

# Effect of Zr Addition Affecting Corrosion Resistance in 2xxx Series Al alloys Used in Steel Plant

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**ABSTRACT:** In this study, the mechanical and corrosion resistance property were investigated according to Zr addition in 2013 Al alloy. To begin with, Al alloy was manufactured through melting and heat treatment. The analysis of micro structure, micro hardness, XRD, EDS and Potentiodynamic polarization test were carried out to check out the feature of corrosion resistance in accordance with Zr addition. As a result, micro structure got refined as Zr was added and lattice constant became a little bigger, which resulted in the decrease of micro hardness. In addition, Zr addition lowered the current density causing the reduction of corrosion rate.

**KEYWORDS:** Al alloy, 2xxx Series, Zr Addition, Corrosion Resistance.

## I. INTRODUCTION

Now most of hot dip galvanizing facility in steel plant consists of light metal, Al alloy with good corrosion resistance property. However, it still has difficulty in corrosion ironically.

Improved high strength Al alloys based on 2013-T3 and 7075-T6 alloys have been mostly used for mechanical and structural materials, which need cladding and surface treatment due to weak formability and weldability including corrosion problem. Recently 2013 alloy (Al-1.7Cu-1.0Mg-0.8Si-0.15Cr wt%) has been developed to solve the above problems.[1] 2013 alloy as an extruded material has more excellent formability than the high strength Al alloys which could be formed and aged in the pipe shape after quenching. 2013-T6 alloy is expected to substitute 2013-T3 alloy because it has an excellent corrosion resistance and the same strength as 2014-T6 alloy. In addition, it was confirmed that it was possible to be high strength with T8 treatment in 2013 alloy[2].

The aim of this study was to investigate the mechanical and anticorrosion property by adding Zr to 2013 alloy even if it has already an excellent high strength and corrosion resistance because it was reported that Zr addition in Al alloy caused grain refinement and improved the corrosion resistance and weldability by changing the preferred corrosion into general corrosion in grain boundary[3-5].

## II. RELATED WORK

1. Al alloy melting- Master alloy was manufactured for induction melting and then Al alloy was melted in the induction furnace. Homogenization was carried out in vacuum heat-treatment furnace at 540°C for 24hours. The degree of vacuum maintained at  $5.5 \times 10^{-5}$  Torr. The heating rate was 5°C/min. and cooling was implemented in the furnace.
2. Sample preparation(Rolling and heat treatment) - Table 1 shows different Zr content in Al alloy sample. Homogenization was performed at 540°C for 24hours and hot rolling at 500°C. Solution heat treatment with 170\*30\*40mm plate was fulfilled at 540°C for 1hour. And then the samples were cut and used for analysis.

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Table 1. Chemical composition of Al alloys

| Sample No. | Cu(wt%) | Mg(wt%) | Si(wt%) | Cr(wt%) | Zr(wt%) | Al(w%) |
|------------|---------|---------|---------|---------|---------|--------|
| 1          | 1.7     | 1.0     | 0.8     | 0.15    | -       | Bal.   |
| 2          | 1.7     | 1.0     | 0.8     | 0.15    | 0.2     | Bal.   |
| 3          | 1.7     | 1.0     | 0.8     | 0.15    | 0.5     | Bal.   |

- Property analysis with Zr content - The samples were polished to 1µm mirror polishing to investigate the micro structure, XRD, and micro hardness. The etching solution was composed of 25ml methanol, 25ml hydrochloric acid, 25ml nitric acid and 1 drop of hydrofluoric acid, which was used for 20~30 seconds. The average of micro vickers hardness with the load of 100g was calculated after measuring 9 points. The test of potentiodynamic polarization was carried out to see the corrosion resistance with Zr content where the equipment, Gamry Instrument G300 model, was used in the condition of area: 1cm<sup>2</sup>, etching solution: NaCl 3.5wt%, Anode:1V, Cathode: -1.5V, reference electrode: KCl, Counter electrode: Pt plate and scan rate: 1mV/S.

### III. EXPERIMENTAL RESULTS

Fig. 1 showed the analysis of XRD on sample 1 where scan step time was 1 second and step size was 0.04. All the peaks were Al belonging to Fm-3m space group where there were no precipitations and oxidation peaks. However, the lattice constant tended to be slightly increased as Zr was doped from 2 theta. Fig. 2 showed the result of optical microscope( x200) in order to observe the microstructure where (a), (b), and (c) showed No.1 alloy, No. 2 alloy, and No. 3 alloy respectively. It was confirmed that Zr refined the size of crystal grain as Zr was added.

