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Effects of Sb Addition on Microstructure and Mechanical Properties of Heat-Treated Recycled Al-Si-Mg Alloy

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Short Research Article

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ABSTRACT

The uses of cast aluminum alloys in automotive and aerospace applications are growing rapidly because of the need to reduce weight and improve the efficiency of the engine as whole. The service life of aluminum cast component is determined by the size, form and distribution of microstructural features throughout the casting, especially in those regions that are critically stressed. The effects of antimony (Sb) additions on the microstructure and mechanical properties of recycled heat-treated Al−10.55Si-4.95Mg alloy were investigated. The results show that Sb can effectively modify the eutectic silicon platelets depending on its geometry. However, modification in the eutectic Si platelets were observed with increase addition of Sb. Improved mechanical properties in the as-cast Al-alloy on tensile strength (121 N/mm^2) and yield strength (91.25 N/mm^2) were obtained at 7.50 wt. % Sb addition.

Keywords: Recycled aluminum alloys; antimony; microstructure; mechanical properties.

1. INTRODUCTION

The usage of aluminum and its alloys have increased in many applications and industries over the decades. The automotive industry is the largest market for aluminum castings and cast products. Aluminum is widely used in other applications such as aerospace, marine

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engineering and building constructions. Parts of small appliances, hand tools and other machinery make use of thousands of different aluminum castings [1-5]. The applications grow as industry seeks new ways to save weight and improve performance.

However, one critical importance in achieving sound quality and reliable products is to focus on quality factors such as melt treatment, degasing and treatment of molten metals with modifiers to reduce or eliminate defects and improve the mechanical properties [6,7]. Cast alloy properties are greatly influenced by melt treatment, casting technique, solidification mode and microstructure. Solidification is the stage at which the microstructure is formed [8-10]. Segregation and hot tearing are among the kind of defects that can occur during solidification. Various kinds of defects are formed at the melting stage and during the handling of the melts in a casting process. Undoubtedly, any defect present or created at the melting stage could be carried to the final microstructure (unless filters) and will, of course, affect the life components of the end products [11-13]. Therefore, it is apparent that the control of the quality of the product begins with the control of the melt.

The effect of Sb additions (0, 0.2 mass%) and cooling rates ($0.56°C·s^{-1}$, $2.03°C·s^{-1}$, $7.42°C·s^{-1}$) on the Al–Si eutectic of hypoeutectic Al–Si alloys were investigated by Yan et al. [14]. The results show that Sb combines with Mg to form a compound Mg_3Sb_2 which poisoned the nucleation particle resulting in increased nucleation undercooling of the eutectic silicon.

Similarly, the influence of separate additions of Bi, Sb and Sr on microstructure, thermal and machinability of Al-11%Si-2%Cu alloy (ADC12) was reported by Marani et al. [15]. They found that the additives depressed the Al-Si eutectic growth temperature and altered the Si morphology.

In addition, the effects of Sb in ZA-27 alloy (Zn-27wt% Al) on its mechanical properties, friction and wear behaviour, ageing and underside shrinkage was investigated by Haoran and Jiaji [16]. Their study shows that Sb has a tendency to accelerate intergranular corrosion of ZA-27 alloy. Microscopic examination indicated that Sb forms a multi-component compound with zinc and aluminum.

In addition, Fatahalla et al. [17] studied the effect of microstructure on the mechanical properties and fracture of commercial hypoeutectic Al-Si alloy modified with Na, Sb and Sr. Yan et al. [18] examined the effect of Sb addition on the hypoeutectic Al–Si cast alloys under different cooling rates while Guo et al. [19] studied the effect of modification with different contents of Sb and Sr on the thermal conductivity of hypoeutectic Al-Si Alloy.

Moreover, the use of design of experiment (DOE) is to collect the maximum amount of relevant information with minimum expenditure of time and resources. It was reported that any aspect of DOE adopted for study should be made simple and possibly be consistence with the requirements of the problem at hand. To minimize the volume of less important constituents especially, the number of experimental runs and maximizes the main important ones (major and minor alloying elements), D-optimal method of DOE was adopted.

2. EXPERIMENT STUDY

As-cast Al-Si alloys produced by conventional processes of melting, pouring and solidification, without post-process consists of coarse flakes of Si platelets that promote brittleness within these alloys. In this study, effects of antimony (Sb) addition on microstructure and mechanical properties of heat-treated recycled Al-Si-Mg alloy was investigated.

