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# Wear behaviour of sand cast eutectic Al-Si Alloy in hydraulic brake fluid

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**ABSTRACT:** The report of investigation of the wear behaviour of aluminium alloy samples used in the floating calliper of master cylinder clutch or brake is presented in this paper. As-received commercial aluminium alloy sample sourced from automobile hydraulic brake cylinder calliper was melted in electric furnace under a controlled atmosphere, and sand cast at pouring temperature range of 700-800 oC into rod of 300 mm long by 30 mm diameter. A wear jig was used to determine the wear resistance of the aluminium samples with and without the use of hydraulic fluid. The microstructures and surface of the as-received and cast specimen were examined under high resolution microscope to assess the effects of wear with and without hydraulic oil. It was observed that the aluminium sample wears faster in the absent of hydraulic fluid and was reduced to a bearable minimum when hydraulic fluid was applied. The results obtained are presented in figures showing the wear rates and weight loss of the aluminium samples with respect to the wear cycle, from which models equations are derived. The test results show that eutectic structured cast aluminium alloy behaves relatively better than the as-received aluminium alloy specimen in oil. It is significant that the oil functions as lubricant on the alloy under test, hence the common deteriorations experience from the cast alloy under service must have aggravated from the chemical adulterations in the oil wherewith a thin film of more wear and chemical resistance would bring effective and significant wear and corrosion protection or both to the surface.

**KEYWORDS:** Wear rate, cast aluminium, sand casting, eutectic Al-Si Alloy, hydraulic brake fluid.

## 1 INTRODUCTION

The use of aluminium alloys in machine building and automobile industries is very popular which is characterised by it high strength to weight ratio. Many engineering devices such as automotive engines, in cylinder blocks and crankcases, cylinder heads, master brake and clutch cylinder are produced from varieties of aluminium alloys [1]. This characteristic is no doubt has contributed to the combination of light weight–high strength characteristics of the component under application. Nevertheless cylinder components contribute to about 30% of total friction in an automotive engine [2] and this may include the hydraulic brake and clutch. Wear is a mechanical material deterioration process occurring on rubbing or impacting surfaces, while corrosion involves chemical or electrochemical reactions of the material. The former is commonly reduced by lubrication while the latter could be controlled by the composition of the fluid. [3]

Hydraulic fluid is used in hydraulic brake and clutch applications in automobiles. Most accepted brake fluids used today are glycol-ether based and are not expected to be corrosive. Untreated or poorly formulated lubricants (mineral-based oils and synthetic-based oils) do not possess the necessary properties to be effective in the demanding lubrication environments that exist today. To perform the above-mentioned functions properly, base fluids need the help of chemical additives as inhibitors [4]. Nigeria automobile markets are circulated with imported low quality or adulterated hydraulic brake oil and aluminium alloy products from the Asian world (specifically China, Taiwan and even Japan) which in many instances do not meet with the international standards specifications [5]. The fluids tend to condense and cause corrosion under service application. Since friction generates heat, there is tendency for temperature change and the occurrence of condensation.

To make things worse, many local foundry shops produce cast aluminium products of very poor surface finishing. The combination of friction and fluid has the potential to cause wear of the aluminium alloy component under application. The corrosive fluid accelerates wear and vice versa [6]. Hence there can be corrosion accelerated wear or wear accelerated corrosion and this is known as tribocorrosion. [7], [8]. Wear, fatigue failure, corrosion, and oxidation all begin at the surface and can rapidly lead to stress concentration, fracture, increased friction, and other problems [9], [10].

There are many reports on the mechanical, thermal, electrical and corrosion behaviours of various classes of aluminium and aluminium alloys in different media and environments such as acid, bases, salts, organic and in-organic fluids and agro-fluids [11], [12]. Tribological and corrosion experiment reports are the most popular and have been in literature. [13], [14], [15]. Wear is a mechanical material deterioration process occurring on rubbing or impacting surfaces, while corrosion involves chemical or electrochemical reactions of the material [16], [17], [18]. Hence, the need to assess the wear characteristics of the cast aluminium alloy in hydraulic fluid under application is investigated and reported in this paper.

## 2 MATERIALS AND METHOD

### 2.1 SOURCING AND THE CHARACTERISATION OF SAMPLE

The aluminium alloy sample was sourced from the floating calliper of the automobile master brake cylinders procured from automobile spare part shop at Ado Ekiti. The specimen was designated as Sample 1 (As received Al alloy). It was melted and sand cast to get a specimen designated as Sample 2 (cast aluminium). The hydraulic fluid sourced from Brake oil (DOT 3) was procured from automobile spare part shop. The equipments used for the experiment include: electronic digital weight meter (model DT-502A, 0.0001g), lathe machine, drilling machine, mitre saw and wear jig.

