A Study on the Characteristics of Bearing Alloys*
(3rd Report)

By Tokuzo Matsuyama** and Takao Kayaba***

Some properties of friction and wear of Al-base bearing alloys under dry or wet condition were investigated. The results of this investigation were as follows: (1) Under dry condition: When the speed was low, the rates of increase of wear decreased with the increase of load. But when the speed became high, the wear increased rapidly with the load beyond a certain amount of load. The wear decreased with the increase of speed to a certain minimum value and the speed at which the wear was minimum, became low as the load increased, and this tendency was conspicuous with AlJ1. (2) Under wet condition: The wear decreased generally with the increases of load and speed. When AlJ1 was used, this decrease was larger. The coefficient of friction of AlJ1 increased rapidly with the decrease of Zn/P below a value of Zn/P where the coefficient of friction showed a minimum value. Under a certain load, the coefficient of friction was almost constant regardless of the speed with every alloy.

1. Introduction

In the first report(1), properties of friction and wear of some kinds of babbitt metals, and in the second report(2), those of Pb-base alloys which were hardened by Na or Ca were investigated under dry or wet condition.

The Al-base alloys were used at first as bearing alloys instead of the old alloys for want of Cu, Sn, Sb etc., which were their principal components. As compared with the old alloys it is difficult to use them as bearing alloys in the handling of the clearances between themselves and the journals, the selection of material for journal, the lubrication management etc. But as they have many excellent properties such as large mechanical strength, small specific gravity, large casting ability etc. which are necessary for bearing alloys, the superiority of them as bearing alloys will have to be recognized.

As the detailed data on the properties of friction and wear of them which were important for bearing alloys have not been available, in this investigation these properties of the two kinds of Al-base alloys which were specified under Japanese Industrial Standard (JIS) were examined, both under dry and under wet condition, and compared with those(1) of babbitt metal.

2. Materials, testing machine and test specimens

Materials and their compositions(4) are as given in Table 1. The principal physical and mechanical properties are shown in Table 2, and compared with those of babbitt metal (Sn 90.5%, Sb 5.5%, Cu 2.5%, As 1.5%).

The wear testing machine with two cylindrical specimens which contacted at each end mutually was used. The specimens were cut from cylindrical ingots, which were annealed after cast into
the heated moulds.

As the hardness of the Al-base alloys is large as shown in Table 2, that of journals which slide on them must be also considerably large. But for the reason that they had been used at first as substitutes for babbitt metals against which the mild steels had been applied, the mild steels were also selected as journals in this investigation.

3. Results and discussions

1. Under dry condition

The wear per unit sliding distance, 1 km, was measured after it became constant. Each value in the figures is the mean of several values.

(1) Load-characteristics: The relations between the applied load and wear at constant speed are shown in Fig. 1.

When the speed was low, the rates of increase of wear decreased with the increase of load and this decrease was larger when AlJ2 was used. If the speed became high, the wear increased rapidly with load beyond a certain amount of load owing to the high frictional heat at the contact surface and the large deformation of specimens. With AlJ1, this occurred under about 3 kg/cm² even at the speed of 0.28 m/sec, but when AlJ2 was used, this did not occur even under the load of 10 kg/cm² at this speed and it was considered to occur beyond this speed with a small rate of increase. This is perhaps due to the larger hardness of basic metal and greater quantities of Al₂Cu, Al₂Ni. Beyond the load under which the wear increased rapidly, the large amounts of alloys adhered to the mild steels which slid on them, and it became impossible to measure the wear, and this tendency became large with speed.

Under a light load the adhesive wear did not occur and the wear decreased with speed like that of babbitt metal. But under a heavy load the adhesive wear occurred under the less values than those in the case of babbitt metal. This is by the reason that the hardness of the base of Al-base alloys is larger than that of babbitt metal and therefore the embeddability of hard particles into the base is worse. Under a light load, the wear of these alloys was rather smaller than that of babbitt metal.

