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WEAR PROPERTIES OF ALUMINUM – SILICON EUTECTIC ALLOY

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ABSTRACT

In this study, wear behaviors of both the as-cast and the heat-treated aluminum-silicon eutectic alloy have been investigated. The cylindrical shaped wear testing specimens were prepared from cast ingot and some of the specimens were then heat-treated according to ASTM standard. Wear experiments on both samples were conducted with a pin-on-disk type wear testing apparatus. The test variables were the rotational speed, input weight, and time/sliding distance. The extent of wear damage was estimated by means of weight loss technique. The full heat-treatment improved the wear properties of the aluminum-silicon eutectic alloy. Simultaneously, observation showed that the wear rate was more pronounced on the as-cast specimens compared to heat-treated ones. The volumetric and specific wear rates were also increased with the increase of rotational speed, however, increase in input weight and sliding distance showed towards decreasing trend.

Keywords*:* Pin-on-disk, As-cast, Heat-treatment.

1. INTRODUCTION

Tribology is the study of friction, wear and lubrication, which involves the movement of one solid surface over another [1]. Research in tribological area, is very important for the purpose of economy, since it is still a major problem and its direct cost estimated to vary between 1 and 4 % of gross national product [2]. Therefore, many attempts have been given to produce more durable materials and techniques to reduce the wear of tools and engineering components. In automotive industry, wear is also a serious problem and it is a vital industry for a developing country like Malaysia. Thus, research in this area has been undertaken to conduct experiment extensively and to explore more data collectively.

Aluminum-silicon alloys are characterized by light weight, good strength-to-weight ratio, ease of fabrication at reasonable cost, high strength at elevated temperature, good thermal conductivity and excellent castability as well as excellent corrosion and wear resistance properties. Thus, these types of alloys are well suited for automotive industry, aerospace structural and military applications. Aluminum-silicon eutectic or near eutectic alloys are cast to produce majority of pistons and are known as 'piston alloy', which provides the best overall balance of properties [3]. Therefore, aluminium-silicon eutectic alloy has been selected as a wear testing material to carry out experiments in the present investigation.

2. EXPERIMENTAL DETAILS

2.1 Charge Materials, Melting, Casting and Specimen Preparation

Scrap motorcycle pistons were used as the basic raw material to produce aluminium-silicon ingots. After removing the rings and the pins from the pistons, they were soaked in a hot NaOH solution and the carbon deposits were removed by using metallic brush. The pistons were then melted in an electric furnace using a steel container (Figure 1). The molten alloy was poured in to a metallic ingot mould to obtain the piston alloy ingot. These ingots were then cut into small pieces and wear specimens were prepared by machining. The specimen size was 5 mm both in diameter and height.

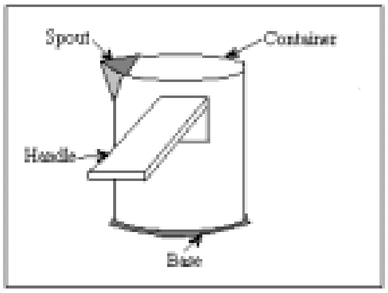

Fig 1. Steel container for melting Al-Si eutectic alloy

2.2 Full Heat-Treatment

About 50 % of the wear specimens were heated in the furnace (CMTS Lab Furnace, type L3/1250, electrically operated) at 535^{o}C (±5^{o}C) for about 8 hours. They were then quenched in hot water at 60^{o}C for about 15 minutes. The specimens were then dried and kept at –10^{o}C for overnight in the deep freezer. The specimens were dried again and heated up to 170^{o}C (±2^{o}C) for 8 hours. The specimens were cooled in the normal room temperature and were ready for wear testing.

2.3 Surface Roughness

The surface of the specimen was cleaned with water and dried with acetone and then it was placed in three jaw chuck to make it leveled. The stylus was placed approximately at the center of the specimen. The profilometer was operated over the specimen and the readings were recorded. The final result was averaged from 5 readings.

2.4 Hardness Measurement

The hardness of the as-cast and heat-treated specimens as well as the hardened steel disk was measured by using Vickers Hardness Tester. Each test was repeated at least five times to get a good average with minimum deviation.