50 kg of aluminum scraps purchased form scrap yard were sorted to remove heavy metals. The scraps were socked in liquid detergent to remove dirt, oil and some organic solvent before charging into the furnace. This was done to avoid air pollution during the melting operation. The formation and distribution of silicon platelets and other defects in the samples prepared were revealed using scanning electron microscope. All of these techniques contribute to the information presented. The scraps were firstly melted in 70 kg capacity electric resistance furnace in a crucible and the molten alloy was poured in sand mold. This was done to achieve reliable results, because the aluminum scraps used were obtained from discarded tricycle pistons, engine cover and radiator.

Granulated solid antimony (Sb) used in this work was procured from the Federal Institute of Industrial Research, Oshodi, Lagos, Nigeria. To ensure homogeneous mixing of the scrap, the molten metal was treated with hexachloroethane (C_2Cl_6) solid degasser and stirred gently for 5 minutes. Dross was removed after successful degassing of the molten alloy. Thus, 4.925 kg of recycled Al-alloy was obtained in ingot form.

In addition, varying percentage of ingots was weight and treated with 3.75, 7.50, 11.25 and 15.00 wt. % of Sb as given in Table 1. Sb was added to the molten meal at temperature 700 ± 5 °C, held and stirred for 5 minutes prior to casting. The mixture was cast into prepared green sand molds and normalized. Samples with dimensions 20 mm diameter by 200 mm were cast. To achieve good and reliable results, the same experimental procedure was observed throughout the melting and casting process.

Similarly, the heat treatment process was carried out in an electric muffle furnace-vecstar 232 model with temperature rating of 2200 ºC. The prepared samples were heat treated at 350 ºC for 5 hour and annealed. The morphology of eutectic silicon particles in the as-cast and heat treated alloy samples were examined using scanning electron microscope.

3. MECHANICAL TESTING

Before carrying out the tests, samples were grounded with emery papers of progressively fine grade 220, 320, 400 and 600 i.e from coarse grade to fine grade. The grinding process was done under running water to wash away the grits and to avoid overheating. Samples were later polishing with selvyte cloth swamped with solution of 0.5 micro-meter silicon carbide until a mirror-like surface was achieved and etched in 2% sodium hydroxide solution (NaOH) for 5 - 10 seconds to reveal the internal structure. The samples were then washed, dried and later viewed under the optical microscope

Hardness of the heat-treated samples were carried out using Brinell hardness test machine. The specimens were brought in contact with the steel ball indenter at applied load of 200 kg and allowed to rest for a dwell time of 15 s. After the load is released, the diameter of the impression produced is measured by means of a microscope fitted with a scale having least count of 0.05 mm. Following the ASTM E10-18, average Brinell Hardness values (BHN) were obtained by taking three hardness readings at different positions on each sample. The Brinell hardness number (HBN) which is the ratio of the load in "kg" to the impressed area in square millimeters, as is calculated by relation:

$$\mathrm{HB} = \frac{2\mathrm{P}}{\pi\mathrm{D}/2\left(\mathrm{D} - \sqrt{\mathrm{D}^2 - \mathrm{d}^2}\right)} \qquad (1)$$

Where, P = test load (kg), D = diameter of ball (mm) and d = diameter of impression (mm).

Tensile tests were carried out on the heat-treated specimens at room temperature using Mosanto Tensometer testing machine. The test samples were machined to standard dimensions as shown in Fig. 1. Each of the specimens was loaded at a strain rate of 4 $\times10^{-4}s^{-1}$ till fractured following the ASTM E8 standard. Five test bars for each alloy sample were examined, and the average values of ultimate tensile strength (UTS), 0.2% offset yield strength (YS), and percentage elongation to fracture (% El) were obtained.

In addition, the impact test was conducted in Charpy V-notch impact texting machine having 140° pendulum drop angle, pendulum weight of 22 kg, impact energy of 300 J at striking velocity of 5 m/s. The impact test bars were performed according to the ASTM E23 standard. A V-notch samples were machined into a bar with a square cross-section area of 10 ×10 mm^2 and a length of 50 mm.