The wear of mild steels which slide on alloys is shown in Fig. 2. As the wear of the Al-base alloys became an adhesive wear even under a comparatively light load, as above mentioned, under a heavy load some of the alloys adhered to the mild steels, and this adhesion became so large with speed and load that the results obtained became uncertain. The wear of mild steel decreased gradually with speed and beyond a certain value of speed the speed did not affect the wear of mild steel, owing to the effect of adhesion. The wear of mild steels was smaller when they slid on AlJ2 which had good characteristics for wear, but was

<table>
<thead>
<tr>
<th>Materials</th>
<th>Compositions, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sn</td>
<td>Cu</td>
</tr>
<tr>
<td>AlJ1</td>
<td>10~13</td>
</tr>
<tr>
<td>AlJ2</td>
<td>6~9</td>
</tr>
</tbody>
</table>

Table 1 Materials and compositions of specimens

![Fig. 1 Load-characteristics under dry condition](image)

![Fig. 2 Wear of mild steel which slides on alloys](image)

Table 2 Principal properties of specimens

<table>
<thead>
<tr>
<th>Materials</th>
<th>Brinell hardness</th>
<th>Tensile strength σb kg/cm²</th>
<th>Elongation δ %</th>
<th>Impact value kg·m/cm²</th>
<th>Specific gravity</th>
<th>Heat conductivity g-cal/cm³·sec·°C</th>
<th>Coefficient of thermal expansion</th>
</tr>
</thead>
<tbody>
<tr>
<td>AlJ1</td>
<td>35</td>
<td>30</td>
<td>12</td>
<td>9</td>
<td>4.1</td>
<td>3.0</td>
<td>0.24</td>
</tr>
<tr>
<td>AlJ2</td>
<td>45</td>
<td>40</td>
<td>15</td>
<td>10</td>
<td>4.0</td>
<td>2.8</td>
<td>0.30</td>
</tr>
<tr>
<td>Babbitt metal</td>
<td>26</td>
<td>7</td>
<td>7.6</td>
<td>15</td>
<td>2.5</td>
<td>7.4</td>
<td>0.15</td>
</tr>
</tbody>
</table>
several times larger than when they slid on babbitt metal.

(2) Speed-characteristics: Fig.3 shows the relations between speed and dry wear under a constant load. There were minimum values in the characteristics curves of both AlJ1 and AlJ2 for speed, and with the increase of load the speed at which the wear was minimum became low, and the region in which the wear was small became narrow. The wear of AlJ2 was generally smaller and the speed at which the wear was minimum was higher and the increase of wear beyond this speed was smaller. Though below the speed of 0.14 m/sec the wear was not measured in this investigation, it is possible to presume from the results of babbitt metals, previously reported, that the wear will become maximum at the speed below this, and then decrease with the decrease of speed, and the speed at which the wear is maximum will become low with the increase of load.

By comparison with the results of babbitt metals from which it was deduced that the speed at which the wear of babbitt metals was minimum was about 2 m/sec, it will be able to be concluded that this speed with these alloys is smaller than that, and the tendency that the wear which is large at a low speed decreases with the increase of speed and the speed at which the wear is minimum becomes low as the load increases is the same as with babbitt metals.

(3) The coefficient of friction: The coefficient of friction under dry condition was calculated. This was also little larger in the beginning of sliding like that of other metals, and after sliding about 10~15 minutes it became constant, this period being influenced by load and speed. The frictional forces increased rapidly if the temperatures rose locally and then adhesion occurred, but they went down again to constant values after a few minutes. And it was impossible to calculate the coefficient of friction if the frictional forces varied violently by adhesion.

Figs.4 (a) and (b) show the relations between the coefficient of friction and speed or load. The coefficient of friction of babbitt metal decreased below a certain value of load and beyond that it was almost constant regardless of the load, though it was influenced a little by the speed. The coefficient of friction of Al-base alloys decreased, too, with the increase of load to a certain value like that of babbitt metal, but the range of load where the coefficient of friction was almost constant was narrower and the coefficient of friction increased by adhesion beyond this range.

Under a light load, the coefficient of friction decreased with increase of speed and the lighter the load was, the larger this decrease became. And it became constant under the load of 3 kg/cm² regardless of the speed. But if the load increased moreover, it increased with speed and the heavier the load was, the larger this increase became. The
coefficient of friction of AlJ1 was much more influenced by load and speed than that of others. But that of AlJ2 changed like that of babbitt metal under a light load and low speed, though under a high speed and a heavy load it increased owing to severe adhesion.