2.5 Exprimental Set-up

Pin-on-disk type wear testing apparatus (Figure 2) has been widely used to study the wear properties of the material and to classify its rank. The test is known as a general test that can determine the sliding wear behaviour of the material pairs and its correlation. The fabrication and operation of the wear testing apparatus has been described elsewhere [4]. The parameters for the test included the size and shape of the pin, load, speed, and the material pairs. The hardened steel disk size was 216 mm in diameter and 15 mm in thickness.

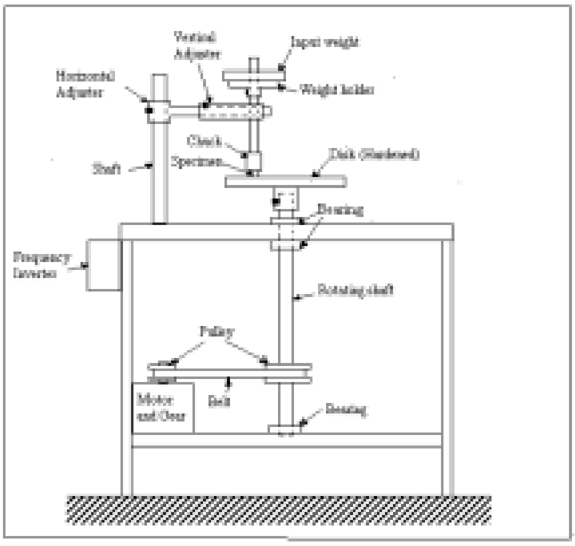

Fig 2. Pin-on-disk type wear testing machine

2.6 Experimental Variables

Wear experiments were carried out with following variables. Three rotational speeds were used, such as 200, 300 and 400 rpm, keeping both the input weight (1.25 kg) and the sliding distance (1150 m) as constant. Three different input weights were used, such as 1.25, 2.50 and 3.75 kg, keeping the speed (300 rpm) and the sliding distance (1150 m) as constant. Three sliding distances were used, such as 1000, 1150 and 1550 m, keeping the input weight (1.25 kg) and the speed (300 rpm) as constant. In the present study, no lubricant was used and the tests were carried out under dry sliding condition.

2.7 Wear Testing

Before starting the actual wear testing, both the aluminum-silicon alloy specimen and the hardened steel disk were cleaned and dried by using cotton dipped in acetone. The initial height of the specimen was measured and the value was recorded. The mass of each specimen was also measured by using electronic digital balance and the value was recorded. The specimen was then placed and fitted in the bit slot and tightened by rotating chuck key into the chuck cap. The specimen was then placed at 30 mm radius of the hardened steel disk. The radius of the disk in each test was recorded to calculate the sliding distance.

However, before starting the experiment, the speed was adjusted using the frequency inverter and counter checked by using tachometer. Initial 1.25 kg input weight was placed on the weight holder. The rotation of the disk and the stop-watch were started simultaneously. The time is very important to calculate the sliding distance. After 5 minutes, the specimen holder was jerked up and stop button was pushed on the frequency inverter to stop the rotating disk. The specimen was unclamped from the chuck, and the specimen and the disk again were cleaned with cotton dipped in acetone. The final mass and height of the specimen were recorded. The weight loss, $\boldsymbol{\Delta w}$ for each specimen was recorded and wear rate, ***W(t)*** in terms of volume loss was calculated by dividing the weight loss to density, $\boldsymbol{\rho}$ and the time, ***t***.

$$W(t) = \frac{\Delta w}{\rho t} \tag{1}$$

The specific wear rate, $\boldsymbol{W_s}$ was calculated by using the following formula:

$$W_s = \frac{W(t)}{v_s F_n} \tag{2}$$

Where $\boldsymbol{v_s}$ is sliding velocity in ***m/s*** and $\boldsymbol{F_n}$ is the input weight or normal load in ***N*** or $\boldsymbol{kgm/s^2}$ with an assumption that the temperature is constant [5, 6].

