

## INTERGRANULAR CORROSION OF AA 5083 - H321 ALUMINUM ALLOY

Petru MOLDOVAN<sup>1</sup>, Carmen Nicoleta STANICA<sup>2</sup>, Gilbert CIOBANU<sup>2</sup>, Ionel  
UNGUREANU<sup>2</sup>, George Manuel IORGA<sup>2</sup>, Mihai BUȚU<sup>1</sup>

*The 5083 alloy H321 temper is one of the most common alloy used in marine environments due to intergranular corrosion resistance in seawater.*

*When the local concentration of Mg is high enough, beta ( $\beta$ ) phase ( $Al_3Mg_2$ ) forms in order to lower the stored energy in the material. The  $\beta$  phase is anodic to the matrix of alloy in seawater and this potential difference provides the driving force for dissolution of the  $\beta$  from the grain boundaries causing intergranular corrosion (IGC).*

*Influence of rolling and annealing parameters on the intergranular corrosion was studied by ASTM G67 Standard Test-Nitric Acid Mass Loss (NAMLT), using optical microscopy (OM), scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy.*

*Results show an increase of the amount of the  $Al_xFe_yMn_z$  and  $Al_3Mg_2$  particles along the grain boundary when the annealing temperature is maintained at 260°C and at slow cooling, seeing a high resistance to intergranular corrosion.*

**Keywords:** 5083 aluminum alloy, heat treatment, microstructure, intergranular corrosion

### 1. Introduction

The aluminum alloy AA 5083 exhibits favorable resistance to corrosion and welding characteristics, making it attractive for application in the marine environment as well as for structural components in transportation and military applications [1, 2].

The ability to detect  $\beta$  phase in commercial alloy in the field is therefore of great interest in order to find material that may be susceptible to IGC (intergranular corrosion).

Intergranular Corrosion (IGC) is preferential attack of either grain boundaries or areas immediately adjacent to grain boundaries in the material exposed to the corrosive environment but with little corrosion of the grains themselves. *Intergranular corrosion* is also known as *intergranular attack* (IGA). *End-grain attack*, *grain dropping*, and “*sugaring*” are additional terms that are sometimes used to describe IGC [3].

<sup>1</sup> University POLITEHNICA of Bucharest, Romania, e-mail: mihaibutu@yahoo.com

<sup>2</sup> S.C. ALRO S.A., 116 Pitesti Street, Slatina 230104, Romania

Most alloys are susceptible to IGA when exposed to specific environments. This is because grain boundaries are sites for precipitation and segregation, which make them chemically and physically different from the grains themselves. Intergranular attack is defined as the selective dissolution of grain boundaries or closely adjacent regions without appreciable attack of the grains themselves.

This is caused by potential differences between the grain-boundary region and any precipitates, intermetallic phases, or impurities at the grain boundaries form. The current mechanism and degree of attack differs for each alloy system.

Precipitates that form as a result of the exposure of metals at elevated temperatures (for example, during production, fabrication, heat treatment, and welding) often nucleate and grow preferentially at grain boundaries.

5xxx aluminum alloys with above 3wt% magnesium (Mg) are susceptible to thermal instability. At relatively low temperature ( $\sim 70^{\circ}\text{C}$ ) over long periods of time (10-20 years), the Mg diffuses to grain boundary regions. When the local concentration of Mg is high enough, beta ( $\beta$ ) phase ( $\text{Al}_3\text{Mg}_2$ ) forms in order to lower the stored energy in the material [5]. In the 5xxx aluminum alloys, intermetallic precipitates such as  $\text{Al}_3\text{Mg}_2$  (anodic) are attacked when they form a continuous phase in the grain boundary. During exposures to chloride solutions, the galvanic couples formed between these precipitates and the alloy matrix can lead to severe intergranular attack. Current susceptibility to intergranular attack and degree of corrosion depends on the corrosive environment and on the extent of intergranular precipitation, which is a function of alloy composition, fabrication, and heat treatment parameters.

The current standard for detecting the degree of sensation in these materials is the ASTM G67 Nitric Acid Mass Loss Test. The precipitation of the second phase in the grain boundaries also gives rise to intergranular corrosion when the material is exposed to chloride-containing natural environments, such as seacoast atmospheres or seawater [6].

