MICROSTRUCTURAL AND MECHANICAL BEHAVIOUR OF ZINC-ALUMINIUM CAST ALLOYS

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ABSTRACT

The objective of this paper is to study the micro structural and mechanical behaviour of ZA27 alloy containing nickel in the range from 1 to 3 wt. %. Elemental analysis was performed by means of energy dispersive X-ray spectroscopy (EDS) analyzer and XRD technique was employed to identify the phase formation of the alloy. The microstructure of the alloy was also examined by SEM. The increase in tensile strength, yield strength and hardness has been discussed and it was noticed that the tensile strength, yield strength and hardness of the alloys increases with increase in nickel content. Metallographic studies showed that addition of nickel resulted in microstructural modifications of the alloy involving the formation of complex intermetallic compounds.

Keywords: EDS, Microstructure, SEM, XRD, Zinc-Aluminum alloys

1. INTRODUCTION

The expeditious advancement in industrial activities, in the past decades, has resulted in the need for new multifunctional materials that possess characteristics not obtainable from any individual material. ZA alloys possess significantly higher strength and have been used increasingly in recent years for industrial applications mainly because of their good mechanical properties, excellent fluidity and castability [1]. These alloys have been used increasingly during the past few years. In recent times, zinc-aluminium based alloys have found considerable industrial applications mainly due to their good mechanical properties, excellent fluidity and castability and present advantages in comparison with copper based and aluminium based alloys, especially high strength with a low casting temperature [2,3]. Studies on ZA alloy with high aluminium percentage showed
that they exhibit good mechanical properties, excellent wear resistance, superior hardness and modulus. Cu and Mg are added to the Zn-Al based alloys to improve the mechanical properties [4,5,11]. The Mg additions used in these alloys to increase the hardness, tensile strength and intergranular corrosion resistance of these alloys. The nickel content used in these alloys increases the hardness, tensile strength and creep resistance of these materials [1,10]. More recently, some investigators have determined the mechanical properties and microstructural features of standard ZA alloys [3,9], but no previous work appears to have been reported on ZA27 alloy containing higher percentage of nickel (1-3%). Therefore this study has been carried out to quantify the effect of nickel content on mechanical properties and microstructure of the modified ZA27 alloy.

2. EXPERIMENTAL PROCEDURE

2.1. Materials and Moulds used
Zinc based alloys were prepared by liquid metallurgy route. The raw materials used to prepare these alloys are 99.99% Zinc and 99.99% aluminium and are melted up to 630°C, then poured into a preheated die of cylindrical pattern of diameter 22 mm and 165 mm long.

2.2. Casting practice
The compositions were melted in an electrical resistance furnace, using graphite crucible and poured into a permanent metal mould, which was preheated to 100°C, the alloys were cast with a 150°C melt superheat. The aluminium and nickel master alloy was stirred carefully into the molten Zn-27% A1 alloys before casting.

2.3. Chemical composition analysis
The composition of the alloy was determined using wet chemical (atomic absorption) spectroscopy and also chemistry of the same alloy was quantified by EDAX analysis as a double check.

2.4. Measurement of tensile, impact and hardness properties
Tensile test was conducted as per ASTM A370 standards at ambient temperature with a strain rate of 1.3x10^{-3}/s using universal testing machine. The impact test was performed in accordance with ASTM E23 standards. Hardness of metallographically prepared samples was measured using a Micro Vickers hardness tester as per ASTM E10 standards.

2.5. Microstructural studies
Microstructural studies of the alloys were carried out using Scanning electron microscope (SEM) and Energy dispersive X-ray spectroscopic (EDXS) facility. The specimens were polished according to standard metallographic practice and etched. The reagent for etching was a solution containing 5 g CrO_{3}, 0.5g Na_{2}SO_{4} and 100 ml H_{2}O and etched for 10-15 minutes.

3. CHEMICAL COMPOSITION
Elemental quantification was performed by atomic absorption spectroscopy. The following table gives chemistry of different developed alloys.
Table 1. Chemical composition of the experimental ZA27 alloy (wt %)

<table>
<thead>
<tr>
<th>Nickel content</th>
<th>Al</th>
<th>Ni</th>
<th>Cu</th>
<th>Mg</th>
<th>Fe</th>
<th>Ti</th>
<th>Pb</th>
<th>Mn</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>24.71</td>
<td>0.001</td>
<td>0.03</td>
<td>0.105</td>
<td>0.09</td>
<td>0.00069</td>
<td>0.0031</td>
<td>0.007</td>
<td>Rem</td>
</tr>
<tr>
<td>1</td>
<td>24.53</td>
<td>1.09</td>
<td>0.03</td>
<td>0.102</td>
<td>0.09</td>
<td>0.0007</td>
<td>0.003</td>
<td>0.007</td>
<td>Rem</td>
</tr>
<tr>
<td>2</td>
<td>23.98</td>
<td>1.95</td>
<td>0.034</td>
<td>0.108</td>
<td>0.09</td>
<td>0.0007</td>
<td>0.003</td>
<td>0.007</td>
<td>Rem</td>
</tr>
<tr>
<td>3</td>
<td>24.10</td>
<td>3.10</td>
<td>0.035</td>
<td>0.120</td>
<td>0.092</td>
<td>0.0007</td>
<td>0.003</td>
<td>0.007</td>
<td>Rem</td>
</tr>
</tbody>
</table>

