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ORIGINAL PAPER

An Investigation of Composite Inclusion Corrosion Resistance Behavior of Thermally Liquid-Melt Inoculated Al-Mg-Si Alloy in Sodium Chloride Medium

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Abstract Inoculation enhances component performance in corrosive oxidizing environments and this provides appreciated protection in high temperature/stress applications. The corrosion enhancement of Al-Mg-Si alloy in 3.65 % NaCl solution with varying concentrations of titanium composite and minor addition of Sn has been studied using linear potentiodynamic polarization. The mechanical property was examined using the micro-hardness technique. From the results all the alloyed samples exhibited lower decreases in corrosion rate with increases in hardness values as the percent of TiO_2 and SnO_2 increases up to 10 %wt in the Al-Mg-Si alloy as compared to the as-cast sample. Strengthening efficiencies of 78, 77 and 30 % were obtained at Al/10Ti-Sn, Al/10Ti and Al/5Ti, respectively. The optimum values were obtained at 10 wt%Ti-Sn. The increases in hardness values and corrosion resistance are attributed to the formation of coherent and uniform precipitation in the metallic lattice. These results show that improved corrosion and mechanical properties are achievable by subjecting the cast Al-Mg-Si alloy to inoculation.

Keywords Inoculation efficiency · Al-Mg-Si · Corrosion resistance

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1 Introduction

The widespread importance of aluminum alloys is enormous due to the outstanding properties. As-cast Al-Mg-Si alloys have been extensively used in marine, automotive, and aircraft production because of their characteristics [1–10]. Among these excellent features are good strengthening behavior, noble corrosion resistance, good extrusion properties and fair cost placement [10–16]. The pitting characteristics of Al-Mg-Si alloy are generally affected by chloride and acidic ions leading to the breakdown in protective films [17, 21]. The strengthening properties of an alloy are often modified by inoculation of an alloy element and modifiers [17–19].

In contrast to information that are extensively available on the reinforcement of alloys with some alloying elements [1, 7–9]. Relatively efforts toward identifying new behavior of composites especially titanium and tin for process development and corrosion resistance are very few. In view of this, our previous study [17], we carefully consider the refiner of nickel in the liquid aluminum melt and the modification corrosion mechanism in 3.65 % NaCl. In this work, the objective is to evaluate the potential of composite dispersive characteristic of Al-Mg-Si/TiO_2-SnO_2 with a view to obtaining improved properties trend of strengthening process that would help to obtain the desired corrosion and mechanical properties.

2 Experimental Procedure

2.1 Materials and Sample Preparation

The substrate used in this work is Al-Mg-Si alloy which was obtained from an aluminum rolling mill in Nigeria with

Table 1 Chemical analysis of the produced Al-Mg-Si Alloy

Element	Al	Si	Mg	Fe	Cu	Mn	Ti	Cr
Composition (wt%)	Balance	0.45	0.50	0.22	0.03	0.03	0.02	0.03

Table 2 Processing method and designation of samples

Sample	Admix
Blank	0
1	5 % TiO_2
2	10 % TiO_2
3	10 % TiO_2 + 10 % SnO_2

chemical compositions as shown in Table 1. All chemical and composite powders used in this work are of analar grade obtained from MERCK and SMM chemical laboratory South Africa. Melt Al-Mg-Si alloy was inoculated in liquid cast-metallurgy of about (50 mm in diameter and 100 mm long). The prepared 3000 kg Al in an ingot form in a crucible was liquefied in an electric furnace under a protective nitrogen census environment. At optimum temperature of 700 °C, elemental TiO_2.SnO_2 particles were inserted into the melt based on the procedure found in Table 2 with varying concentration and stirred systematically. The process was allowed for about 2-3 minutes for proper admixture and precipitation during which the temperature was sustained for super heating to occur. The processed liquid melts were then poured into a permanent cast iron mould pre-heated to about 200 °C. The working materials were pure Al (95 wt%) TiO_2 (99.98 wt%) and SnO_2 (99.97 wt%). Inoculated Al-Mg-Si alloy portions were sectioned using a Struec cutting machine to dimension 20 ×10 mm using a linear potentiodynamic polarization method. The procedure of alloy progression, conditioning and solidification in the melt medium is specified in Table 2.

2.2 Electrochemical Studies

The electrochemical studies were performed with an Autolab PGSTAT 101 Metrohm potentiostat using a three-electrode cell assembly in a 3.65 % NaCl static solution at 40 °C. The developed alloy was the working electrode, platinum electrode was used as counter electrode and Ag/AgCl was used as reference electrode. The anodic and cathodic polarization curves were recorded at a constant scan rate of 0.003 V/s which was fixed from ±1.5 mV. From the Tafel corrosion analysis, the corrosion rate, potential and linear polarization resistances were obtained.

