EFFECT OF DOUBLE THERMAL AGEING TREATMENT ON THE HARDNESS AND CORROSION RESISTANCE OF Al- Cu- Si- Ni ALLOY IN NaCl SOLUTION

M. Abdulwahab¹, O. B. Umaru*², M.A. Bawa², S. M. Adams³, C. S. Ezema¹

¹Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, Nigeria
²Department of Mechanical/Production Engineering, Abubakar Tafawa Balewa University, Bauchi, Nigeria
³Department of Metallurgical and Materials Engineering, University of Nigeria, Nsukka
*Corresponding author email: buokatengwu@atbu.edu.ng

Abstract
This work investigated the Corrosion behavior and hardness characteristics of double thermally treated Al-Cu-Si-Ni alloy in NaCl solution. The alloy was produced using sand casting method, and sectioned into small pieces of 10mm long each. Some of the sectioned samples were subjected to single thermal ageing treatment (STAT) and used as control, while others were subjected to double thermal ageing treatment (DTAT). The thermally treated samples were used for corrosion and hardness test in accordance with ASTM A370 and ASTM E8-08b. The result showed that the double thermally treated samples have higher hardness value than the single thermally treated samples as the ageing time increases with an increase of 24.6% at 2hrs. Equally, the corrosion resistance of the treated alloy improved with ageing time.

Keyword: Corrosion, Aluminium alloy, Pre-aged, ageing

1.0 Introduction
Aluminium exists in nature as an ore of bauxite, kaolinite, nepheline, which are processed to get the valuable aluminium. Pure aluminium is silvery white, non-magnetic, with melting point of 650 °C, has an FCC structure and a relatively low density (2.7g/cm³ as compared to 7.9g/cm³ for steel and 8.86g/cm³ for copper), high electrical and thermal conductivities and resistance to corrosion in some common environment such as atmosphere, water and salt water (NaCl) (Khanna, 1999). Aluminium is remarkable for the metal's low density and for its ability to resist corrosion due to the phenomenon of passivation. Structural components made from aluminium and its alloys are vital to the aerospace industry and are important in other areas of transportation and structural materials. The most useful compounds of aluminium, at least on a weight basis, are the oxides and sulphates (Callister, 2009). Aluminium forms strong chemical bonds with oxygen and as compared with most other metals, it is difficult to extract it from the ore, such as bauxite, due to the high reactivity of aluminium and high melting point of most of its ores. For example, direct reduction with carbon, as is used to produce iron, is not chemically possible because aluminium is a stronger reducing agent than carbon. Indirect carbothermic reduction can be carried out using carbon and Al₂O₃, which forms an intermediate Al₄C₃ and can further yield aluminium metal between the temperature ranges of 1900–2000°C. This process is still under development and requires less energy and CO₂ than the Hall-Héroult process. The extraction process require high electricity consumption and suitable in countries with abundant electricity supply (Callister, 2007). Aluminium has become one of the leading metals for both industrial and domestic use today due to its light weight, easy to work, pleasing appearance and other desirable properties (Umaru et al., 2016). Aluminium is normally alloyed unless when corrosion resistance and/or workability is more important than strength or hardness. The properties of aluminium are
improved when alloyed with elements such as copper (Cu), silicon (Si), nickel (Ni), magnesium (Mg), chromium (Cr), manganese (Mn), zinc (Zn), in the right amount (Abdulwahab et al., 2017; Umaru et al., 2017).

Aluminium alloys are the largest proportion of nonferrous alloys used in automotive components, material containers, and most especially in aircraft industries. The most vital aluminium system is Al-Cu, which is widely used in producing duralumin for making aircraft parts, due the fact that copper provides a basis for precipitation hardening alloy, by the formation of sub-microscopic particles of copper-aluminium (CuAl₂) (Umaru et al., 2016). Many different types of destructive attack can occur to marine structures, ships and other equipment used in sea water service. Year upon year the cost of marine corrosion has increased until it is estimated today at 4 % of the Gross National Product. Many ship superstructures and liquid cargo containers are made of aluminum due to its low weight and acceptable strength (Wan Nik et al., 2010). The successful development of aluminium castings in parts and components applications requires that the casting display a combination of high strength and toughness in thin and thick sections. These properties are strength and integrity of the microstructures. Therefore, the hardness and Marine corrosion is a perennial problem not only to moving vessel but also ports and anything kept in the sea or exposed to sea environment for a period of time. Corrosion is fundamental process which plays an important role in economics and safety. Apparently, corrosion cannot be avoided, but its severity can be reduced to a lower magnitude. The term aqueous corrosion describes the majority of the most troublesome problems encountered when metal material is in contact with sea water and various methods have been employed to reduce corrosion (Wan Nik et al., 2010). Despite various ways of evaluating corrosion resistance of metals/alloys, the weight loss method of investigating corrosion was used due to its simplicity and method of result computations. Since the service condition is a major factor in selection of the mechanical property to be tested for, hence other properties apart from corrosion have to be investigated and based on this fact, the hardness and corrosion behavior of double thermally aged Al-Cu-Si-Ni alloy was determined.

