Mechanical Properties of Nanostructured Mg-5wt%Al Alloy

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ABSTRACT

Nanostructured Mg-Al metal composites have been synthesized using Mechanical Alloying (MA) resulting in a Mg-5wt%Al alloy. The ball milling time ranged from 0 to 20 hrs. The alloys were then hot extruded. Samples were cut at 15° interval from 0° to 90° from each resulting rod. Each sample was tested for its hardness using the microhardness tester. Results showed that samples with 5 and 10 hours of ball milling time have the highest value of hardness. The difference in cutting angles of the samples for each duration of ball milling showed no significant variations in hardness value.

INTRODUCTION

Nanostructured materials, which include metals, have received much attention as advance engineering materials due to their unique physical and mechanical properties. At room temperature, the mechanical properties of nanostructured materials are superior to their coarse-grained counterparts. Intensive research on these materials has been performed since the pioneering investigations of H. Gleiter.

Magnesium is the lightest of all structural metals. However, pure metal magnesium is not valuable in many technological applications. As in the engineering of other metals, alloying of magnesium has been used to obtain superior mechanical properties. Aluminum has the most favorable effect on magnesium of any of other alloying elements. It improves strength and hardness, and it widens the freezing range and make the alloy easier to cast.

This study is to investigate how the amount of milling time affect the hardness of Mg-5wt%Al alloys and to determine whether there are variations in hardness of the alloys at different angles.

EXPERIMENTAL PROCEDURES

Mg-5wt%Al alloys, which have already been milled for 0, 5, 10, 15 20 hours and extruded, were in the form of rods. Each rod (5 of them in total, each with different ball milling time) was cut at different angles from 0° to 90° at 15° intervals. The cutting angle is defined as θ as shown in Figure 1 below:
The samples were grouped into fives according to their milling time and casted in a short cylindrical mould with 30ml of co-cast transparent resin. 30 drops of harderner (1 drop per ml of resin) were added and the casts were left for half an hour.

To ensure a flat surface for the hardness test, about 1mm on both sides of the cast were grinded using sandpaper. The surfaces to be tested were further grinded with another 3 sandpapers of different roughness, from the coarser to the less coarse ones. Water was used as lubricant. The samples were then polished with diamond slurry in 3 steps. Firstly, 6 μm diamond slurry was used followed by 3 μm and then 0.25 μm. Alcohol was used as the lubricant.

Once a mirror-like finished is obtained and no scratches were seen when the samples are put under a microscope, the samples were put in a ultrasonic vibrator to get rid of dirt particles and micro fibers of the polishing cloth. The samples are then dried using a blower and a dryer.

A microhardness tester (HV) was used to test for the hardness of the samples. The load used was 25gf with dwelling time of 15 secs. Each sample was tested several times to get the best, closest 5 readings. The 5 readings were then averaged.

**RESULTS AND DISCUSSION**

The average hardness values for all the samples are tabulated in Table 1 and plotted on Figure 2:
<table>
<thead>
<tr>
<th>Milling Time</th>
<th>0°</th>
<th>15°</th>
<th>30°</th>
<th>45°</th>
<th>60°</th>
<th>75°</th>
<th>90°</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>60.94</td>
<td>60.14</td>
<td>61.76</td>
<td>58.32</td>
<td>60.42</td>
<td>61.22</td>
<td>61.62</td>
<td>60.63</td>
</tr>
<tr>
<td>5</td>
<td>111.76</td>
<td>110.58</td>
<td>117.60</td>
<td>114.18</td>
<td>112.58</td>
<td>117.72</td>
<td>112.04</td>
<td>113.78</td>
</tr>
<tr>
<td>10</td>
<td>112.18</td>
<td>114.10</td>
<td>114.90</td>
<td>114.66</td>
<td>112.66</td>
<td>112.90</td>
<td>114.74</td>
<td>113.73</td>
</tr>
<tr>
<td>15</td>
<td>56.78</td>
<td>50.26</td>
<td>49.02</td>
<td>51.38</td>
<td>56.08</td>
<td>50.18</td>
<td>58.40</td>
<td>53.16</td>
</tr>
<tr>
<td>20</td>
<td>58.28</td>
<td>53.52</td>
<td>53.78</td>
<td>54.00</td>
<td>50.60</td>
<td>56.08</td>
<td>59.26</td>
<td>55.07</td>
</tr>
</tbody>
</table>

Table 1: Average hardness values for the samples

The hardness test results showed that samples with 5 and 10 hours of milling time have the highest value of hardness but the hardness decreased when the samples are milled for longer duration of 15 and 20 hours. This phenomenon is caused by the differences in the grain size of the alloy.

During milling, constant collision of the metal powder with the balls and vials causes the powder particles to undergo a high rate of plastic deformation. The internal strain within the grain increases with increasing dislocation density. As the dislocation density reaches a certain point in the heavily strained region, the grains break up to form sub-grains. These sub-grains undergo additional plastic deformation to break down further. Hence, the grain size of the alloy decreases as the milling time is increased. Grain size significantly influenced the mechanical properties of metals. It plays a part in a
metal’s resistance to plastic deformation and as hardness is just a metal’s resistance to plastic flow, grain size is an important factor that explains the differences in hardness value.

Magnesium, at room temperature, has only two modes of plastic deformation: basal slip and twinning. With smaller grain sizes, the amount of grain boundaries will be more and it is these grain boundaries that interfere with the movements of dislocations (grain refinement strengthening). Also, the increase in dislocation density will cause dislocations to tangle (strain hardening). Hence, these resist the occurrence of basal slip and twin formation. Therefore, this explains why specimens with 5 and 10 hours of milling have high hardness values.

However, prolong milling duration seems to lower the hardness values. One thing to note is that, grain size will not reduce indefinitely. Although grain size is observed to decrease rapidly at the early stage of milling, it will saturate in the later stages. This happen approximately after 15 hrs of milling. Dislocation density will also decrease. Studies have shown that below a critical minimum grain size, there is absence of dislocations as the ultra fine grain can no longer support dislocations. At this grain size, weakening mechanism (e.g. viscous type flow) operates leading to a decrease in hardness value. Also, due to the high reactivity of Mg, an oxide film, MgO together with secondary phases $\text{Al}_2\text{Mg}_{17}$ and $\text{Al}_3\text{Mg}_2$, causes embrittlement and this contamination is expected to be severe as the milling time prolongs leading to the reduction in the hardness.

The hardness test results also shows that the alloy is isotropic, i.e. the difference in angle and hence direction, had no significant variations in the hardness value. This is due to the fact that the specimen had been hot extruded. Unlike in cold working, hot working will not result in the grains being elongated. The grains will continue to have their random and unrelated orientation and thus as a whole, the alloy will not be anisotropic. In cold working, the grains will be elongated in one direction and contracted in the other. Consequently, its mechanical properties in the two directions will be different.

CONCLUSION

Hardness of Mg–5wt%Al alloy has been found to increase after 5 and 10 hours of milling through grain refinement strengthening and strain hardening. However, further milling will cause the hardness to decrease. Hot working has been confirmed to produce products without directional properties as results have shown that the angle at which the hardness test is done had no significant impact on the hardness values.
REFERENCES

1. Roberts, C.S. (1960), Magnesium and Its Alloys, John Wiley and Sons, Inc

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