The coefficient of friction of Al-base alloys under stable frictional condition was rather about 25% smaller than that of babbitt metal, but there was the drawback that the range in which it was constant was very narrow, as compared with that of babbitt metal.

2. Under wet condition

The bearing metals are usually used under wet condition and so no wear of surfaces must occur if each contact surface is separated by the oil film, but it is impossible to avoid wear by the bad condition of semi-fluid friction at the beginning or stopping of running, or the drop of viscosity by the frictional heat. The motor-oil was used as a lubricant like in the case of babbitt metal. Because the wear under wet condition was much smaller than the dry wear, it was measured per sliding distance of 10 km.

(1) Load-speed characteristics: The wet wear of each material and mild steel which slides on it is shown in Figs. 5 (a) and (b) at the constant speed of 0.47 m/sec and the constant load of 80 kg/cm². It was common with each material that the wet wear decreased with the increase of load or speed, though the rates of decrease of wear of AlJ1 were larger. The wear of AlJ2 was little smaller than that of AlJ1 under every load and speed, except when the speed exceeded about 1 m/sec.

The wet wear of mild steel on which AlJ1 slid was not affected so large with load and was always smaller than that of AlJ1, but that of mild steel on which AlJ2 slid was very slightly larger than that of AlJ2. If the load was constant, the wear of mild steel was almost equal regardless of the speed whether it slid on AlJ1 or AlJ2. This is due to the difference of hardness and amounts of primary crystals. Therefore the hardness of mild steel is insufficient against the Al-base alloys.

(2) The coefficient of friction: The relations between load and the coefficient of friction are shown in Fig. 6.

From this Figure it was found that the coefficient of friction of babbitt metal and AlJ2 increased slowly with speed under a light load, and this increase became small with the increase of load. And therefore the coefficient of friction became nearly equal regardless of the load or speed beyond a certain value of load. Then, the chance of breakdown of the oil film was comparatively small and so lubrication did not come into imperfect state. But when AlJ1 was used under a heavy load, the boundary lubrication occurred easily owing to the breakdown of the oil film, and the frictional heat became large. And therefore the coefficient of friction of AlJ1 which was large under a light load and a high speed decreased with the increase of load, but beyond a certain value of load it increased again slowly with the rising of temperature of oil.

(3) The temperature rise of lubricant: Also under wet condition, it is suggested that the temperature at the contact surface is very high under a heavy load applied. The greater part of frictional heat generated at the contact surfaces is transmitted to the testing machine through the specimens, and the rest is spent to raise the temperature of lubricant. Because the lubricant heated by this energy is cooled by the surroundings, the temperature of oil does not rise if the heat

![Graph showing wear characteristics under wet condition](image1)

![Graph showing coefficient of friction](image2)
transmitted to the oil is not large. But if the condition becomes severe it rises slowly and becomes constant at last if the heat transmitted becomes equal to the heat dissipated. The viscosity of the lubricant is affected very much by the temperature. Therefore the coefficient of friction is influenced by the temperature of lubricant. Fig. 7 is the sample of temperature rise when 80 cc of oil are used without circulation.

The temperature of oil became almost constant after a few minutes. As the heat both dissipated and transmitted became large according to the increase of the heat generated at the contact surfaces under a heavy load, the temperature of oil maintained a higher value than that when under a light load. Because the heat transmitted exceeded that dissipated when AIJ1 was used under the load of about 240 kg/cm², the temperature of oil rose rapidly and then seizure occurred. As the heat conductivity of babbit metal was less than that of Al-base alloys, the temperature rise of oil was large at first, but not so large as when AIJ1 was used even at the load of 240 kg/cm².

Fig. 8 shows the relations between the temperature rise of oil after 3 hours sliding and the applied load, and also the relations between the load and viscosity of oil. The temperature rise with AIJ2 was smaller than that with babbit metal, but the rates of increase of them by the load was almost equal. Against this, though the temperature rise with AIJ1 was like that of AIJ2 under a light load, it increased with the increase of load. The viscosity of oil decreased rapidly beyond a certain value of load, and this decrease was largest with AIJ1.