2.0 Methodology

Al-Cu-Si-Ni cast alloy with chemical composition as shown in table 1 below was produced in the Department of Metallurgical and Materials Engineering, Ahmadu Bello University, Zaria, following the method described in Abdulwahab (2007). The alloy was sectioned into thirty (30) coupons using hacksaw and a smooth surface was obtained by hand filing.

<table>
<thead>
<tr>
<th>Table 1: Chemical composition of as-received Al-Cu-Si-Ni alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composition</td>
</tr>
<tr>
<td>Amount (Wt. %)</td>
</tr>
</tbody>
</table>
Figure 1: Schematic diagram of double thermal ageing treatment (DTAT).

Six of the sectioned samples were subjected to single thermal ageing treatment (STAT) following the methods in Umaru et al. (2012), Abdulwahab et al. (2013) and Umaru et al. (2013) by heating to 510°C, held for 3hrs, quenched in warm water (65°C) and then raised to 170°C aged for 4hrs before cooling in air as shown in Figure 1.

Twenty four (24) samples were divided into four groups and subjected to double thermal ageing treatment (DTAT) such that each group containing six samples were pre-aged at 90°C for 1-4hrs at 1hr intervals before they were raised to 170°C for 4hrs. and finally allowed to cool in air. One sample from each group treated, making a total of four samples were subjected to hardness test, while the remaining five samples were used for corrosion test. The corrosion test was done by weight loss analysis and the rate of corrosion determined as contained in Callister (2009). The hardness test was determined by using a Rockwell hardness tester i.e Indentec universal hardness testing machine of 8187.5LKV (B) model and having a minor load of 98.0665 N and major load of 588.399 N.

3.0 Results and Discussion

Table 2: Hardness Test result of non-heat treated (control) and heat treated samples

<table>
<thead>
<tr>
<th>Pre-ageing time (hrs.)</th>
<th>Hardness value (HRF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (control)</td>
<td>4.9</td>
</tr>
<tr>
<td>1</td>
<td>5.5</td>
</tr>
<tr>
<td>2</td>
<td>6.5</td>
</tr>
<tr>
<td>3</td>
<td>5.8</td>
</tr>
<tr>
<td>4</td>
<td>5.7</td>
</tr>
</tbody>
</table>

The hardness value reaches maximum (6.5) when pre-aged for 2 hrs which indicate a 24.6% improvement which is in agreement with Umaru et al. (2012). This can be attributed to the refinement of the grains at 2hrs (see plate C). However, the decrease in hardness value at 3 and 4 hrs, may be that an over aged stage was reached (see plates D and E).

Equally, it was observed that samples that undergo DTAT had a better corrosion resistance than the control samples depending on the duration of ageing time of the alloy. This might be due to
the presence of intermetallic compounds which form hard and passive phase. Once the alloy is in corrosive media, these phases’ serves as strong protective barrier to further corrosion attack, and this might also be that the aluminium oxide film that usually form on the surface serves as inert and protective layer against further corrosion.

![Figure 2: Variation of corrosion rate with time of exposure in NaCl solution for both double and single treated samples.](image)

From Figure 2, the corrosion rate of the treated alloy decreases gradually from control and suddenly increases for 3 and 4hrs pre-aged samples which is in agreement with Umaru et al. (2013). This increase is probably due to the effect of over ageing and the intensity of the solution attack on the surface of the alloys, which slightly reduces the corrosion resistance of the alloy. The lowest corrosion rate can be attributed to the possibilities of a uniformly dispersed precipitates throughout the grain boundaries, and at this temperatures, the microstructure have been refined by the heat treatment into a fine dispersion.

![Figure 3: Micrograph of as-received single thermally treated Al-Cu-Si-Ni alloy x100](image)

![Figure 4: Micrograph of as-received double thermally treated Al-Cu-Si-Ni alloy pre-aged](image)
4.0 Conclusion
From the results of this study the hardness property of Al-Cu-Si-Ni alloy was best with an increase of 24.6% when double thermally treated at 2hrs as compared with the control. These is probably due to extreme relieve in internal residual stresses than when single thermally treated. Secondly, the Al-Cu-Si-Ni alloy had better corrosion resistance when double thermally treated in all cases as compared with the control.

References


Umaru, OB., Abdulwahab, M. Yaro, SA. Asuke, F. and Fayomi, OSI. 2013. Influence of pre-ageing thermal condition on the corrosion characteristics of A356.0 type Al-Si-Mg alloy. International conference on sustainable manufacturing and operations management, ISOM organized by Mechanical Engineering Department of Global Institutes, Amritsar (India) and Mechanical and Production Engineering Department, University of Mauritius, Mauritius, held at University of Mauritius, Mauritius, 26-28th June, pp. 86-92. Published by GIAP, India; ISBN: 9788192578125.