3. RESULTS AND DISCUSSIONS

3.1 Composition of Al-Si Eutectic Base Alloy

The alloy used in the present study contains 12.2% Si, which is a eutectic variety. The comparison of the alloy is shown in Table 1. The composition was analyzed by using SEM having EDX facility. This type of alloy is easy to cast and offers optimum fluidity to cast thin sections [7, 8]. Probably these are the reasons why motorcycle piston (where very thin sections are required to cast) is made with eutectic variety of aluminium-silicon alloy.

Table 1: Composition (%) of Al-Si eutectic alloy

Si	Mg	Cu	Fe	Ni	Mn	Sn	Pb	Zn
12.2	0.14	2.0	0.8	0.4	0.35	0.07	0.12	0.7

3.2 Surface Roughness

Table 2 shows the values of surface roughness (Ra) in µm for as-cast and heat-treated specimens and disk materials for each conditions of experiment. Larger value of Ra indicates the surfaces have relatively higher asperity heights. This would contribute to the amount of real area of contact and true stress for each asperity.

Table 2: Average surface roughness values for the specimen and the disk materials

Conditions	Surface Roughness, Ra (µm)			
	As-cast Specimen	Hardened Steel Disk	Heat-treated Specimen	Hardened Steel Disk
Speed 300 rpm, input wt 1.25 kg and sliding distance 1150m	0.6994	0.4580	0.6174	0.4637
Speed 300 rpm, input wt 1.25 kg and sliding distance 1550 m	0.6860	0.4119	0.6146	0.4242
Speed 300 rpm, input wt 3.75 kg and sliding distance 1150 m	0.6726	0.4081	0.6187	0.4492

However, the real area of contact, average gaps and mean asperity contact pressure are important performance variables to understand friction and wear characteristics [9]. Pressure that applied on the highest peak of an asperity can be extremely high compare to the nominal load. Thus, when two contacting bodies in sliding motion with high asperity, pressure will eventually produce hot spots, which can accelerate micro crack nucleation and wear particle generation. Therefore, in order to make this variation within acceptable range, the values of surface roughness for all specimens and any specified experimental area of the disk were measured and recorded until a suitable range in facing process were achieved [10]. However, with few exceptions, the roughness values for the specimens and the disk material obtained in the preliminary tests were within the acceptable range.

3.3 Hardness Measurement

Figure 3 shows the comparison of hardness for the as-cast and heat-treated wear test samples as well as the hardened steel disk on which the actual wearing actions had been carried out. Therefore, it was necessary to know the hardness of the materials that were on sliding actions before starting the actual wear test. It can be seen that the disk material (counter body) is about 3.5 and 2.5 times harder than the as-cast and heat-treated samples, respectively. These hardness values are quite satisfactory to conduct sliding tests under dry condition. Similar experiments were also carried out by other investigators [11, 12, 13] using pin-on-disk type wear testing apparatus for various ferrous and non-ferrous materials.

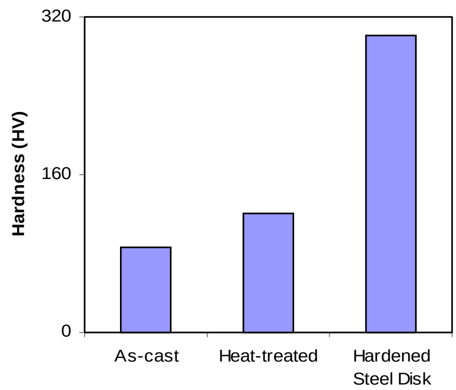

Fig 3. Hardness values of wear test specimens and the hardened steel disk

3.4 Wear Properties of Al-Si Eutectic Alloy

When two metal surfaces slide over each other, the sliding reactions between them increase the wear of the materials progressively. The softer specimen will wear and lose some weight, while it will slide over the hardened steel disk. The hardened counter body will also wear, but it is so negligible that can be ignored [14]. Moreover, the standard pin for testing should be preferably spherical [15] to overcome tilting during experiments. Due to some difficulties in preparing the specimens as spherical, cylindrical shaped specimens having 5 mm diameter and 5 mm height keeping the aspect ratio within unity was used in the present study. In order to ensure that the sliding operations have been carried out on smooth and flat surfaces, the initial and final heights of each specimen were measured at several places after each wear test. Adjustment had been carried out immediately after the test whenever it was necessary so that the specimen would not tilt during the sliding operation. This arrangement made the contacting surfaces of the specimen and the steel disk uniform [15]. The difference in rotational speed, input weight and the sliding distances influence the wear and its mechanisms [16]. All these have shown with different perspective of wear for both the as-cast and heat-treated samples of the aluminum-silicon eutectic alloy and have been discussed below separately.

