

Investigation of Mechanical, Corrosion and Microstructural Behaviour of Heat Treated Cr-Modified Al-Mg-Si Alloy

Abstract

Despite the choice of Al-Mg-Si alloy as a material for innumerable industrial and structural applications, challenges such as undesired scratch resistance, formability and mechanical properties deterioration in saline environment hinders the extent of its application for automotive and aerospace components. Nevertheless, with the growing interest in the application of Al-Mg-Si alloy in automotive and aerospace industries, there is need for cautious control of thermal treatments and inclusion of alloying elements with requisite potentials for enhancing the microstructure and mechanical properties of the alloy. Chromium is known to improve strength and corrosion resistance in several applications. Therefore, this study focuses on the investigation of the effect of Cr particles inclusion in Al-Mg-Si alloy. The effect of ageing heat treatment on selected properties of Al-Mg-Si-Cr alloy was also studied in this work. The Al-Mg-Si and Al-Mg-Si-Cr alloys were developed using a two-step stir casting technique. Chromium was added to Al-Mg-Si alloy at varying percentages of 0, 0.5, 1.0, 1.5, 2.0 and 2.5. All the samples were solution treated in an electric furnace at 500 °C for 30 minutes and water quenched. Then the samples were artificially aged at 210 °C for 3 hours and quenched in natural air. The hardness test revealed that the inclusion of Cr particles in Al-Mg-Si alloy samples increased hardness from 35.03 Kgf/mm² (hardness of Al-Mg-Si-0%Cr alloy sample) to a maximum value of 126.54 Kgf/mm² (hardness of Al-Mg-Si-1.5%Cr alloy sample). After heat treatment, the hardness of Al-Mg-Si-0%Cr alloy sample increased to 80.84 Kgf/mm², while that of Al-Mg-Si-1.5%Cr alloy sample decreased slightly to 120.88 Kgf/mm². The impact strength test also showed that the inclusion of Cr in Al-Mg-Si alloy increased impact strength from 9.52 J/mm² (impact strength of Al-Mg-Si-0%Cr alloy sample) to a maximum value of 19.04 J/mm² (impact strength of Al-Mg-Si-2.0%Cr alloy sample). After heat treatment, the impact strength of Al-Mg-Si-0%Cr alloy sample increased marginally to 10.09 J/mm², while that of Al-Mg-Si-2.0%Cr alloy sample decreased slightly to 17.57 J/mm². The tensile and electrochemical tests revealed that the heat-treated Al-Mg-Si-1.0%Cr alloy sample exhibited the highest tensile strength and lowest corrosion rate of 152 MPa and 0.0014 mm/year, respectively. The microstructural examination further revealed that the inclusion of Cr particles in Al-Mg-Si alloy

improved its surface morphology. Al-Mg-Si-1.0%Cr alloy sample was adjudged to possess the best microstructural properties. Therefore, this sample is recommended as a potential material for machine tools and other structural or advanced manufacturing applications.

Keywords: Al-Mg-Si, Al-Mg-Si-Cr, Chromium, Mechanical properties, Microstructure and Corrosion rate

1. Introduction

Aluminium alloys are widely used in the automotive industry as an alternative material to steel. The attraction for Al alloys is due to their low density, recyclability, superior mechanical properties and good corrosion resistance [1-3]. The corrosion resistance property of Al alloys is as a result of the stability of the aluminium oxide layer formation on exposure to air [4-6]. Material designers have also shifted emphasis to the pursuit of low cost and high-performance characteristics materials like Al alloys, which are suitable for the products required [7, 8]. The scope of these materials is further expanded with the help of post-processing treatment and alloying elements, which combines the individual properties of those materials to create the desired products properties [9, 10]. Post-processing treatments such as heat treatment have played major roles in recent developments in this field since it promotes a general refinement of the microstructure and improves the physical properties of alloys [11-13]. Heat-treatment has also been reported to improve the strength of aluminium alloys through a process known as precipitation-hardening which occurs during the heating and cooling of the alloy, with the formation of precipitates matrix of the alloy [14-16]. Likewise, ageing heat treatment has been used for the improvement of the microstructure of aluminium alloys. Two different methods of ageing: artificial and natural ageing have been reported in many works of literature [17-19].

Moreso, microstructure and other properties of aluminium alloys have been improved through the addition of alloying elements such as Si, Mn, Cr, Cu, Zn, Sn, Ag, Fe, e.t.c [20-22]. For instance, some of these alloying elements have been included in Al-Mg-Si alloys by a good number of researchers to produce a selection of different materials that can be used in a wide assortment of structural applications [23-26]. Chromium was discovered to increase the low-temperature properties and enhanced the creep resistance of Al-Mg-Si alloys marginally [27, 28]. The study also revealed that Mn and Cr additions affect the kinetics of recrystallization and parameters of grain-boundary relaxation of Al-4.9Mg alloys. The Cr particles helps in preventing

recrystallization and grain growth, hence refining the grains [29]. Chromium has been used as alloy addition to AA6xxx alloys to control the grain structure by producing dispersoids that pin grains and limit grain growth. Hence, the mechanical properties of aluminium the alloys were improved [30]. Grain refinement plays a vital function in determining the significant characteristics of aluminium alloy products. It enhances plasticity and tensile intensities, increases feeding complex castings, and minimizes the possibility of hot tearing and porosity [31, 32].