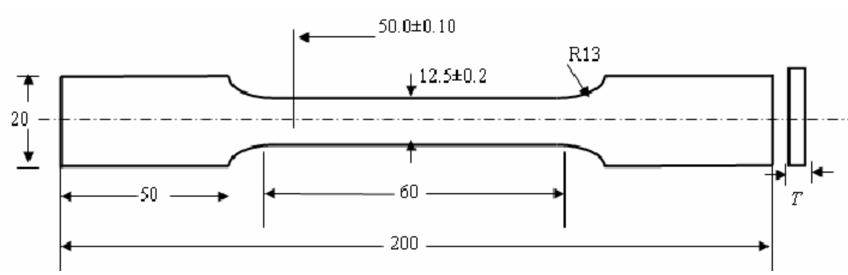


Fig. 1. Guage length for Tensile Test bar

4. RESULTS AND DISCUSSION

Presented in Table 1 is the result of experimental run and the responses obtained from the mechanical tests of the cast samples. As shown in Table 1, the variation of hardness, tensile, yield strength, impact strength, % elongation against the (wt. %) Sb was presented. Results obtained from the hardness test samples for each weight fraction of Sb shows that the hardness increases up to 15 wt. % addition of Sb. The tensile strength on the other hand increases up to 7.50 and decreases with increase wt. % addition of Sb. Similar phenomenon were observed for yield strength and % elongation respectively. The impact strength of the as-cast samples increases with increasing amount of Sb.

5. MICROSTRUCTURAL ANALYSIS

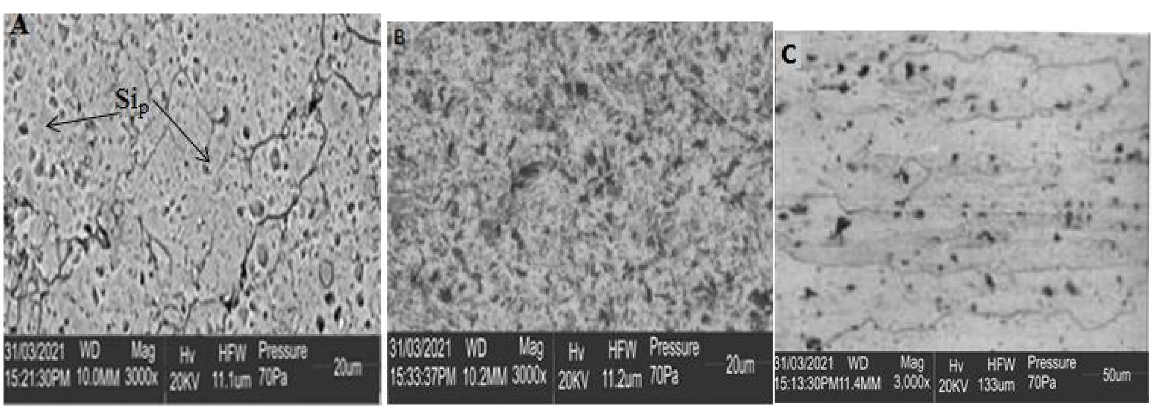
The results comprises of chemical composition of the untreated sample and as-cast samples treated with Sb. The changes in silicon platelets as observer within the micrographs at 3000X magnification were shown in Fig. 2 after modification and heat-treated at 350°C for 5 hours, while Table 2 shows the compositional analysis of each of the Al-alloy sample investigated.

The SEM images shown in Fig. 2(a) for untreated sample reveal the presence of coarse silicon platelets of different geometries. Little modification in the as-cast samples was noticed up to 7.5 wt. % Sb addition, Fig. (2b and 2c). The presence of intermetallic compounds was also observed within the micrographs. Fig. 2(c) shows the redistributed constituent of Si particles in the structure as a result of heat treatment. Consequently, treatment of the molten Al-alloy with Sb (wt. %) reduces the coarse silicon platelets into fine particles of regular geometries and pronounced modification phenomenon were observed up to 15 wt. % addition of Sb.

Fig. 3(b) shows the EDS of Al-alloy unmodified and sample treated with 15 wt. % Sb respectively.