3.4.1 Wear at Various Speeds

As the rotational speed of the hardened steel disk increases, the mass loss of the specimen material also increases. The heat that generates between two contacting surfaces in sliding condition is due to friction. As a result, the surface energy of both materials reduced and since aluminum-silicon alloy has less hardness compared to the hardened steel disk, the specimen will abrade and adhere with the disk. It can be seen from Figure 4 that as the rotational speed of the disk (counter body) is increased, the wear rate is also increased for both the as-cast and heat treated materials. However, the specific wear rate (Figure 5) is slowing down as speed is increased from 300 rpm to 400 rpm. It can be seen that this is more pronounced in heat-treated samples. The reason might be that during sliding, heat is developed due to friction and the material becomes softer and weaker. As a result, the rate of wear is high for as-cast sample, whereas for heat-treated samples, the developed heat might not affect much to reduce the hardness of the material due to inherent characteristics of the heat-treated alloy [17]. Thus, the overall wear damage for heat-treated sample was found to be less.

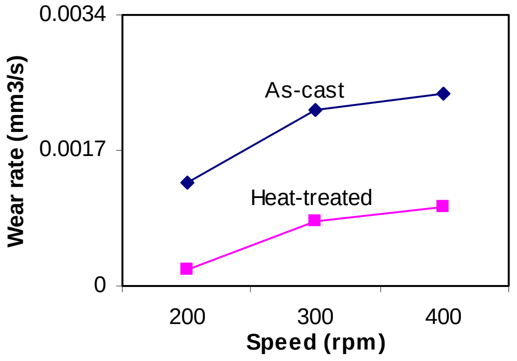

Fig 4. Wear rate versus Speed

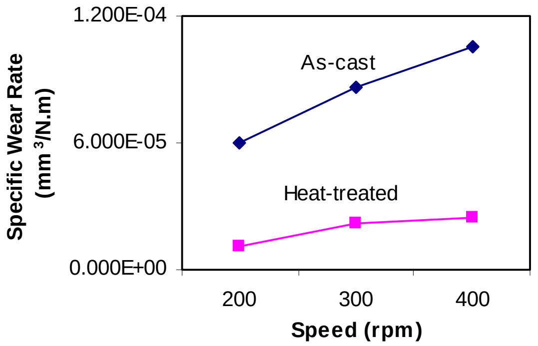

Fig 5. Specific wear rate versus Speed

3.4.2 Wear at Various Input Weights

Input weight is regarded as normal load on the specimen. When this load is increased, the real surface area in contact would be more and because of this, friction between two sliding surfaces would increase. Due to friction and more real surface area in contact with the harder material, it will grind the softer material at higher rate. It is noticeable from Figure 6 that the wear rate is increased with slight variation at higher input weights (2.50 kg and 3.75 kg), especially for as-cast specimen but the specific wear rate are quite low for both samples (Figure 7). Sliding with higher load will increase the strain-hardening of the materials that are in contact. This will increase the resistance to abrade or erode, resulting reduced wear rate. Probably, this is the reason that at higher load, the real surface area in contact is more, which increases the gripping action and due to this, wear rate has slowed down.