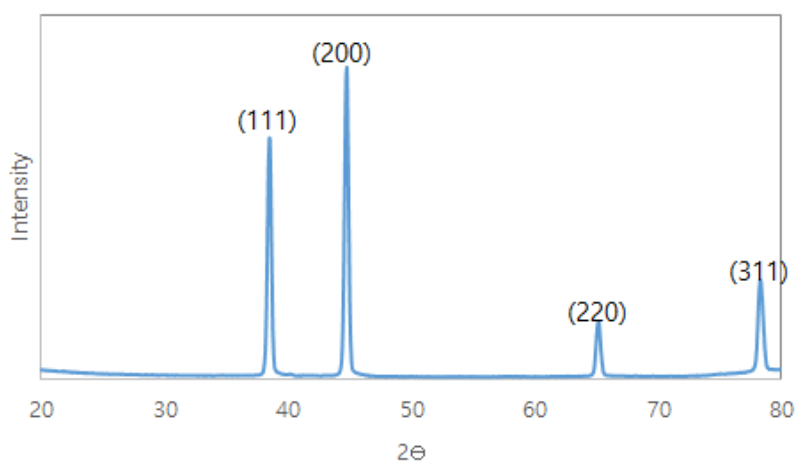


Fig. 1. X-ray diffraction pattern of sample 1

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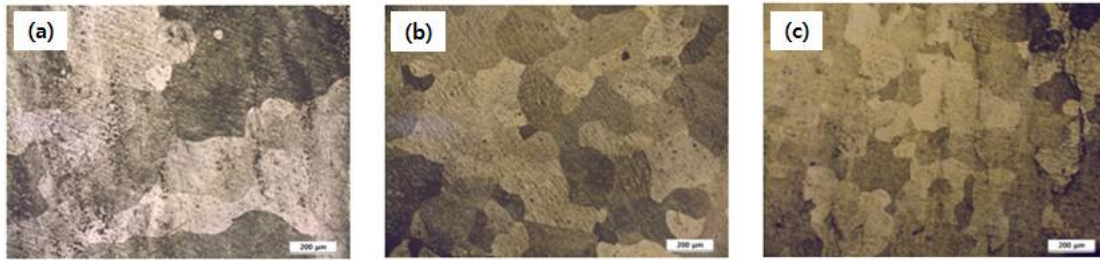


Fig. 2. Optical microstructure of Al alloys(OM, x200); (a) Sample No.1, (b) Sample No. 2, (c) Sample No.3

Table 2. Test result of Vickers hardness on samples

|                       | Sample No.1 | Sample No.2 | Sample No.3 |
|-----------------------|-------------|-------------|-------------|
| Vickers hardness (Hv) | 118.9       | 109.2       | 107.2       |

Table 2 shows the change of hardness by using the microhardness, indicating the average value of 9 times of measurement points with load of 100g except for the minimum and maximum values. The average hardness value was lowered lower in inverse proportion to Zr content in the sample, which was considered to have relations the increased size of lattice constant mentioned in the previous results of XRD analysis. As lattice constant increased, the distance between the adjacent elements grew apart, which was considered to influence the bonding force resulting in the decrease of the hardness.

The following figure 3 shows the results of potentiodynamic polarization test depending on Zr content.

Potential ( $E_{corr}$ , V) refers to the potential generated on the surface of the corroded test sample to the reference electrode on the condition of open circuit and corrosion resistance was confirmed to be excellent in proportion that current density ( $I_{corr}$ , A) lowered in the all of potential area[6,7].

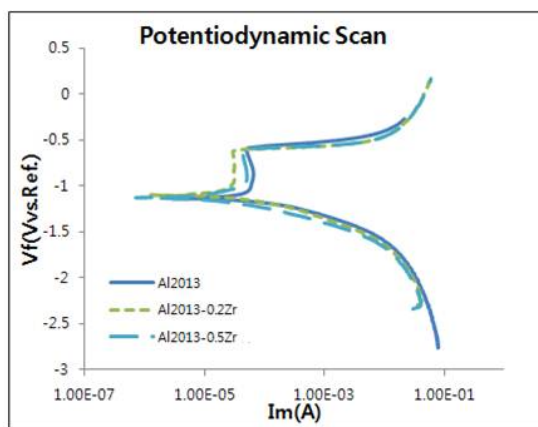


Fig.3. Potentiodynamic curves of Al alloys in NaCl solution

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First of all, taken as a whole, all alloys on the condition of 3.5% NaCl solution at normal temperature showed -2.9 V to 0.2V and the passivity area was formed. Corrosion potential was found to lower in proportion to the increase of Zr content.

