1.** Chemical composition of AA6061 and AA6063 (wt. %).

| | Fe | Si | Cu | Mn | Mg | Al |
|---|---|---|---|---|---|---|
| 6061 | 0.192 | 0.565 | 0.205 | 0.050 | 0.872 | 97.96 |
| 6063 | 0.197 | 0.412 | 0.024 | 0.032 | 0.480 | 98.76 |

### 2.2. Heat treatment procedures

Solution heat treatment of samples was carried out at 550 °C for 2h, followed by water quenching to room temperature. Some of these specimens were tested in the as naturally aged condition for 168h and the other specimens were artificially aged at 180 °C for 4h, 8h, 24h to obtain what have been termed the under-aged (UA), peak-aged (PA), over-aged (OA), naturally-aged (NA) and as-cast (AC) conditions, respectively.

### 2.3. Hardness Measurements

The Brinell hardness values were measured for the samples after grinding on SiC papers from 240 till 2000 grade, followed by polishing on polishing lapped cloth using 1 µm diamond suspension. The Brinell hardness test with a 2.5 mm indentation ball tip was applied to the samples under 62.5 kg load. The hardness test was repeated 5 times for each sample and their average values were given in Table 2.

**Table 2.** The Brinell hardness (HB) values of the alloys are studied in this work.

| | As Cast (AC) | Naturally Aged (NA) | 4h (UA) | 8h (PA) | 24h (OA) |
|---|---|---|---|---|---|
| 6061 | 54.7 | 77.5 | 106.1 | 112.2 | 106.9 |
| 6063 | 43.7 | 49.9 | 64.8 | 70.6 | 62.7 |

### 2.4. Electrochemical Measurements

Potentiodynamic polarization test was applied to the 6xxx alloy specimens in 3.5% NaCl solution at room temperature. The surface of the ground and polished each sample was adjusted to 1 $cm^2$.

The Potentiodynamic polarization test device (Ivium Compactstat) is composed of an electrochemical cell, a working electrode, a reference electrode, and a counter electrode. The reference electrode used was an Ag/AgCl solution with a potential of 0.065 mV. The counter electrode used was a platinum plate with 4 $cm^2$ surface area. The AA6063 and AA6061 samples were used as working electrodes. Initially, an open circuit potential (OCP) of the samples was designated by holding specimens for 15 min in the solution. After that, the potentiodynamic polarization experiments were performed at 250 mV below and above the measured OCP values with a scanning speed of 0.5 mV/s. In conclusion, corrosion potential (Ecorr) and corrosion current (Icorr) values were calculated by using obtained Tafel curves as a result of these tests.

### 2.5. Microstructure

The samples were ground from 240 till 2000 grade, polished, and finally etched with Keller solution for 35 seconds. Metallographic examinations were carried out with an image analyser assisted Nikon Eclipse MA 100 light microscope.

## 3. Results and Discussion

### 3.1. Potentiodynamic polarization in 3.5% NaCl

Fig. 1. and Fig. 2. show the Tafel curves obtained by potentiodynamic polarization tests in 3.5% NaCl for samples aged at 180 °C for 4h, 8h, 24h, aged naturally and cast with DC casting. The Ecorr and Icorr values derived from these curves were listed in Table 3. Of all samples tested, the peak-aged condition for each alloy reveals the highest icorr. In this way, the results of experimental works have confirmed that different aging conditions dramatically affected the corrosion behavior of the investigated alloys including Ecorr and Icorr. The change in the Icorr was tested in % 3.5 NaCl solution after casting and natural, under, peak, over aging conditions for the specimens of each alloy. The Icorr values initially increased with aging time reaching peak value and then decreased. Ecorr values of 6063 are more negative values than Ecorr values of 6061. This situation is associated with the amount of Cu. Table 1 shows that the wt. % of Cu of 6061 is higher than 6063. It has also been reported that Cu is one of the elements which can shift Ecorr of Al in the noble direction in the neutral NaCl solution [11].

When the corrosion behavior of 6061 is examined in different situations, it is seen that the formation of precipitates in the structure has a positive effect on the corrosion behavior, but this effect varies according to the distribution in the alloy (Fig.1). In NA sample, precipitates were distributed homogeneously. Thanks to this situation, corrosion resistance increased and started late.

