EFFECT OF COPPER ADDITION ON THE STRUCTURE AND MECHANICAL PROPERTIES OF Al-4%Zn ALLOY

1NWAEJU, C. C., 2ODO, J. U., 1 JISIEIKE, S.C. 2EDOZIUNO, F. O.

1. Department of Metallurgical & Materials Engineering, Nnamdi Azikiwe University, Awka
2. Department of Metallurgical Engineering, Delta State Polytechnic, Ogwashi-Uku

Abstract

This research work investigated the effect of copper addition on the structure and mechanical properties of Al-4%Zn alloy. The properties studied were tensile and yield strength, percentage elongation using universal tensile testing machine (SRNO0723), impact strength using charpy machine (U1820), and hardness using Brinell hardness tester model B 3000(H). The specimens were prepared by doping 0.5-3.0 wt% of Cu into the Al-4%Zn alloy at interval of 0.5 percent. The specimens were prepared according to BS 131-240 standards. Microstructural analysis was carried out using metallurgical microscope (L2003A). Result obtained revealed that hardness, impact strength and yield strength of the alloys increased with increase of copper content up to 3.0 wt% respectively. Tensile strength was increased up to 1.5 wt% copper addition and above it decreased. Percentage elongation on the other hand decreased with increasing copper content. Microstructural analysis revealed α-Al rich phase dendrites surrounded by α + γ2 phase. β-phase (CuAl2) particles formed in the interdendritic region of Al4%Zn -Cu alloys. The Al-4%Zn alloy doped with Cu proved to increase hardness, impact and yield strength and reduced ductility and is therefore recommended for application in auto industry for production of bearing components.

Keywords: Commercial pure aluminium, zinc, mechanical properties, structure.

1. Introduction

Aluminium and its alloy are gaining huge industrial significant because of their outstanding combination of properties over base alloy [1]. These properties includes high specific strength, desirable appearance, non toxic, non-sparking, non-magnetic, good corrosion resistance, good electrical and thermal conductive etc. [2,3]. These properties led to the association of aluminium alloys with transportation particularly with aircraft and space vehicles, construction and building, containers and packaging, and electrical transmission lines [4]. Zinc based alloy have a number of advantages over traditional bearing materials [5]. It has been found to be of high strength and cost effective substitute to conventional bearing bronze under heavy load and slow medium speed applications [6, 7]. These advantages can be summarised as high resistance to wear, excellent castability and low cost. Aluminium as basic raw materials in automobile and automotive industries often suffers from severe dangers when it comes under supportive attack of wear and tear in some aggressive media regardless of its corrosion resistance [8]. The development of aluminium sheets materials for automobile and automotive industries is in increasing demand, because thrust of materials research is directed at design of smaller and lighter components so as to reduce fuel consumption and running cost though not at the expenses of quality such as tensile strength and hardness [9]. These materials are always light in weight and provide alternative to steel sheet in structural panel applications [9, 10]. Currently the formability of aluminium alloy sheet is hindered by the presence of relatively brittle intermetallic compound, which are distributed throughout the matrix. These particles can induce damage and premature failure in wide variety of sheet forming and bending operations. This study therefore seeks to overcome these problems by adding copper, in variable compositions to the current generation of structural and automotive aluminium alloys (Al-4%Zn) to produce improved properties.

Copper and its alloy have been known with their moderate hardness, ductility, toughness and high electrical conductivity, machinability and corrosion resistance. Their high surface area to volume ratio has reduced their use from over head wire. However, they are used as alloy for architectural application, biofueling resistance, electrical housing wiring etc. The toxicity of copper on aquatic bacterial and algae has contributed to the use of copper in alloy development for undersea application. Copper has found in use most both as parent metal and alloying element in the development of alloy materials for various engineering applications [11].
2. Materials and Methods

2.1 Materials and equipment
The different materials and equipment namely commercially pure aluminium, zinc granules, copper granules, bailout crucible furnace, hacksaw, and iron table, weighing balance, steel crucible pot, impact testing machine (U1820), hardness testing machine (A 3000 H), universal tensile testing machine (SRNO0723), emery papers of different grits, air-drying machine, metallurgical microscope (L2003A), a digital camera, lathe machine, etc. were used in doing this work.

2.2 Method

a) Melting and casting of alloys: This operation was carried out to produce seven separate specimens for the research work. The bailout crucible furnace with steel crucible pot was pre-heated for about 10 minutes. For control sample, 453.32g of Al and 22.22g of Zn granules were measured out. Aluminium was charged into the furnace pre-set at 660°C and heated till it melted. Zinc granules was then added to the melt and stirred properly to ensure homogeneity. The alloying element (copper) was then introduced based on compositions, after the control ample had been cast. The melt was manually stirred intermittently in order to ensure homogeneity and to facilitate uniform distribution of the alloying element. Sand casting method was used after removal of the molten metal alloy from the furnace and carefully skimming off the dross. The molten metal was poured into the mould cavities and allowed solidify for about 2 minutes before removal from the mould. The samples were cleaned and stored for tests. The samples were cut and machined to the required specific dimensions, using lathe machine.

b) Mechanical test: The tensile strength was determined with SRNO0723 tensile testing machine, while a Brinell hardness machine with 2.5mm diameter ball indenter and 62.5N minimum was used to determine the hardness property. This equation BHN = \( \frac{P}{(\frac{D}{2})^2 - \sqrt{D^2 - d^2}} \) was used in calculating the result of the hardness. Where BHN: is the brinell hardness number, P: is applied load (N), D: ball (indenter) diameter (mm), d: notch diameter (mm). Charpy impact test machine (U1820) was used to carry out impact strength.

