Wear resistance of leaded aluminium alloy prepared by mechanical alloying

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Al-10 wt% Pb alloy was prepared by mechanical alloying (MA) in a laboratory attritor mill. The X-ray diffraction studies of MA powder was carried out. After degassing, the powder was consolidated by hot pressing. Studies on microstructure, grain size and pore structures in the consolidated alloy were carried out using image analysis technique. Wear resistance of the alloy was evaluated using pin-on-disc method.

Use of aluminium alloys for bearing applications has increased considerably in recent years. These alloys have good seizure and score resistance, good corrosion resistance, high fatigue strength and high thermal conductivity. These alloys invariably contain tin as an alloying element which is costly. Lead can be an attractive alternative to the tin, as it is much cheaper. It has been reported that leaded-aluminium alloys are highly suitable for bearing applications. However, there are metallurgical problems associated with production of these alloys because of wide miscibility gap between lead and aluminium in the molten state (Fig. 1). The two metals are virtually insoluble in each other at room temperature. The situation is further aggravated by large solidification range of their alloys and wide density difference, which greatly increase the kinetics of lead segregation during melting and freezing. As a result of all these problems it is quite difficult to produce Al-Pb castings having uniform distribution of lead.

In recent years, attempts have been made to develop special techniques for incorporating lead in aluminium alloys such as induction and ultrasonic stirring during melting and casting, induction stirring and continuous strip casting, impeller mixing and bottom discharge chill casting, centrifugal casting, atomizing, powder roll-compacting and sintering, iso-static pressing of mixed powders followed by cold extrusion and rolling and hot roll-extrusion.

In the present investigations, attempts have been made to disperse lead in aluminium matrix by mechanical alloying technique. The mechanical alloying technique employs a high energy ball mill and the charge consisting of powder components and the steel balls as grinding media. During the processing the charge is sufficiently work hardened, inter-diffused and gets fragmented into small particles which results in improved dispersion. Recently, the technique is gaining grounds for alloying difficult or normally incompatible materials. The composition Al-10 wt% Pb was selected for these studies as it has been proved that 10 wt% Pb is the minimum acceptable lead content particularly if aluminium bearings are to be used under thin oil-film conditions.

Experimental Procedure

For preparing mechanically alloyed Al-10 wt% Pb sample, atomized aluminium powder (<45 μm) and lead powder (<32 μm) in requisite amount were put in a laboratory scale attrition mill. 1 wt% stearic acid was added to the powder change as process control agent. Mechanical alloying was carried out under the following parameters; rpm - 350, ball to charge ratio-6:1, time - 2 h. The attrition mill used was made of

![Fig. 1 - Al-Pb phase diagram](image-url)
X-ray diffraction of the MA powder was carried out using Philips X-ray diffractometer-1840. MA powder was degassed at 200°C for two hours in a vacuum of 10^{-2} torr. The MA powder was consolidated by hot pressing at 500°C, under a pressure of 60 MPa. Lieca Q500 MC image analyzer was used for optical metallographic studies.

Wear resistance of the samples was measured using pin-on-disc type of wear testing machine. The wear pins of 10 mm (L) and 6 mm (dia) were prepared. The wear pins were fixed in the machine on a wheel made of EN-24 steel, and the wheel was rotated for 30 min at 500 rpm. To measure the wear weight loss per unit area was calculated.

**Results and Discussion**

XRD pattern of the MA Al-10 wt% Pb powder (Fig. 2) shows appearing of two new small peaks (2θ = 44.10°, 75.50°) indicating formation of a new phase.

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**Table 1—Grain size and porosity characteristics in the Al-10 wt% Pb alloy**

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Specimen</th>
<th>Grain size of aluminium (mm)</th>
<th>Total porosity (%)</th>
<th>Roundness</th>
<th>Equivalent diameter (µm)</th>
<th>Anisotropy</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Al-10 wt% Pb</td>
<td>0.032</td>
<td>10.28</td>
<td>2.45</td>
<td>12.44</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>(blended)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>Al-10 wt% Pb</td>
<td>0.022</td>
<td>8.14</td>
<td>2.57</td>
<td>10.49</td>
<td>0.84</td>
</tr>
<tr>
<td></td>
<td>(MA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Table 2—Wear resistance of Al-10 wt% Pb alloy**

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Specimen</th>
<th>Wear rate (w) (mg/mm²)</th>
<th>Wear resistance (1/w) (mm²/mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Al-10 wt% Pb (blended)</td>
<td>1.23x10^3</td>
<td>8.16x10^2</td>
</tr>
<tr>
<td>2.</td>
<td>Al-10 wt% Pb (MA)</td>
<td>4.93x10^4</td>
<td>20.27x10^3</td>
</tr>
</tbody>
</table>
In normal alloying, the Al-Pb phase diagram (Fig. 1) shows no additional phase except the aluminium and lead but due to mechanical alloying process large surface energy, stresses and lattice defects are created in the two phases which may lead to formation of this new phase.

Figs 3 and 4 show microstructure of the samples prepared with blended and MA powders, respectively. These micrographs clearly show refinement of structure as a result of mechanical alloying. During the MA processing, as recrystallization temperature of the lead (−3°C) is even below the room temperature, it undergoes only plastic deformation and does not get work hardened. Its particles achieve lamellar shape. While the aluminium particles undergo plastic deformation and work harden to get fragmented. These fragments then stick to the surface of the lead lamellae. The lead lamellae melt during hot pressing (Pb M.P.=327°C) giving homogeneous distribution of lead in the aluminium matrix. Grain size and porosity structure in the two samples, given in the Table 1, shows that grain size is finer and the porosity is finer, rounded and uniformly distributed in the MA specimen.

Comparison of wear resistance of the two specimens (Table 2) show an appreciable increase (−2.5 times) in wear resistance of the sample prepared using MA powder, which can be attributed to the (i) better bonding in the aluminium matrix and (ii) homogeneous distribution of Pb in the sample at a finer scale. During hot pressing, rupture of Al₂O₃ film present on aluminium particles takes place and fresh aluminium surface gets exposed. The presence of finer distribution of Pb droplets in the matrix then, provides better chances of contact of the fresh aluminium surfaces which improves bonding in the aluminium matrix. The finer distribution of Pb provides better lubrication at the vicinity of the aluminium grains, which reduces the wear of the aluminium matrix. The Pb being soft, during rotation of the disc it may spread to cover surface of the aluminium grains and reduce its wear. Moreover, the Pb is also a good sink to embed the work hardened aluminium particles produced by wear which otherwise could cause wear of the matrix.

Conclusions
The following conclusions have been drawn from this study. Mechanical alloying technique produces an uniform distribution of Pb in the aluminium matrix. The refinement of microstructure of Al-10 wt% Pb alloy and uniform distribution of lead improve wear resistance.

References