EFFECT OF COPPER ADDITION ON CORROSION PROPERTIES OF EN AW 6082 ALLOY

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Abstract
The chemical composition of the 6082 alloy and the production cycle were recently revised in order to achieve a more uniform structure with no evidence of coarse grains across the section. This was achieved by alloying the standard 6082 alloy with Cu to improve its age hardening capacity without a separate solution heat treatment. However, Cu addition degrades the corrosion resistance of the alloy due to the formation of Al-Cu precipitates along the grain boundries. These precipitates are cathodic with respect to the aluminum matrix and thus encourage intergranular corrosion. The present work was undertaken to identify the impact of Cu addition on the corrosion properties of the revised EN AW 6082 alloy. A series of experimental EN AW 6082 alloys with 0.27, 0.45 and 0.89 wt% Cu were tested in the present work in salt spray and potentiodynamic tests and the results will be reported.

Keywords: EN AW 6082, corrosion, copper, alloying

BAKIR İLAVESİNİN EN AW 6082 ALUMİNYUM ALAŞIMLARININ KOROZYON ÖZELLİKLERİNE ETKİSİ

Özet
6082 alaşımlarının kimyasal kompozisyon ve üretim yönteminde yakın zamanda yapılan değişiklik ile tane büyümesine meydan tanımadan daha uniform bir yapıda kesit elde edilmiştir. Bunu sağlamak için standart 6082 alaşımına bakır ilavesi yapılmış ve bu sayede alaşımın yaşlandırma kabiliyeti herhangi bir çözeltiye alma işlemi uygulamadan geliştirilmiştir. Ancak Cu ilavesi ile alaşımın korozyon direnci tane sınırlarında oluşan bakır içerikli intermetalik fazlardan dolayı düşmektedir. Bu çökeltiler matris fazına göre katodik davranış göstererek intergranüler korozyona sebebiyet vermektedir. Bu çalışmada Cu ilavesinin EN AW 6082 alaşımına etkisi incelenmiştir ve 0,27 - 0,45 ve 0,89 bakır içerikli deneme 6082 alaşımları ile birlikte korozyon deneylerine tabi tutulup, sonuçları raporlanmıştır.

Anahtar Kelimeler: EN AW 6082, korozyon, bakır, alaşımlama

1. INTRODUCTION

Mass reduction is one of the most important technical issues in transport industry. Energy consumption, greenhouse gas emission and safety deeply depend on the weight of the material used. In order to achieve light weight, wrought aluminum alloys are commonly used in automotive industry as structural components and mainly 6xxx series aluminum alloys are recently studied for this purpose, because of their great response to precipitation hardening (1-3).

It is a well known situation that copper addition into aluminum alloy remarkably increases the mechanical properties (4,5). However, addition of copper introduces a side effect on the alloys corrosion properties, because precipitates like $Al_xCu_yMg_zSi_w$ (Q), Al_2CuMg and $CuAl_2$ (θ) are acting as cathodes in the micro scale (6) (Figure 1). Aluminum 6xxx series alloys mainly encounter with intergranular corrosion (IGC) as a result of alloying (7), particularly by copper addition (8). Alloying with copper even at low concentrations like 0.1 wt% exposes the alloy to IGC (9). Copper containing precipitates are more noble than the matrix phase and this causes a micro galvanic coupling at grain boundaries (10).

IGC of Al alloys can be explained by precipitation of discrete particles during heat treatment more at the grain boundaries than in the matrix. This makes grain boundaries more noble than the matrix. After the active regions are depleted by the corrosion process, the matrix becomes purer from the initial state with an increased potential difference (11). Also the thermomechanical background of the material also affects the susceptibility to ICG. For example, overaging conditions brings precipitates from the coherent state to an incoherent and globular state and this eliminates ICG and introduces pitting corrosion, but underaging increases the susceptibility of the alloy.