When the second phase is precipitated in a continuous network along grain boundaries, the preferential attack of the network causes whole grains to drop out of the specimens. Such dropping out causes relatively large mass losses of the order of 25 to 75  $\text{mg}/\text{cm}^2$  (3.9 - 12  $\text{mg}/\text{in}^2$ ), whereas specimens of materials resistant to IGC lose only about 1 to 15  $\text{mg}/\text{cm}^2$  (0.2 - 2.3  $\text{mg}/\text{in}^2$ ). Intermediate mass losses occur when the precipitate is randomly distributed [4].

The purpose of this paper was to highlight how influence the amount of magnesium and heat treatment appearance of Intergranular Corrosion, and to preventively, controlled annealing and cooling (H321).

## 2. Experimental procedure

The slabs were cast on Wagstaff installation at S.C. ALRO S.A. Slatina (Romania), scalped 15 mm each side, heated at  $520^{\circ}\text{C} \pm 10^{\circ}\text{C}$  at least 4 hours, hot rolled (ingot lay down temperature =  $520^{\circ}\text{C}$ ), annealed at  $250^{\circ}\text{C}$  (one hour) and at  $260^{\circ}\text{C}$  (one hour and three hours). All samples were slow cooled at  $50^{\circ}\text{C}/\text{hour}$  and stretched 1,5-3%, having the final thickness of 25 mm.

The chemical composition (specification) is according to the Table 1.

Table 1

**AA5083-H321, Specification composition – ISO AlMg4.5Mn (wt%)**

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Na	Al
min	-	-	-	0.50	4.30	0.07	-	-	bal.
max	0.40	0.40	0.10	0.90	4.90	0.20	0.25	< 4ppm	bal.

Sample material from five different batches was cut into 50 mm (parallel to the direction of the product) by 6 mm by product thickness. The nominal composition of samples, determined by spectrometry, is given in Table 2.

Table 2

**The nominal composition of AA5083–H321 (wt%)**

Sample	Si	Fe	Cu	Mn	Mg	Cr	Zn	Na	Al
1	0.12	0.20	0.026	0.60	4.50	0.098	0.020	0.0003	bal.
2	0.19	0.23	0.018	0.55	4.60	0.100	0.020	0.0003	bal.
3	0.11	0.18	0.022	0.53	4.65	0.086	0.017	0.0003	bal.
4	0.09	0.17	0.011	0.56	4.70	0.092	0.017	0.0002	bal.
5	0.09	0.18	0.012	0.56	4.70	0.092	0.017	0.0002	bal.

The specimens used for studying the IGC susceptibility were prepared in accordance With ASTM G67. This method consists of immersing test specimens in concentrated  $\text{HNO}_3$  (71%) at  $30^{\circ}\text{C}$  for 24 h and determining the mass loss per unit area of exposed surfaces as the measure of intergranular susceptibility.

Samples 1 and 2 were annealed at  $250^{\circ}\text{C}$  (one hour) and cooled slowly to  $50^{\circ}\text{C}/\text{hour}$ . Sample 3 was annealed at  $260^{\circ}\text{C}$  (one hour) and cooled slowly to  $50^{\circ}\text{C}/\text{hour}$ . Samples 4 and 5 were annealed at  $260^{\circ}\text{C}$  (three hours) and cooled slowly to  $50^{\circ}\text{C}/\text{hour}$ . Sample mass was measured at the end of each test and the mass loss was calculated.

Mass loss obtained for each sample is given in Table 3.

Table 3

**The sample mass loss after intergranular corrosion test**

Sample	1	2	3	4	5
Mass loss ( $\text{mg}/\text{cm}^2$ )	2.65	6.18	10.35	15.75	25.67

### 3. Results

Microstructures of samples analyzed from samples 1 and 2 shows minor pitting (Fig. 1) and pitting and pit-blistering (Fig. 3). Figs. 2 and 4 shows discontinuous grain boundary precipitation.

Microstructure of sample analyzed from sample 3 shows pitting and pit-blistering (Fig. 5). Fig. 6 shows a few semicontinuous grain boundary is precipitates. Microstructures of samples 4 and 5 shows intergranular corrosion (Fig. 7 and Fig. 9). Fig. 8 shows that more of 70% of the grain boundary is continuous. Fig. 10 shows continuous grain boundary precipitation.