Table 3 shows Ecorr (V) and Icorr (A). It was found that the values of Ecorr (V) and Icorr (A) changed according to the addition of Zr, which influenced the formation of Al passive film. The changed value of Icorr (A) was more distinctive than that of Ecorr (V) and the value of Icorr ( $\mu\text{A}$ ), current density, was the highest of 112 without the addition of Zr and increasingly decreased from 33.2 to 18.4 in an order of the amount of Zr addition. As mentioned before, the corrosion resistance was excellent in proportion that the value of current density lowered, which was confirmed exactly when checking the corrosion rate.

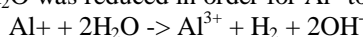
When it comes to the corrosion rate, it was confirmed that it lowered in the same as the current density, showing that Sample 1 was 48 mpy, Sample2 14 mpy, and Sample3 7 mpy. Therefore, significant changes were found depending on Zr content and the most excellent corrosion resistance was confirmed at 0.5% of Zr content.

Table 3. Ecorr (V) and Icorr ( $\mu\text{A}$ ) value of Al alloys

|             | Ecorr (V) | Icorr ( $\mu\text{A}$ ) |
|-------------|-----------|-------------------------|
| Sample No.1 | -1.130    | 112.0                   |
| Sample No.2 | -1.100    | 33.20                   |
| Sample No.3 | -1.130    | 18.40                   |

Meanwhile, it is known that more resistance to pitting corrosion occurred in proportion that Al content was increased:  
 $\text{Al}^{3+} + 3\text{e}^- \rightarrow \text{Al} \Phi = -1.7 \text{ V}$  [8]

As Al was ionized at -1700mV in anode,  $\text{Al}^{3+}$  and  $\text{Al}^{++}$  are formed. The film of  $\text{Al}_2\text{O}_3$  was formed easily because  $\text{H}_2\text{O}$  was reduced in order for  $\text{Al}^+$  to form  $\text{Al}^{3+}$



$\text{Al}_2\text{O}_3$  formed at this time formed a thick film of 0.0025-0.025mm on the surface[9]

A negative ion on the passive film of  $\text{Al}_2\text{O}_3$  thus formed was replaced by  $\text{Cl}^-$  at the very weak point of being combined with oxygen or in the place of OH ion, which resulted in the decrease of interfacial tension between oxide film and solution, causing pitting corrosion by replacing other ions with the adsorbed negative ion.

The following table 4 shows the analysis of the surface component on each test sample by using SEM and EDS after the corrosion test. As seen in Table 4, Al content on the surface was confirmed to increase in proportion to Zr content, which was assumed that Zr directly affected Al content remaining on the surface after corrosion.

Table 4. Element composition of Samples after the corrosion test

| Sample number | Element (wt%) |      |     |     |      |      |     |      |       |
|---------------|---------------|------|-----|-----|------|------|-----|------|-------|
|               | Al            | Cu   | Mg  | Si  | Cr   | Zr   | O   | C    | Total |
| 1             | 82.4          | 1.45 | 0.8 | 0.5 | 0.05 | -    | 2.2 | 12.6 | 100   |
| 2             | 84.9          | 2.1  | 0.6 | 0.4 | 0.08 | 0.02 | 1.7 | 10.2 | 100   |
| 3             | 85.1          | 2.0  | 0.8 | 0.2 | 0.1  | 0.1  | 2.1 | 9.6  | 100   |

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Thus, it was confirmed that the increased Al content had more resistance to the pitting corrosion and in case of Zr addition, Zr ion played a role of suppressing the activity of Cl<sup>-</sup>, which increased passive potential.

## IV. CONCLUSION

The corrosion properties of 2013 Al depending on the amount of Zr content was analyzed in this study, and the conclusions are as follows

1. The size of the crystal grains was refined according to the amount of Zr addition.
2. It was confirmed that lattice constant increased microscopically by the addition of Zr, which resulted in the decrease of microhardness.
3. The current density lowered in accordance with the amount of Zr addition, which increased the corrosion resistance.

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