Table 2. Mechanical properties of ZA27 obtained from the experiments

<table>
<thead>
<tr>
<th>Nickel content</th>
<th>UTS (MPa)</th>
<th>Yield Strength (MPa)</th>
<th>Ductility (%)</th>
<th>Hardness (MVHN)</th>
<th>Impact Energy (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>236.00</td>
<td>203.00</td>
<td>10.80</td>
<td>115</td>
<td>4</td>
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<tr>
<td>1</td>
<td>288.65</td>
<td>224.57</td>
<td>8.77</td>
<td>121</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>295.18</td>
<td>238.30</td>
<td>6.03</td>
<td>127</td>
<td>7</td>
</tr>
<tr>
<td>3</td>
<td>328.84</td>
<td>248.95</td>
<td>3.65</td>
<td>135</td>
<td>8</td>
</tr>
</tbody>
</table>

Fig. 1 Typical EDXS of ZA27 with 3% Ni

Fig. 2 Typical XRD of ZA27 with 3% Ni

Fig. 3 UTS & Yield strength Vs Wt% Ni

Fig. 4 Ductility Vs Wt% Ni
Fig. 5 MVHN Vs Wt % Ni

Fig. 6 Impact energy Vs Wt % Ni

Fig. 7 SEM microstructures of as cast ZA27 alloy containing: (a) 1% Ni, (b) 2% Ni, (c) 3% Ni (d)3 % Ni (5KX), Single arrow: η Zinc rich phase, Double arrow: α+ η eutectoid phase, Triple arrow: primary α phase , ε- Meta stable phase α+ η
4. RESULTS AND DISCUSSION

The results obtained from the tests, clearly reveal that the addition of nickel to the developed alloy has a significant effect on mechanical properties.

EDXS analysis and XRD was carried out on the developed alloys in order to know the exact composition as shown Fig.1 and Fig.2. Fig.3 shows that ultimate tensile strength, yield strength increases as nickel content increases. The increase in ultimate tensile strength, yield strength and hardness is due to solid strengthening effect and also due to formation of intermetallic phases observed along the grain boundaries. Fig.4 shows that ductility decreases continuously with increase in nickel percentage. This is because the intermetallics acts as barriers for the elongation [9]. Fig.5 shows that hardness increases as nickel content increased. The impact energy increases marginally with nickel content as shown in Fig. 6.

Microstructural examination of the alloys was conventionally carried out using Scanning electron microscope. The etching agent used was CrO$_3$ and Na$_2$SO$_4$. As the nickel content increases, the microstructure seems to get refined appreciably as seen in Fig 7. XRD analysis was carried out to identify the phases present in the alloys. The various intermetallic compounds noticed are AlNi$_3$, Zn, AlNi$_3$ and Al$_{0.403}$Zn$_{0.597}$ as shown in Fig.2. The diffraction diagram shows peaks corresponding to those of the Zn-rich and Al-rich phases of the binary Zn–Al system and the presence of Zn, AlNi$_3$, AlNi$_3$, and Al$_{0.403}$Zn$_{0.597}$ were seen from the XRD pattern (Fig.2). Zn, AlNi$_3$ and AlNi$_3$ peaks are observed at 2θ =36.45, 43.42 and 22.92 degrees, where as Al$_{0.403}$Zn$_{0.597}$ observed at 38.94 and 45 degrees.

4.1. Effect of Nickel content on microstructure

From the experimental results it is found that the tensile strength, yield strength and hardness of the alloys increased as wt% nickel increases. It is observed from the microstructure that the addition of nickel led to the formation of ε phase in the interdendritic regions of the zinc–aluminum–nickel alloys which is shown in Fig. 7(a-d). Basically the intermetallic phases are very hard and brittle which results in increase in the strength and hardness at the cost of ductility. In addition, the nickel-rich particles may also acts as barriers for the elongation because they are harder and more brittle. These are the reasons why the yield strength and tensile strength of the alloys increase with increase in nickel content [9-10]. The histogram Fig.5 shows that hardness of the alloys increases as the nickel content increased. The increase in this property may be related to the solid solution hardening and formation of hard and brittle nickel-rich intermetallic phases along the grain boundaries. Similar explanations have been offered in the literature [1, 4]. The microstructure of the alloy shown in Fig.7 consists of aluminum-rich (α) phase and zinc-rich (η) phase, while the grey structure surrounding is a mixture of zinc-rich and aluminum rich phases (α+η). The dark regions are the zinc-rich (η) phase.

5. CONCLUSIONS

The results of current study indicate that with the addition of nickel in the range of 1–3 wt.%, increases the tensile strength, yield strength and hardness of the developed alloys. The addition of nickel in Zn–Al alloys reported the formation of AlNi$_3$, Zn, AlNi$_3$ and Al$_{0.403}$Zn$_{0.597}$ intermetallics. Which increases hardness of alloy. The decrease in ductility was due to formation of hard and brittle intermetallics. Impact energy absorbed will increase slightly with increase in nickel content. Microstructural analysis revealed the alloy comprised primary α dendrites surrounded by the eutectoid α+ η and metastable phase ε.
REFERENCES