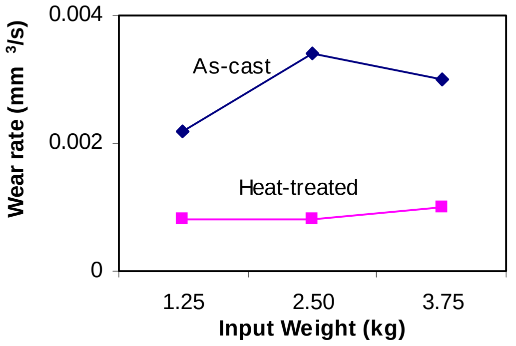

Fig 6. Wear rate versus Input weight

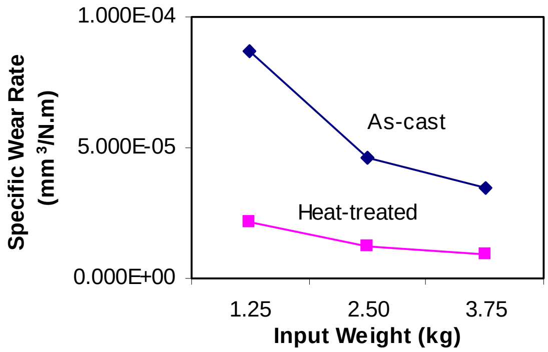

Fig 7. Specific wear rate versus Input weight

3.4.3 Wear at Various Sliding Distances

At longer sliding distances, the volumetric wear rate (Figure 8) and specific wear rate (Figure 9) are quite low. This can be explained as during sliding operation, heat is developed due to friction and makes some of the adhered materials softer and loosen. As sliding continues, these loosened particles/debris are thrown away showing higher loss in weight. In case of heat-treated sample, this heat could not affect much to the material, because of its inherent characteristics obtained due to different heat treatment cycles. On the other hand, this heat affected the as-cast properties of the alloy and showed higher weight loss.

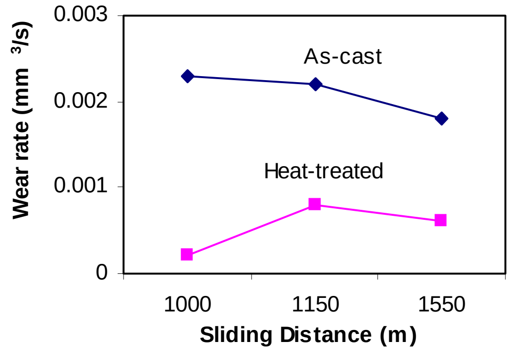

Fig 8. Wear rate versus Sliding distance

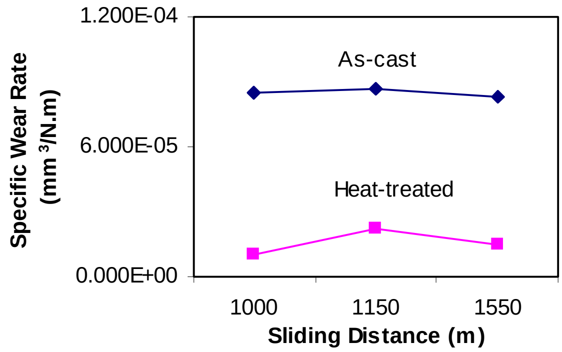

Fig 9. Specific wear rate versus Sliding distance

4. CONCLUSIONS

The following conclusions can be drawn from the experiment of the present study:

(a) In general, the increase in wear with an increase in input weight, rotational speed and sliding distance is observed for both the as-cast and heat-treated specimens of aluminum-silicon eutectic alloy.

(b) The wear is more pronounced in the as-cast samples compared to the heat-treated ones due to some inherent characteristics obtained during different heat treatment cycles.

(c) The volumetric and specific wear rates are also increased with the increase of rotational speed, but with the increase of input weight and sliding distance both wear rates show towards decreasing trend.

(d) The contacting surfaces of the materials become work-hardened due to sliding with higher load, which results slower wear rate.

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7. NOMENCLATURE

Symbol	Meaning	Unit
Δw	Weight Loss	(g)
$W(t)$	Wear Rate	(mm^3/s)
ρ	Density,	(g/mm^3)
t	Time	(s)
W_s	Specific Wear Rate	($mm^3/N.m$)
v_s	Sliding Velocity	(m/s)
Fn	Input Weight	(N)
Ra	Surface Roughness	(μm)