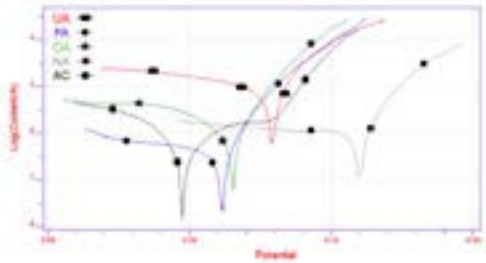



**Figure 1.** Tafel curves in 3.5% NaCl solution for 6061 samples; aged for different times at 180 °C, aged naturally and cast with DC casting.

According to the corrosion results of the 6063 alloy (Fig 2.), the overgrowth and heterogeneous dispersion of the precipitates formed in the OA sample decreased the corrosion resistance of the structure, while the homogeneous distribution of the precipitates and the formation of small sizes, as in the 6061 alloy, improved the corrosion resistance.

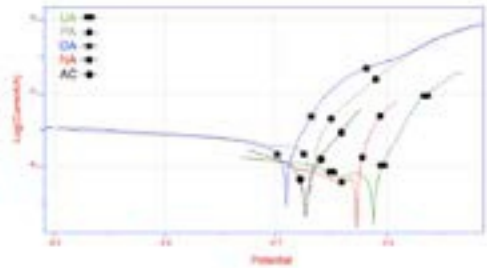



**Figure 2.** Tafel curves in 3.5% NaCl solution for 6063 samples; aged for different times at 180 °C, aged naturally and cast with DC casting.

**Table 3.** Potentiodynamic test results of the all samples.

| Specimens | Ecorr (V) | Icorr (A) |
|---|---|---|
| 6061 UA | - 0.5715 | 3.02 x $10^{-3}$ |
| 6061 PA | - 0.5890 | 3.19 x $10^{-3}$ |
| 6061 OA | - 0.5868 | 1.66 x $10^{-3}$ |
| 6061 NA | - 0.5390 | 2.15 x $10^{-3}$ |
| 6061 AC | - 0.6034 | 1.60 x $10^{-3}$ |
| 6063 UA | - 0.6130 | 1.10 x $10^{-3}$ |
| 6063 PA | - 0.6693 | 5.07 x $10^{-3}$ |
| 6063 OA | - 0.6904 | 2.68 x $10^{-3}$ |
| 6063 NA | - 0.6277 | 1.90 x $10^{-3}$ |
| 6063AC | - 0.6749 | 1.43 x $10^{-3}$ |

### 3.2. Microstructure

Optical microscopy examinations of the surfaces of corrosion-tested specimens reveal a strong dependence of the dominant corrosion form on the Cu content and aging time. After the corrosion testing, the surface examination results by optical microscopy for samples in different aging conditions are shown in Fig. 3, Fig. 4, Fig. 5, Fig. 6, and the corrosion mode change as a function of aging time as summarised in Table 4.

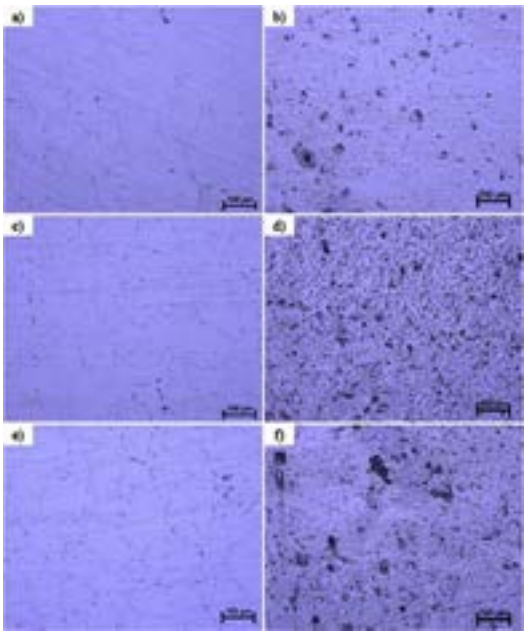


**Figure 3.** Optical micrographs of 6061 samples surfaces in different aging conditions after corrosion testing for in 3.5% NaCl: a) UA before corrosion testing; b) UA after corrosion testing; c) PA before corrosion testing; d) PA after corrosion testing; e) OA before corrosion testing; f) OA after corrosion testing.

Artificial aging increases the pitting susceptibility of 6061, and the pitting susceptibility increases with increasing aging time (Fig. 3d, Fig. 3f). After corrosion testing, grain boundaries are evident on the surface of the over-aged sample of 6063, exhibiting localized IGC attack (Fig. 5f).