Table 1. Experimental Results obtained from D-optimal Technique

	Constituents (wt. %)		Responses				
Experimental Run	**Al Alloy**	**Sb**	**Hardness BHN)**	**Tensile Stength (N/mm^2)**	**Yield Strength (N/mm^2)**	**Impact Strength (J)**	**Elongation (%)**
1	79.50	0.00	65.25	98.27	78.90	49.62	2.87
2	72.35	3.59	75.13	107.42	88.25	56.72	4.65
3	70.00	7.50	76.81	121.83	91.25	57.61	7.39
4	70.00	11.25	82.01	118.95	92.01	58.28	5.01
5	70.00	15.00	79.00	115.16	86.04	62.53	4.51



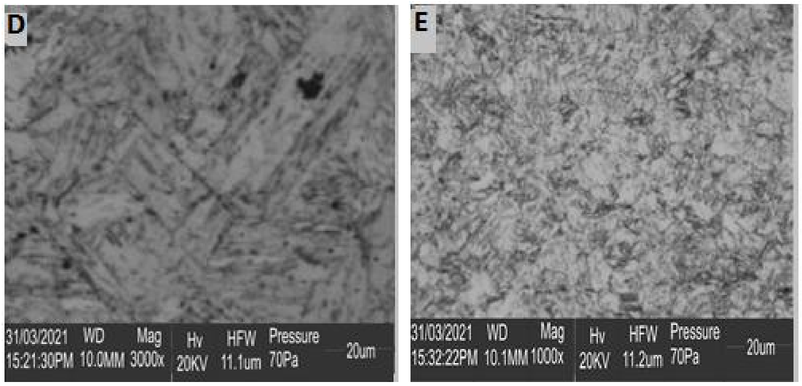


Fig. 2. SEM image of Cast Recycled Al-alloy Modified with (b) 3.75Sb, (c) 7.50Sb, (d) 11.25Sb and (e)15.00Sb, Heat-treated at 350 °C for 5 hours (3000X Magnification)

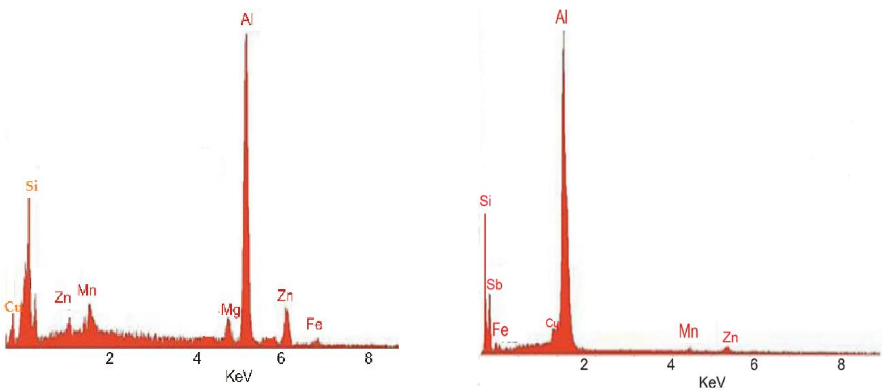


Fig. 3. Energy dispersive x-ray spectroscopy for samples (A and E)

Table 2. Chemical Composition of the As-Cast Al-Alloy (wt. %)

	Elemental (wt. %)			Samples	
Composition	Al-Si-Cu	Al-3.75Sb	Al-7.50Sb	Al-11.25Sb	Al-15.00Sb
Al	76.820	75.920	80.550	79.040	74.430
Si	10.550	10.420	9.310	9.040	9.011
Mn	0.491	<0.491	<0.401	<0.461	<0.441
Mg	4.951	4.851	3.846	3.832	3.801
Cu	3.278	3.278	3.361	3.368	3.365
Fe	1.310	1.220	0.950	0.950	0.950
Ni	0.421	0.421	0.421	0.421	0.421
Cr	0.056	0.054	0.053	0.046	0.037
Zn	1.500	1.430	1.470	0.412	0.364
Sb	--------	2.610	5.370	8.160	12.910
Other	<0.357	<0.301	<0.270	<0.270	<0.270

6. CONCLUSION

Recycled Al-alloy has not completely satisfied material engineers' quest to meet the trends of Al-Si alloys functional requirements, due to as-cast mechanical properties limitations. This work was therefore, undertaking to study the effect of antimony as modifier on recycled aluminum alloy. It was observed that Sb modification combined with heat-treatment improve the coarse silicon platelets into fine particles of varying geometries. However, the effect of antimony on mechanical properties of aluminum alloy yield better improvement compared with unmodified sample.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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