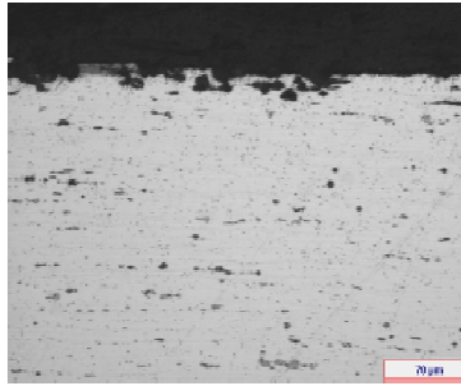


Fig. 1. Sample 1 - Pitting, 200X

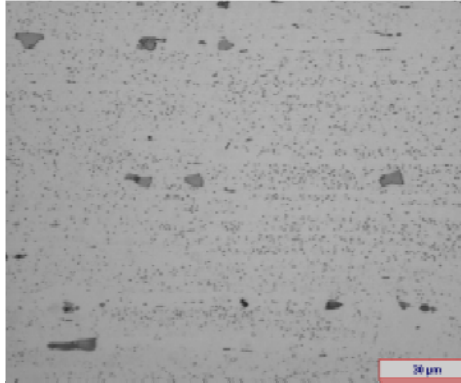


Fig. 2. Sample 1 - Discontinuous grain boundary precipitates, 500X

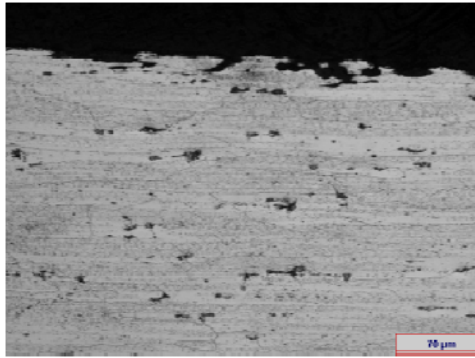


Fig. 3. Sample 2 - Pitting and Pit-blistering, 200X

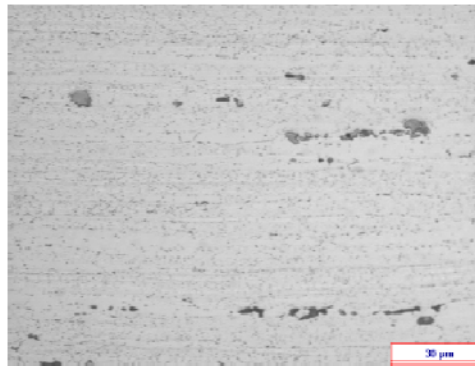


Fig. 4. Sample 2 - Discontinuous grain boundary precipitates, 500X

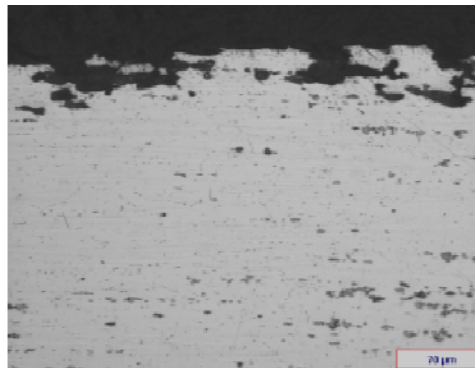


Fig. 5. Sample 3 - Pitting and Pit-blistering, 200X



Fig. 6. Sample 3 - Few semicontinuous grain boundary precipitates, 500X

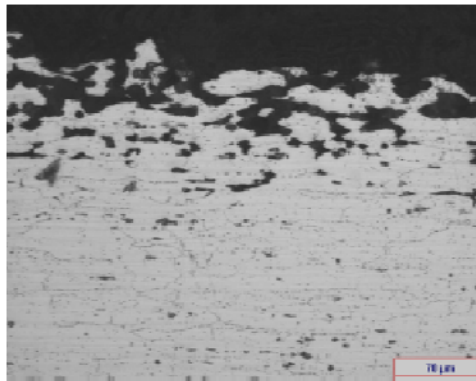


Fig. 7. Sample 4 - Intergranular corrosion, 200X

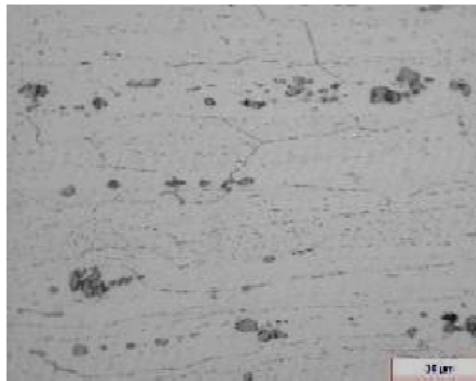


Fig. 8. Sample 4 - Semicontinuous grain boundary precipitates, 500X