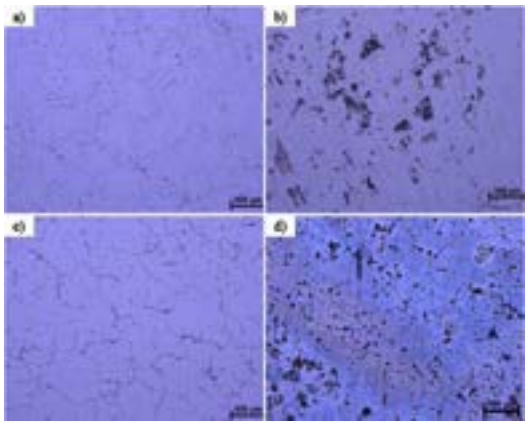


**Figure 4.** Optical micrographs of 6061 sample surfaces in naturally aging and as-cast conditions after corrosion testing in 3.5% NaCl: a) NA before corrosion testing; b) NA after corrosion testing; c) AC before corrosion testing; d) AC after corrosion testing.

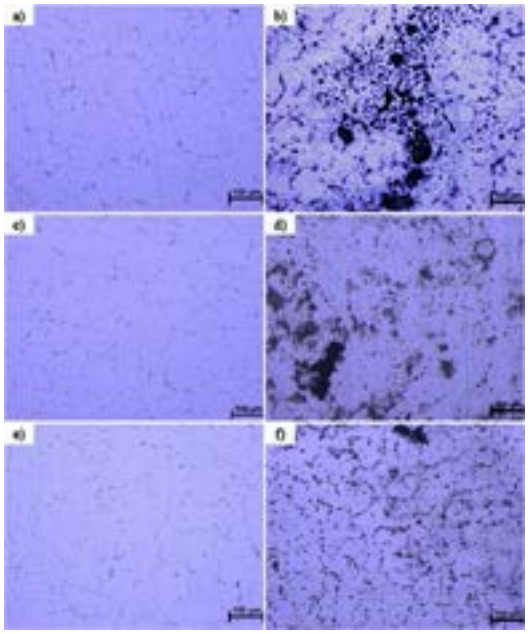


**Figure 5.** Optical micrographs of 6063 samples surfaces in different aging conditions after corrosion testing for in 3.5% NaCl: a) UA before corrosion testing; b) UA after corrosion testing; c) PA before corrosion testing; d) PA after corrosion testing; e) OA before corrosion testing; f) OA after corrosion testing.

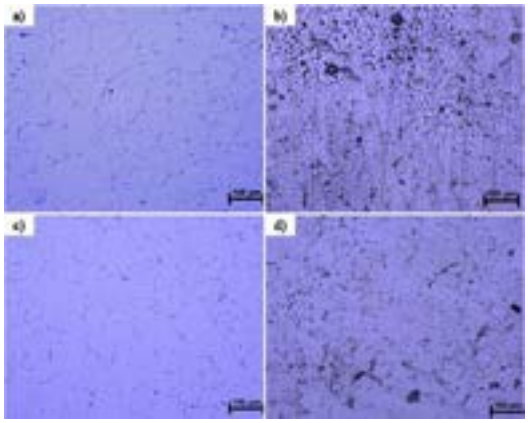


**Figure 6.** Optical micrographs of 6063 sample surfaces in naturally aging and as-cast conditions after corrosion testing in 3.5% NaCl: a) NA before corrosion testing; b) NA after corrosion testing; c) AC before corrosion testing; d) AC after corrosion testing.

**Table 4.** Results from corrosion testing in 3.5% NaCl of the studied alloys.

| Specimens | Corrosion mode |
|---|---|
| 6061 UA | Slight pitting |
| 6061 PA | Moderate pitting |
| 6061 OA | Moderate pitting |
| 6061 NA | Slight pitting |
| 6061 AC | Slight pitting |
| 6063 UA | Localized IGC |
| 6063 PA | Moderate pitting |
| 6063 OA | Localized IGC |
| 6063 NA | Moderate pitting |
| 6063AC | Slight pitting |

**4. Conclusions**

- The maximum Icorr values correspond to the peak hardness.
- AA6063 with the low amount of Cu shows more negative Ecorr values.
- Pitting was the dominant corrosion mode for AA6061 with a high amount of Cu.
- The pitting susceptibility increased with increasing aging time.
- The overaged condition of the low Cu sample showed that the dominant corrosion mode was Localized IGC.

**Acknowledgments**

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