2.3 Hardness Study

The alloy samples were determined according to Dura scan Emco test standard using Fm Series with digital display micro hardness tester. The indentations were taken along the surface of the alloyed sample using a load of 100 g for 10 s dwell time. The microhardness of the samples was determined with 20 μm spacing between corresponding indentations and average mean value recorded for each sample under examination.

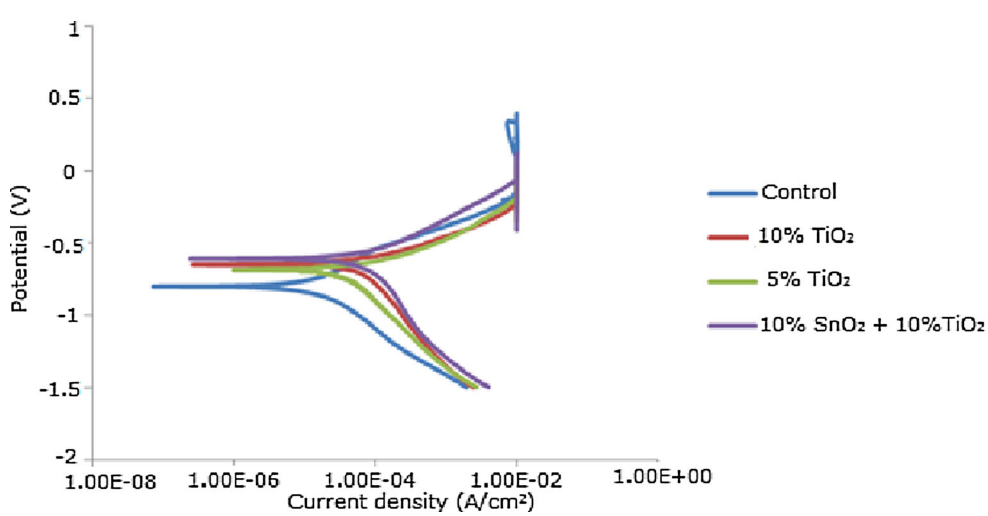

Fig. 1 Linear potentiodynamic polarization curves for as-cast Al-Mg-Si alloy inoculated Al-Mg-Si alloy in 3.65 % NaCl solution

Table 3 Potentiodynamic polarization data obtained from Tafel plot for as-cast Al-Mg-Si and alloyed Al-Mg-Si samples

Samples	ba (V/dec)	bc (V/dec)	Ecorr, Obs (V)	jcorr (A/cm²)	CR (mm/y)	Rp (Ω)
Al/10 %Ti-Sn	0.03833	0.033974	-0.69251	1.44E-06	0.001913	5449.7
Al/10 %Ti	0.053398	0.039093	-0.79953	1.88E-06	0.002503	5218.8
Al/5 %Ti	0.024302	0.041977	-0.68609	4.10E-06	0.005451	1522.2
Al/0 %Ti	0.058467	0.009311	-0.85214	4.99E-06	0.00599	1164.8

3 Results and Discussion

3.1 Electrochemical Studies of the Composite Induced System

Figure 1 shows the linear potentiodynamic polarization curves of all the admixed samples. The effects of different concentration of TiO_2 additive and minor addition of Sn on cast Al-Mg-Si alloy are seen from the potential/current trend. Convectional cast Al-Mg-Si alloy was used as a control to other alloy enhanced composite admixed melts. Obviously all particle inoculated admixed melts provide good active-passive behavior.

More so, the influence of trace Ti and that of Ti-Sn on Al has a great effect on the growth, nucleation and the passivation potential as observed in Fig. 1 and Table 2. This excellent behavior of all TiO_2 admixed in all concentrations described the perfect interaction, and the stability of this inoculant on the vacancies site. On the linear scan, the corrosion potential of the inoculated sample 5 % TiO_2 is -0.68609 V, 10 % TiO_2 is -0.79953 V, 10 % TiO_2 + 10 % SnO_2 is -0.6925 V while that of as-cast Al is -0.85214 V.

The best resistance polarization (Rp) value for the synergistic blend (10 %TiO_2-SnO_2) was 5449.7(Ω) compared to that of the as-received sample of 1164.8(Ω) as shown in Table 3. The increase in Rp suggested a positive improvement in the corrosion polarization resistance of the metal in the presence of the refiners. This indicates obviously that the aluminum matrix is protected. Subsequently, Ti/Sn admixture gives a positive influence of improve strength and corrosion stability. More so, the potential and the activities of each constituent at the solid solution might also be responsible for the stabilized potential.

3.2 Inoculation Efficiency and Mechanism

Figure 2 presents the comparative evaluation of inoculation efficiency with important parameters such as polarization-corrosion density (PP-Icorr), potentiodynamic polarization-corrosion rate (PP-CR), and potentiodynamic linear polarization resistance (LPR) as used by [2, 3]. From the comparative examination, it was apparent that the inoculant efficiency from all processes agreed; this proving that refiner potential shows maximally on Al-Mg-Si matrix in sodium chloride. In general, the perfect and improved characteristic of the inoculated sample from the corrosion resistance behavior studied can be traced to the balance conditioning properties between the control alloy and the harnessed inoculant which is believed to provide a suitable intermediate [14, 17].