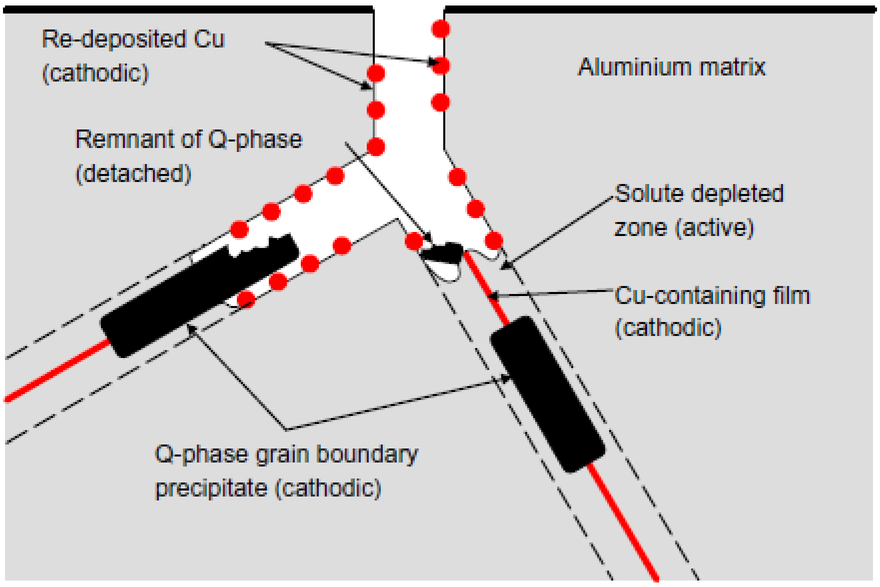

Figure 1. IGC mechanism, conceptual (7).

Although there has been some research on the corrosion properties of Al 6xxx series alloys by copper addition, there remains a need to investigate the effect of copper addition at higher concentrations and in the unsolutionized condition (3). In this present study, the aim is to examine the effect of copper addition on the corrosion properties of EN AW 6082 at high concentrations up to 0.89 wt% in the T5 temper.

2. EXPERIMENTAL

400 mm long EN AW 6082 extruded bars (copper amounts varying from 0.07 to 0.89 %wt.) with a diameter of 42 mm were used for industrial scale forging experiments. Chemical compositions of the alloys used are given in table 1.

Table 1. Chemical compositions of aluminum alloys and their designations (%)

Alloy	Designation	Si	Mn	Cu	Mg	Cr	Fe	Zn	Ti
Standard 6082	**ST**	1.02	0.57	0.07	0.75	0.22	0.26	0.01	0.03
Exp. 6082 with 0.27 % Cu	**0.27**	1.09	0.68	0.27	0.80	0.18	0.25	0.01	0.03
Exp. 6082 with 0.45 % Cu	**0.45**	1.13	0.67	0.45	0.68	0.18	0.25	0.01	0.03
Exp. 6082 with 0.89 % Cu	**0.89**	1.03	0.72	0.89	1.01	0.03	0.44	0.12	0.01

2.1. Heat Treatment

The suspension components were produced in the T5 temper, where the aging process was employed without a separate solutionizing treatment. To solutionize adequate Mg and Si levels before the aging process, some revisions were carried out in the preheating, forging and post forging actions. The round bars were preheated to 520 °C, a slightly higher temperature with respect to that employed in the standard T6 process and were forged into the same suspension components with the same forging parameters. These forgings were quenched in water right after the forging operation and were artificially aged at 180 °C for 8 hours (Figure 2).

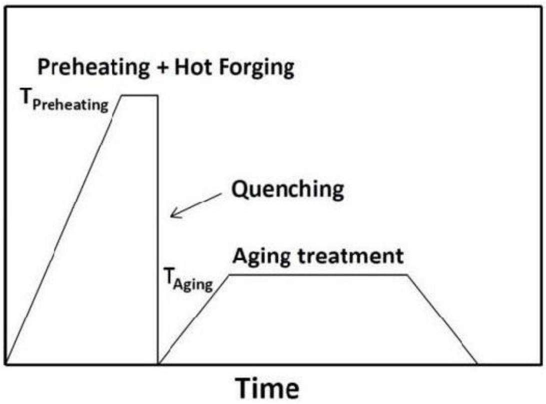

Figure 2. T5 processing of extruded bars.

2.2. Specimen Preparation

Aged specimens were cut to a thickness of 5mm and a diameter of 23mm. For surface preparation they were ground up to 2000 grit emery paper and washed with distilled water before corrosion testing.

2.3. Corrosion tests

Salt spray tests were applied according to ASTM B117 standard for 15 and 21 days and the results were macro examined to see the corrosion residues.