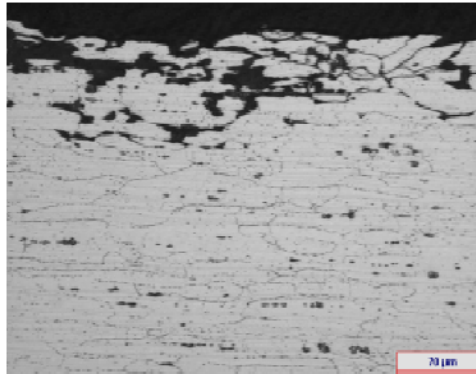


Fig. 9. Sample 5 - Intergranular corrosion, 200X

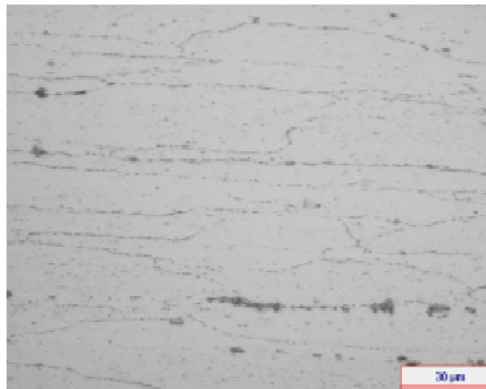


Fig. 10. Sample 5 - Continuous grain boundary precipitates, 500X

The microstructural features of AA5083-H321 alloy such as intermetallic phases were studied using scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy.

Fig. 11 shows a typical SEM micrograph of the sample 1 and sample 2. Figs. 12 (a, b) shows typical EDS spectra of the particles.

Fig. 13 shows a typical SEM micrograph of the sample 3 and sample 4. Figs. 14 (a, b) shows typical EDS spectra of the particles.

Fig. 15 shows a typical SEM micrograph of the sample 5. Figs. 16 (a, b) shows typical EDS spectra of the particles.