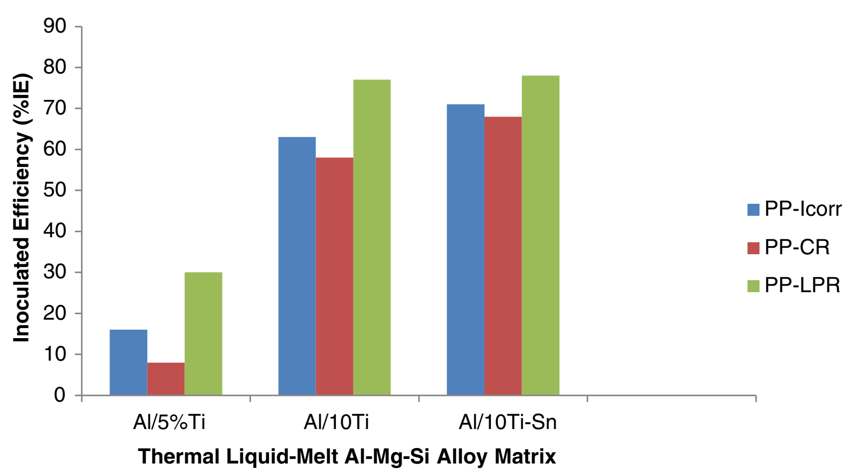

Fig. 2 Inoculatory efficiency (IE) blend for Al/5 %Ti, Al/10 %Ti and Al/10 %Ti-Sn concentration obtained from potentiodynamic polarization-corrosion rate (PP-CR), potentiodynamic polarization-corrosion current (PP-Icorr), and linear polarization resistance (LPR)

Particles of Ti will facilitate grain refinement and improved strength compatibility which is expected of the composite of titanium. The serviceability of material which is alloyed is quantified to a huge extent by the conditioning addition and the metallurgical processes engaged [17]. Also, it has been shown to, that refiners added to a melt cumulate to the structural modifications resulting to the establishment of intermetallic complex compounds [1, 14]. In view of this, the possibility and probability of a solid bound alloy phase system of Ti/Sn matrix formation of complex intermetallic compounds with Al-Mg-Si provide the satisfactory sites for the nucleation which is responsible for the corrosion resistance.

3.3 Effect of Inoculant on Hardness Behaviour of Samples

The microhardness (HVN) value of the Al-XTiO_2.Sn alloy for each sample at different concentrations of composite condition was measured. Figure 3 shows the average microhardness profile for the matrix. Hardness increased from 42.56 HVN for base Al to approximately 65.5 HVN for Al-XTiO_2.SnO_2 about 23.04HVN significant improvements. This trend follows in all incorporated samples of TiO_2 and SnO_2 at their various percentages.

The variation of microhardness as a function of distance from the substrate interface was examined and the average mean of all conditioned samples were examined. The tremendous improvement in hardness especially in the binary conditioned composite was attributed to the formation of Ti and Sn stable properties [16–18]. Attest that the particles have the affinity to form solid precipitates, Interfacial diffusion which might result to fine-grained structure of the conditioned alloys and the dispersed particles in the fine-grained matrix may obstruct the easy movement of dislocations, to give a higher hardness value.

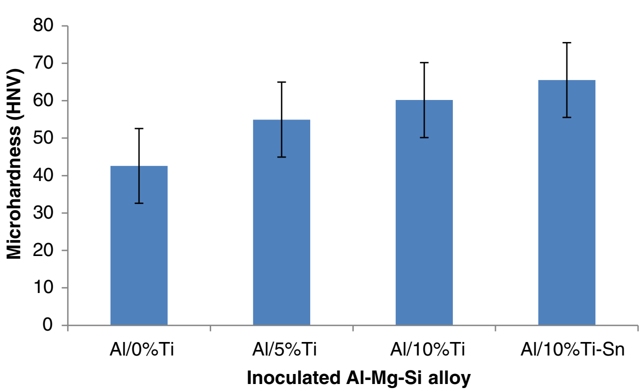

Fig. 3 Variation of hardness behavior on as-received and conditioned materials

4 Conclusion

- TiO_2.Sn has been found to be a good modifier for Al-Mg-Si alloy in sodium chloride solution
- The introduction of TiO_2.Sn of varying concentration causes a significant decrease in corrosion rate as compared to the conventional as-received alloy.
- The microhardness behavior of the inoculated alloy improved with over 70 % hardness value in all admixed samples. The conditioning properties of the alloy obstruct the easy movement of dislocations and hence improve the hardness property.
- The inoculated efficiency (%IE) of all Al-Mg-Si matrixes in the presence of composite increased compared to the control cast product.

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