Potentiodynamic tests of standard EN AW 6082 and copper containing experimental alloys were performed using potentiodynamic polarization module of Reference 600 Potentiostat by Gamry at ambient temperature in 2.0 wt.% NaCl solution. A standard three electrode cell configuration was used with a platinum weave as counter electrode, a saturated calomel electrode (SCE) as reference electrode and the test specimen as working electrode (WE).

Tafel extrapolation tests: Primarily open circuit potential (OCP) measurements were performed for 1 hour (3.6k seconds). Tafel extrapolation tests were executed between -300 mV and +300mV (vs. OCP) with the scan speed of 0.17mV right after OCP measurements. The resultant Potential – Current figures were used to evaluate the corrosion current densities of specimens according to Stern-Geary equation (Eq. 1).

$$R_p = \frac{B}{i_{corr}}, \quad B = \frac{b_a b_c}{2.3(b_a - b_c)} \qquad \text{(Eq. 1)}$$

Cathodic polarization tests: Cathodic polarization tests were also applied after execution of OCP tests described earlier. Measurements were taken in the range of 0 to -600 mV's from the OCP of test materials. Cathodic polarization tests were applied in order to get a higher linear range in the cathodic arm for preventing incorrect results obtained from Tafel extrapolation tests.

3. RESULTS AND DISCUSSION

3.1. Salt Spray Tests

Salt spray tests reveal an overview about the corrosion behaviour of materials surfaces. Corrosion susceptibility of alloys as a function of copper content was estimated via visual inspection (Figures 3 and 4).

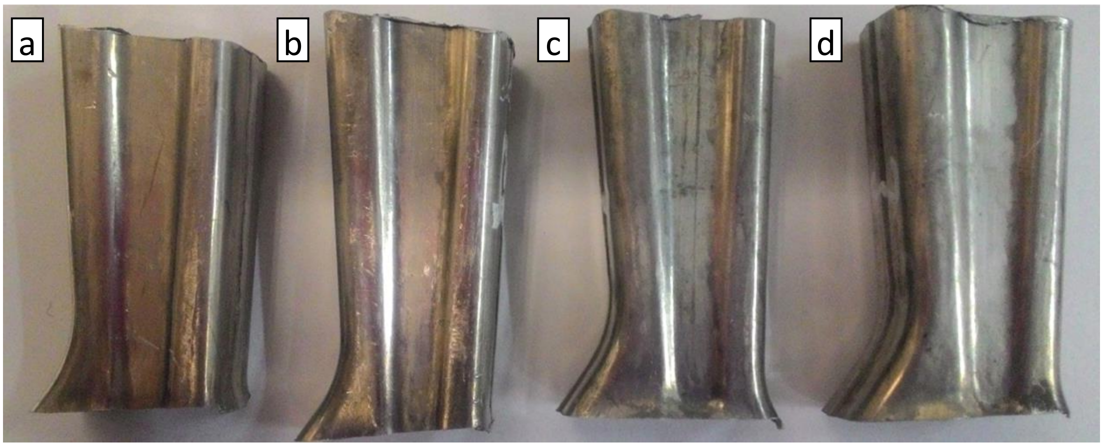

Figure 3. Photos of specimens after 15 days (near 350 hours) of salt spray test ST (a) 0.27 (b), 0.45 (c), and 0.89 (d) respectively.

Figure 4. Photos of specimens after 21 days (near 500 hours) of salt spray test ST (a) 0.27 (b), 0.45 (c), and 0.89 (d) respectively.

Figure 3 clearly shows that, after 15 days of salt spray test, none of the specimens exhibit significant corrosion products. Figure 4 (i.e. 21 days), on the other hand, suggests that all of the specimens have started to corrode. 0.89 % copper containing experimental 6082 alloy is heavily corroded. It is fair to conclude from the foregoing that 0.89 % wt. copper containing specimen is the least corrosion resistant while specimens having 0.07, 0.27 and 0.45% wt. copper are more resistant to corrosion.

3.2. OCP measurements

OCP measurements of the alloys show a regular shape and stay stationary on their potential. Copper is more noble than the standard 6082 alloy. Therefore, by adding copper intermetallic compounds and solid solution will have higher copper concentrations and this increases the OCP values of alloys.