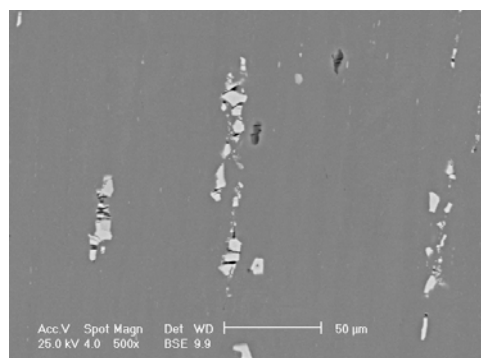


Fig. 11. Typical SEM micrograph of samples 1 and 2

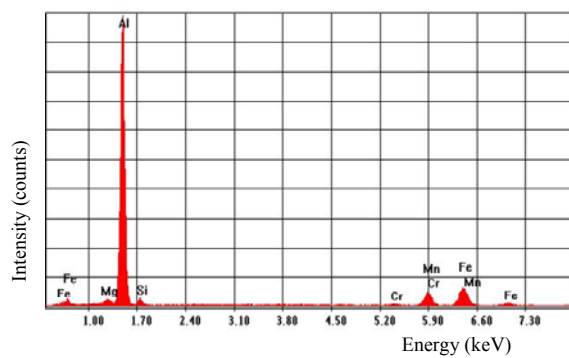


Fig. 12a. EDS spectra of grey particles shown in Fig.11

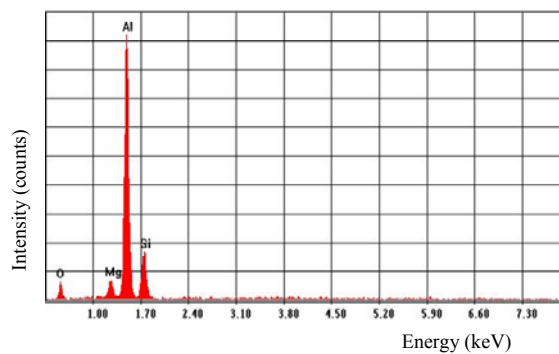


Fig. 12b. EDS spectra of dark particles shown in Fig.11



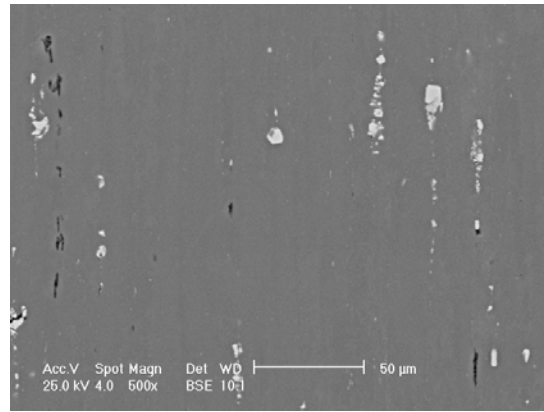


Fig. 13. Typical SEM micrograph of samples 3 and 4

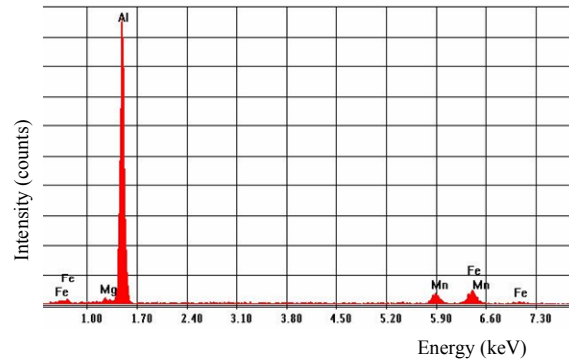


Fig. 14a. EDS spectra of grey particles shown in Fig.13

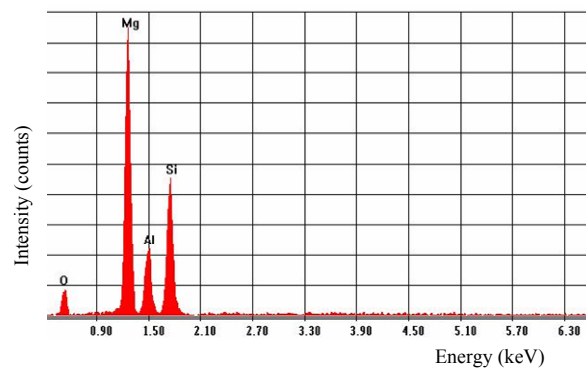


Fig. 14b. EDS spectra of dark particles shown in Fig.13

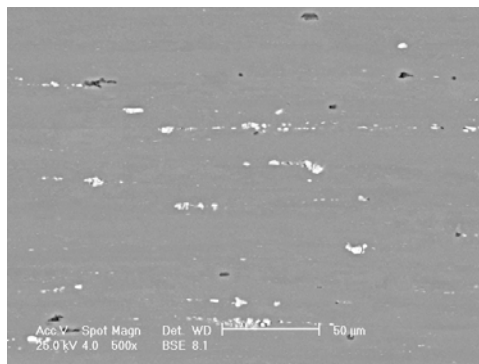


Fig. 15. Typical SEM micrograph of sample 5

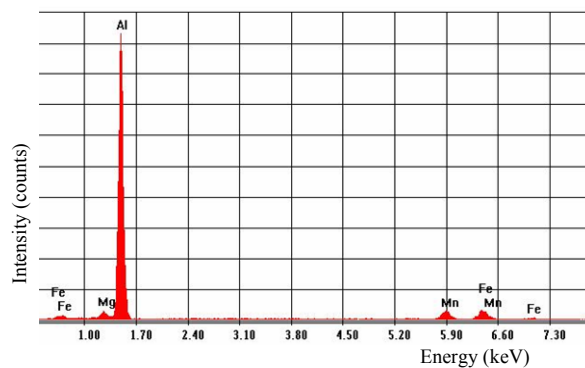


Fig. 16a. EDS spectra of grey particles shown in Fig.15

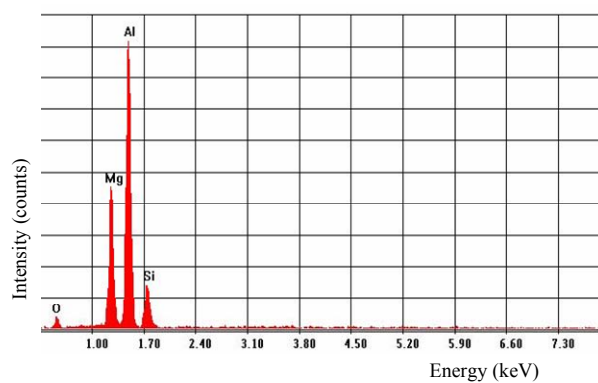


Fig. 16b. EDS spectra of dark particles shown in Fig.15

Tables 4 and 5 shows representative results of the quantitative EDS microanalysis.

Table 4

**EDS point analysis of the grey particles, wt.%**

Sample	Mg	Al	Si	Mn	Fe	Cr
1-2	1.70	71.61	3.92	8.80	13.45	0.52
3-4	1.75	78.99	-	8.35	10.91	-
5	2.64	81.42	-	7.46	8.48	-

Table 5

**EDS point analysis of the black particles, wt.%**

Sample	Mg	Al	Si	O
1-2	4.48	53.22	24.27	18.03
3-4	34.46	15.55	32.15	17.84
5	18.75	54.33	17.57	9.35

Several researches [5] have studied the IGC susceptibility of AA-5083 alloy and the general consensus is that it is caused by preferential precipitation of magnesium-rich particles, the  $\beta$  phase ( $\text{Al}_3\text{Mg}_2$ ), along the grain boundaries. The results obtained in our experiments show an increase of the amount of the intermetallic particles ( $\text{Al}_x\text{Fe}_y\text{Mn}_z$  and  $\text{Al}_3\text{Mg}_2$ ) along the grain boundary (sample 5) for the annealing temperatures of 250-260°C range and 1 - 3 hours.