(4) The relation between $Zn/P$ and the coefficient of friction: Fig. 9 shows the relations between $Zn/P$ and the coefficient of friction obtained from the results above mentioned. The notations $Z$, $n$ and $P$ represent the viscosity of lubricant used, the revolutions per minute and the applied load respectively.

Generally, even in the range where the lubricant film was formed, the oil film became thin owing to the temperature rise and viscosity drop if the applied load increased, and the coefficient of friction decreased in proportion to the decrease of $Zn/P$. This decrease was large with AIJ1, and very small with AIJ2.

If $Zn/P$ decreased still more, the frictional heat became large and the boundary lubrication occurred by the breakdown of oil film. The coefficient of friction showed a minimum value at a certain value of $Zn/P$ and increased below that. This increase was largest with AIJ1, but with AIJ2 or babbit metal this was so small that the coefficient of friction showed nearly an equal value.

4. Conclusions

The friction and wear tests under dry or wet condition for the Al-base bearing alloys which were specified under JIS were carried out, the results being compared with those of babbit metal. The results of this investigation are as follows:

1. Under dry condition

(1) When the speed was low, the rates of increase of wear decreased with the increase of load. But if the speed became high, the wear
increased rapidly with the load beyond a certain amount of load. The wear decreased with the increase of speed to a certain minimum value and the speed at which the wear was minimum became low and the range of speed in which the wear was small became narrow rapidly as the load increased. These tendencies were conspicuous with AIJ1. The wear of mild steel which slid on alloys became uncertain under a heavy load or a high speed because of adhesion.

(2) The coefficient of friction of AIJ1 changed like that of babbit metal, and though under a light load it was almost constant regardless of the speed, it increased extremely under a heavy load. This increase with AIJ1 was so extreme that the range in which the coefficient of friction was constant was very narrow in spite of load and speed. The minimum value of coefficient of friction of Al-base alloys was rather smaller than that of babbit metal.

2. Under wet condition
(1) The wear decreased generally with the increase of load and speed, and this decrease was larger when AIJ1 was used. The wear of mild steel which slid on these alloys was nearly equal to that of alloys. (2) Under a certain load, the coefficient of friction was almost constant regardless of the speed with every alloy. (3) The temperature rise of lubricant was smallest with AIJ2. The coefficient of friction of AIJ1 increased rapidly with the decrease of $Zn/P$ below a value of $Zn/P$ where the coefficient of friction showed a minimum value.

References
(3) JIS H 5402.

### An Application of Dimensional Analysis to the Characteristics of Wear under Dry Condition*

By Keikichi Ebihara** and Kunikazu Hayashi***

A dimensional analysis is carried out for a simple sliding wear under dry and steady state, based on the experimental evidences reported by G. Hughes and R. T. Spurr (1955), and K. J. Trigger and B. T. Chao(1956). Applying the analysis to several experimental data on wear, a simple theory is derived, that is, the rate of wear per unit normal pressure and sliding distance is a function of dimensionless numbers containing $p$ and $v$, where $p$ and $v$ denote normal pressure and sliding speed respectively. And it is shown that this fact coincides with Holm's theory.

### Introduction

A theory on galling wear has been proposed by R. Holm in 1946, that is, the amount of wear is proportional to the normal pressure and sliding distance, while inversely proportional to the hardness of the softer of the two rubbing materials(5). The theory was verified experimentally by G. Hughes and R. T. Spurr, in 1955, on wear of Montan wax(5).

For metals in general it is neither possible to know the hardness under the rubbing conditions without great difficulty, nor can one demonstrate Holm's law directly with experiments. However K. J. Trigger and B. T. Chao(5) measured, with the wear of cemented carbide tools, the rubbing surface temperature of a tool. Then plotting the wear of the tool against the surface temperatures, they found that the rate of wear per unit normal pressure and the distance of travel is represented with one curve, i.e. the rate of wear is the function of rubbing surface temperature alone. From Trigger and Chao's investigation it could not be

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