As a result of 1 hour OCP measurement, 0.07, 0.27, 0.45 and 0.89 wt% Cu containing alloys respectively will show higher electropositivity (Figure 5). All alloys show a similar structure after they are stable. The main cause of the zig-zag structure of OCP is caused because of the presence of aggressive electrolyte. Therefore, it is a need to break the measurement in a short term. In Table 2 OCP results after 1 hour can be seen.

Table 2. OCP results of alloys after 1 hour measurement.

	ST	**0.27**	**0.45**	**0.89**
OCP (mV) vs. SCE	-730	-718	-712	-704

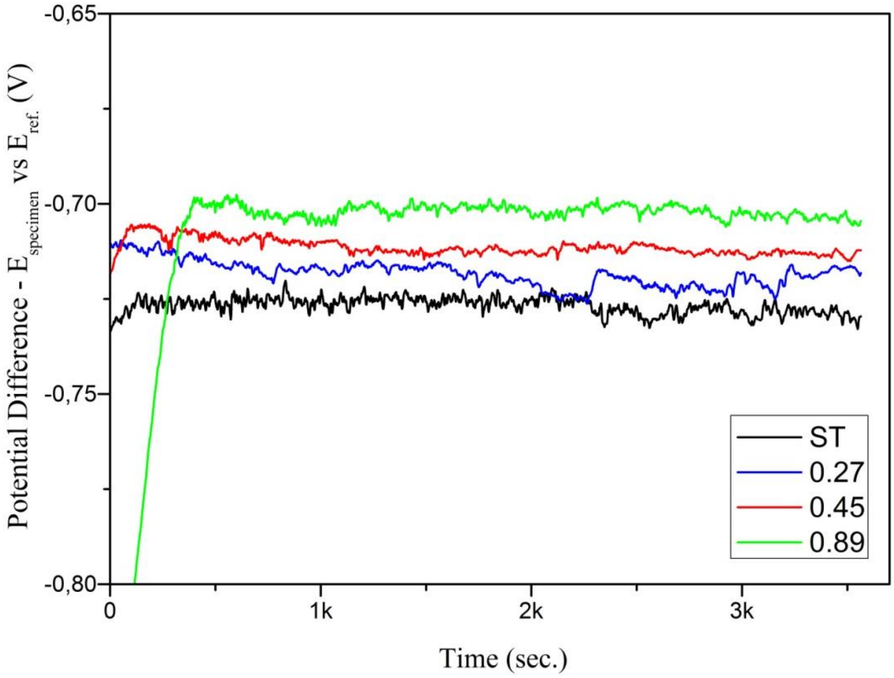

Figure 5. Open circuit potentials of alloys over 1 hour of measurement in 2 wt.% NaCl solution.

3.3. Potentiodynamic polarization tests

In Tafel extrapolation curves anodic arm of alloys show very sharp increase in the current densities. This means anodic constants are very small and therefore corrosion rates of materials increase. Also over -0.5 volts there is oscillation on the current with increasing potential. This shows that, over -0.5 volts vs. SCE pitting corrosion starts on all alloys.

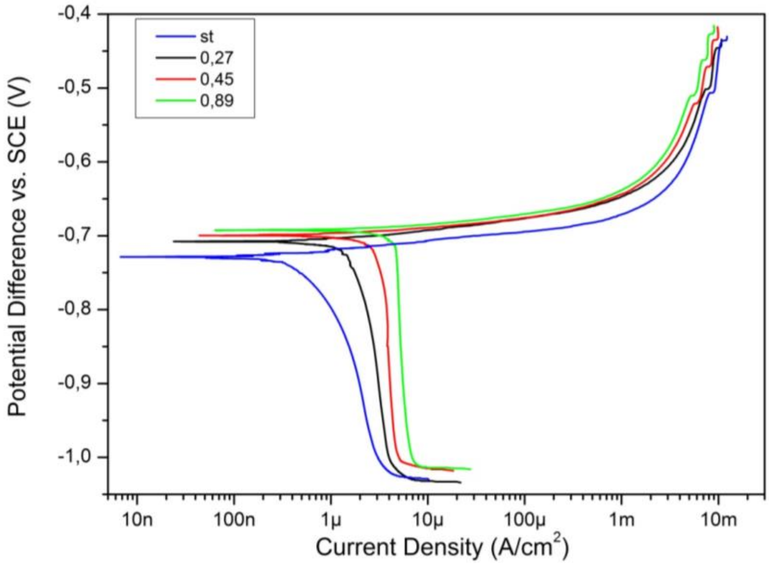

Figure 6. Tafel curves of alloys, between ±300 mV.