#### 4. Conclusions

1. A correct correlation between warm rolling and annealing is critical to obtain a suitable microstructure of AA5083 alloys. Annealing at temperatures range of 250-260°C creates a “homogeneous” structure.
2. Slow cooling favors the formation of discontinuous intermetallic particles ( $\text{Al}_x\text{Fe}_y\text{Mn}_z$  and  $\text{Al}_3\text{Mg}_2$ ) along boundaries ensuring a high resistance to intergranular corrosion (IGC).

#### REFERENCES

- [1] *Carmen Stănică, P. Moldovan, Gh. Dobra, G. Popescu, M. Butu*, Microporosity Formation in DC Cast 5083 Alloys, *Light Metals* 2007, pp. 733-737.
- [2] *Carmen Stănică, P. Moldovan, G. Dobra, C. Stănescu, D. Bojin*, Influence of iron and manganese on structure and microporosity of the DC cast AA5083 alloy, *Light Metals*, 2009, pp. 823-826.
- [3] *B. Phull*, Evaluating Intergranular Corrosion, *Corrosion: Fundamentals, Testing, and Protection*, Vol 13A, ASM Handbook, ASM International, 2003, pp. 568–571.

- [4] *I. E. Bumiller, M. Shedd, B. Kezerooni, W. Adedeji, R. G. Kelly*, The Electrochemistry of Intergranular Corrosion in Sensitization in 5xxx Aluminum Alloys, 2009 DoD Corrosion Conference.
- [5] *M. Conserva, M. Leoni*, Met. Trans. A, Physical Metallurgy and Materials Science (Jan 1975), pp. 189.
- [6] ASTM G67, Standard Test method for Determining the Susceptibility to Intergranular Corrosion of 5XXX Series Aluminum Alloy by Mass Loss After Exposure to Nitric Acid (NAMLT Test)<sup>1</sup>.
- [7] *I. N. A. Oguocha, O. J. Adigun, S. Yannacopoulos*, Effect of sensitization heat treatment on properties of Al-Mg alloy AA5083-H116, J. Mater. Sci. (2008), 43, pp. 4208-4214.