Furthermore, chromium is a common addition to many alloys of the aluminium–magnesium series because it has a large effect on electrical resistivity. Chromium has a low diffusion rate and forms finely dispersed phases in wrought products. Extensive literature studies indicate that major work has been carried out on Al-Mg-Si-Cr alloy for many structural applications. The need to improve the properties and quality of aluminium alloy using simple foundry and conventional casting technique for the economic development of aluminium alloy instigates the need for this work. Al-Mg-Si alloy has been widely used for several industrial and structural applications [33-36]. However, due to a few challenges, it is rarely used for some advanced structural applications. The main aim of this work is to examine the effect of chromium addition on the mechanical, microstructural and corrosion properties of Al-Mg-Si alloy. This work further examined the effect of heat treatment on the mechanical, microstructural and corrosion characteristics of Al-Mg-Si-Cr alloys. Heat-treating the alloys containing the appropriate percentage of Cr particles was done and examined for potential machine tools applications.

2. Materials and Method

2.1. Alloy production

Aluminium scrap (mostly trophy beverage cans) was sourced and used as the base aluminium alloy. This decision was made to show that aluminium waste in our environment can be converted into a very good choice material for different kinds of engineering applications. Using optical emission spectroscopy, the approximate chemical compositions of the alloy are: 1.50% manganese (Mn), 0.70% iron (Fe), 0.20% copper (Cu), 0.05% magnesium (Mg), 0.60% silicon (Si), 0.10% zinc (Zn) and Al balance as the principal element. This characterization revealed that

the alloy is Al 3003 alloy. These are similar to those of authors Ref. [37]. The volume percentage by weight of magnesium and silicon was constant at 0.6% and 7%, respectively for all the samples. The mass of Al 3003 alloy was also constant at 500 g for all the samples. **The chemical composition of the experimental alloys is shown in Table 1, which indicated** that chromium was incorporated into Al-Mg-Si composite at levels of 0, 0.5, 1, 1.5, 2 and 2.5% using the two-step stir casting method (liquid metallurgy technique) to produce Al-Mg-Si-Cr alloy. The Aluminum 3005 alloys having 92.4, 91.9, 91.4, 90.9, 90.4, and 89.9 percent by weight, based on the charge calculations, were at first heated to 300 °C for 45 minutes to aid the alloy's wettability. The magnesium and chromium powder were preheated to 900 °C and silicon particles were also preheated to 1100 °C to further aid the alloy's wettability. Thereafter, the Al 3003 alloy particles were charged into a furnace at 780 °C, and allowed to dispel heat until the alloy was in a semi-solid form at about 600 °C. At the semi-solid stage of the Al 3003 alloy, preheated magnesium, silicon and chromium powder were introduced into the alloy, and manually stirred for 5-7 minutes.

Table 1: Chemical composition of the experimental alloys

Sample	Percentage of Al 3003 (%)	Weight of Mg (g)	Weight of Si (g)	Percentage of Cr (%)	Weight of Cr (g)
Al-Mg-Si-0%Cr	92.4	3.25	37.88	0	0
Al-Mg-Si-0.5%Cr	91.9	3.26	38.08	0.5	2.72
Al-Mg-Si-1.0%Cr	91.4	3.28	38.29	1.0	5.47
Al-Mg-Si-1.5%Cr	90.9	3.30	38.5	1.5	8.25
Al-Mg-Si-2.0%Cr	90.4	3.32	38.72	2.0	11.06
Al-Mg-Si-2.5%Cr	89.9	3.34	38.93	2.5	13.9

2.2. Heat treatment

The cast products of Al-Mg-Si and Al-Mg-Si-Cr alloys were made to undergo heat treatment. The heat treatment was carried in an electric furnace. All the samples were solution heat treated in an electric furnace at 500 °C for 30 minutes and were water quenched after which they were aged. T6 condition was applied to products that are solution heat-treated and then aged artificially. All the samples were aged artificially at 210 °C for 3 hours and then quenched in natural air.

2.3. Electrochemical test

A computer-controlled potentiostat, NOVA 2.1 was used for the electrochemical study. The analysis was performed using NOVA 2.1 electrochemical software and a three-electrode corrosion cell set up containing a counter electrode (CE), reference electrode (RE) and alloys as the working electrode (WE). The samples for the polarization test (WE) were cut out into 10 mm x10 mm and mounted on epoxy resin. The exposed surfaces of the samples were prepared by polishing them with emery cloths with increasing grit size from 60–1200. Afterwards, the CE, RE and the WE were connected, and thereafter inserted in an electrolyte (3.5 wt.% NaCl). Exposed surfaces area of 100 mm² was ensured for the samples in the electrolyte. Time was allowed for the samples to reach open circuit potential (OCP) in the test medium and was noted. Polarization was measured at a scan rate of 1mV/s at a potential initiated at –250 mV to +250 mV. The Tafel curves were plotted; the anodic and cathodic polarization curves of the Tafel were further extrapolated to obtain the values of corrosion current densities (j_{corr}) and corrosion potentials. The corresponding corrosion rates (CR) for the alloys were then determined using Equation 1 [38].

$$\text{CR (mm/yr)} = \frac{0.00327 \times \text{EW} \times j_{\text{corr}}}{\rho} \quad (1)$$

Where: j_{corr} (A/cm²) is the corrosion current density, EW (g) is the equivalent weight of the metal and ρ (g/cm³) is the density of the metal.

2.4. Mechanical tests

2.4.1. Brinell's hardness

Brinell's hardness test was used to determine the hardness of the metal surfaces. The hardness test was carried out following ASTM A29/A29M-15. For this test, the specimens of Al-Mg-Si and Al-Mg-Si-Cr alloys were cut to cylindrical shapes of length 30mm and diameter 8mm. The specimens were polished to remove the possible presence of defects. The specimens were then placed under a standard steel ball (indenter) of diameter 10 mm and the mercury gauge was set to zero as the reference point on the tester. The force of 225 kgf as indicated on the mercury gauge was applied on the specimens for about 15 seconds. The indentation diameters on the specimens were measured after the load and ball were removed. The Brinell hardness numbers of the samples were then calculated using Equation 2 [39].