(c) Metallography: Preparation of sample material was done by grinding, polishing and etching, so that the structure can be examined using optical metallurgical microscope. The samples were grinded by the use of series of emery papers in order of 220, 340, 400, 600, 800, 1000, and 1200 grits and polished using fine α-alumina powder. An iron (iii) chloride acid was used as the etching reagent before mounting on the microscope for microstructural examination and photographing.

3. Results and Discussion
Results of the ultimate tensile strength (UTS), impact strength, ductility, and hardness responses by test specimens are displayed in Table 1 and Figures 1-4 while the micrographs developed from the specimens are shown in Plates1-7. Micrographs of Al-4%Zn dopped with 0.5-3.0% copper are shown in Plates 2-7. Apart from different intermetalics, two major phases were revealed under the optical microscopes viz: α-Al rich phase dendrites surrounded by α+γ2 phases and β-phase. The β-phase; (CuAl2) particles were formed in the interdendrites region of Al-4%Zn-Cu alloys. The number and size of β-phase particles increased with copper content of the alloys. This acted as a load bearing phase, producing hardening effects and increased wear resistance in the alloy [12].

![Plate 1. Al-4% Zn(control) x100](Plate1.png)

![Plate 2. Al-4% Zn + 0.5% Cu x100](Plate2.png)
Table 1. Mechanical properties of Al-4%Zn doped with copper

<table>
<thead>
<tr>
<th>Sample wt%</th>
<th>UTS (MPa)</th>
<th>Yield strength (MPa)</th>
<th>% Elongation</th>
<th>Hardness (BHN)</th>
<th>Impact (Joules)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (Al-4%Zn)</td>
<td>475</td>
<td>201</td>
<td>5.30</td>
<td>111</td>
<td>5.65</td>
</tr>
<tr>
<td>A + 0.5% Cu</td>
<td>486</td>
<td>211</td>
<td>7.10</td>
<td>123</td>
<td>6.84</td>
</tr>
<tr>
<td>A + 1.0% Cu</td>
<td>489</td>
<td>243</td>
<td>6.50</td>
<td>134</td>
<td>12.3</td>
</tr>
<tr>
<td>A + 1.5% Cu</td>
<td>501</td>
<td>246</td>
<td>6.40</td>
<td>139</td>
<td>16.2</td>
</tr>
<tr>
<td>A + 2.0% Cu</td>
<td>498</td>
<td>257</td>
<td>6.20</td>
<td>147</td>
<td>18.04</td>
</tr>
<tr>
<td>A + 2.5% Cu</td>
<td>478</td>
<td>266</td>
<td>6.20</td>
<td>158</td>
<td>23.15</td>
</tr>
<tr>
<td>A + 3.0% Cu</td>
<td>468</td>
<td>271</td>
<td>5.90</td>
<td>149</td>
<td>26.18</td>
</tr>
</tbody>
</table>
Figure 1. Effect of copper content on the UTS of Al-4%Zn alloy.

Figure 2. Effect of copper content on the % elongation of Al-4%Zn alloy.

Figure 3. Effect of copper content on the hardness of Al-4%Zn alloy.
The variation of tensile strength, hardness, % elongation and impact energy of the test alloys as a function of copper content are shown in Table 1 and Figures 1-4. It was observed that the impact strength and hardness of Al-4%Zn alloy increased as the composition of Cu increases as shown in Figures 3 and 4. Addition of copper to the binary Al-4%Zn alloy results in solid solution strengthening of the α-phase and formation of copper-rich β-phase. Solid solution strengthening effect (solution of copper in α-phase) caused an increase in both hardness and impact strength and decreased ductility as shown in Figures 2, 3, and 4.

Ultimate tensile strength of the alloys was found to increase with increased in Cu content up to 1.5wt% before decreasing. The decrease observed in tensile strength of the alloys containing more than 1.5wt% copper may be explained in terms of over clustering of the particles as could be seen in the microstructure. When the copper content in Al-4%Zn alloy exceeds 1.5wt%, formation of hard and brittle β-phase which has sharp edges that weakens the interdendritic region of the alloys is predominant, and when the material is tested in tension, this gave rise to early crack initiation and subsequently failure.

4. Conclusions and Recommendation
This study has revealed that yield strength, hardness and impact strength of Al-4%Zn alloy can be greatly improved with addition of 0.5-3.0 wt% copper. The addition of Cu in the Al-4%matrix significantly depressed the precipitation of other intermetallics in the matrix surface and resulted increased in UTS to certain weight composition. The following conclusions are therefore deduced from the research:

- Addition of copper to commercially pure aluminium and 4%Zn alloy transforms the columnar structure to equi-axial grain.
- When copper content increased, new phase like β-phase is formed in the interdendritic regions of Al-4%Zn alloy causing increase in the hardness.
- Hardness, yield strength and impact strength of the alloy increased continuously with increasing copper content while percentage elongation showed reversed trend.
- Ultimate tensile strength of the alloys increased with increasing Cu-content up to 1.5wt% but above this decreased as the copper content increased.
- For effective tensile strength, copper addition up to 1.5% to Al-4%Zn should be used for production of automotive and automobile components.

Acknowledgement
The authors wish to acknowledge the assistance of the staff of Foundry and Machining Section, Scientific Equipment Development Institute (SEDI) and Materials Testing Laboratory, Civil Engineering Department University of Nigeria Nsukka for making their equipments available for use.
References