The cathodic arms of tafel curves start with a miscalculation. Although applied voltage (-300mV vs. OCP) was not very high, the beginning of the curves start with a deflection and current measurements are very high. Because current measurements need to be linear at least in this range cathodic polarization tests were applied in order to calculate Tafel constants.

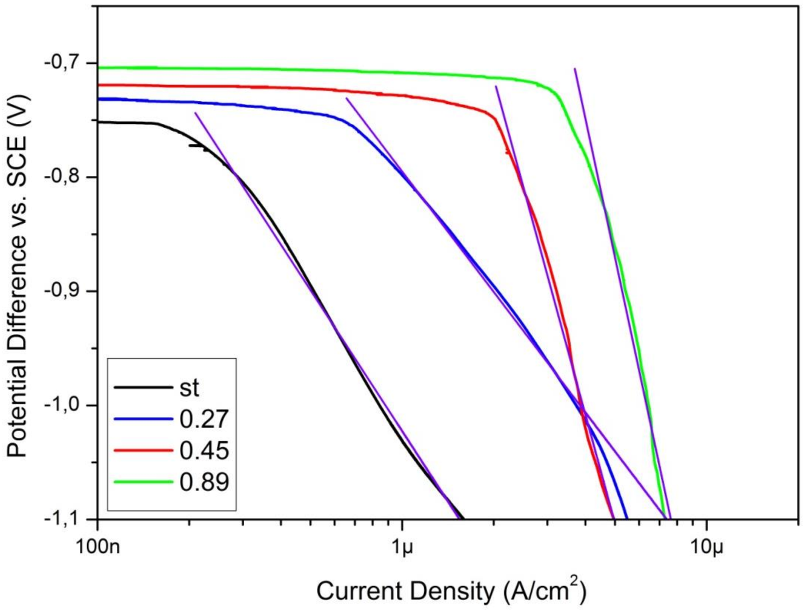

Figure 7. Cathodic polarization curves of alloys with linear fit.

In cathodic polarization curves cathodic Tafel constants were calculated from the slope of the curves, where the current change in cathodic arm of the slope is more reliable than Tafel curves. With increasing copper addition, it is clear that the slope of the curves increases (Figure 7) and this causes an increase in the corrosion rate of the material.

Table 3 shows electrochemical properties of alloys obtained from potantiodynamic polarization curves. Although V_{corr} is increasing with increasing copper content, I_{corr} also increases. The resultant corrosion rates of alloys show compatible results with salt spray tests. Standard 6082 alloy has the least corrosion rate and the worst alloy is the specimen with 0.89 % wt. copper addition.

Table 3. Corrosion properties of alloys obtained from Tafel and cathodic polarization curves.

	V_{corr} (mV)	I_{corr} (μA)	β_a (mV/decade)	β_c (mV/decade)	Corrosion Rate (mpy)
ST	-729	208.7 x10^{-3}	-17.6	410.5	277.9 x10^{-3}
0.27	-708	653.1 x10^{-3}	-17.5	351.1	869.9 x10^{-3}
0.45	-700	2.029	-15.7	979.4	2.702
0.89	-693	4.640	-16.6	1,252	6.177

4. CONCLUSION

The increase in mechanical properties with increasing copper is unfortunately accompanied with a decrease in the corrosion resistance.

In potentiodynamic tests, it is proved that increased copper addition gives the alloy higher susceptibility to corrosion. A copper content of 0.45 %wt appears to be a limit to achieve superior mechanical properties without degrading the corrosion resistance of 6082 alloys too much.

0.89 % wt. copper containing 6082 alloy was severely effected in both corrosion tests and showed the highest corrosion rate in potentiodynamic polarization tests. Therefore, this alloy should be used with great caution in automotive suspension parts.

The microstructures of the specimens submitted to salt spray tests should be examined in more detail in order to understand the behavior and the severity of corrosion reaction.

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