The chemical compositions of Aluminium alloy specimens were determined using Atomic Absorption Spectrometer (AAS) Thermo series 2000 Model. The results of chemical composition are presented in Table 1. The properties of hydraulic fluid (brake oil) as published by the manufacturer is given on Table 2 (Appendix). Micro-structures of as-received and cast aluminium alloy samples were studied under higher resolution metallurgical microscope with digital camera. The microstructures of the sections were examined under x200, x400, x800 magnifications and are presented in Plates 4.1 (a-c) and 4.2 (a-b). An average of four points of harness tests was carried out over an area of each of the specimen surface to determine the BHN following the standard procedure and specification tables attached to the machine. The BHN is determined using Equation 1 and the results of hardness tests are presented in Table 3.

$$\mathrm{BHN} = \frac{\mathrm{F}}{\frac{\pi}{2}\mathrm{D}(\mathrm{D}-\sqrt{\mathrm{D}^2-\mathrm{D}_i^2}} \quad (1)$$

Where BHN = the Brinell hardness number, F = imposed load in kg, D = diameter of the spherical indenter in mm, Di = diameter of the resulting indenter impression in mm

### 2.2 PREPARATION OF TEST SAMPLES

The specimen for the wear test are prepared from 2000 g of as-received aluminium alloy sourced from automobile master brake calliper (piston) was melted at range of temperature of 750~800 $^{o}$C in electric furnace under a controlled atmosphere. The alloy was sand cast into rod of 30 cm long by 3 cm diameter (Plate 1) from which the set of piston specimen were cut and machined out. The cast aluminium was turned on the lathe machine to obtain smoother surface of the sample. They were machined to obtain pistons of 10 cm long by 1.2 cm diameter suitable for wear resistance test (Plate 2). The surface of the aluminium alloy samples were grinded and polished with different types of polishing grit which include 50µm, 60µm, 100µm, 220µm, 320µm, 400µm, 600µm, 800µm, 1200µm and 2400µm on the grinding and polishing machines.

***Plate 1: Turned cast aluminium alloy*** ***Plate 2: Machined specimen for wear test***

### 2.3 WEAR TEST OF ALUMINIUM ALLOY SAMPLES WITH AND WITHOUT HYDRAULIC FLUID

The as-received Aluminium alloy or cast machined sample (calliper or piston) specimen is material inserted inside master cylinder of the wear test jig machine after taking the initial weight of the specimen. The machine is powered on to jig the aluminium alloy piston thereby causing some wearing effect on it during the operation of the machine. The specimen was jig at different wear cycles or revolutions (1,225 to 269,500 wear cycles). The final weight of the specimen was determined using a very sensitive digital weight meter. The experiment was first performed without filling the oil cavity with bake oil and later performed with the use of hydraulic fluid for necessary comparison of the wear rate.

Determining the wear surface area A of aluminium alloy specimen

$d = 15$ mm, $l = 100$ mm

$A = l \times \pi d/2 = 23.565$ cm$^2$

Where d = diameter, l = length of the specimen and A = wear surface area

The volume loss (wear volume) of aluminium alloy sample during the experiment was determined using Equation 2,

Density ρ (in gcm$^{-3}$) = mass M (g)/ volume V (cm$^3$). (2)

where V = Wear volume loss $V_w = M/\rho$,

given that $\rho_{aluminium} = 2.7$g cm$^{-3}$

Whereas the wear rate was calculated in mg/cm$^2$/mins using Equation 3

Wear rate = $V_w / \rho A t$ (3)

Where: $V_w$ = Wear volume loss (cm$^3$), M = Weight loss or wear loss (mg), ρ = Density of the material (in gcm$^{-3}$) = 2.7gcm$^{-3}$ for aluminium alloy

A = Surface area of wear exposure ($cm^2$), t = Wear time (in minutes)

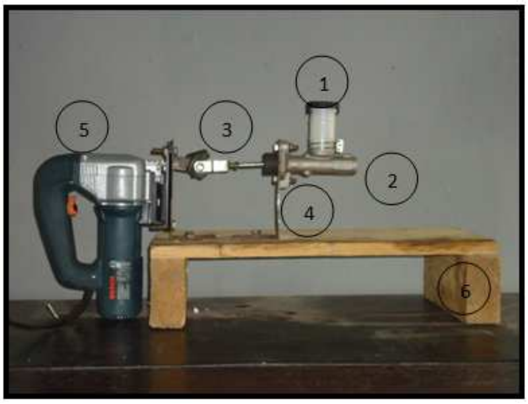
1 minute revolution of jigging = 1225 wear cycles.

Wear resistance, *R,* which is simply defined as the reciprocal of wear volume w:

$$R = \frac{1}{W} \quad (5)$$

Where the wear volume is given as $W = k_3 \frac{Ld}{H}$ (6)

In Archard's equation which was derived for adhesive wear but also, has proven very useful in abrasive wear. The results and micrographs of surface wear of as-received and cast aluminium alloys with and without oil are presented in Figures 1-4 and Plates 6-8.




1-Hydraulic brake oil chamber

2-Cylinder containing the calliper

3-Coupling

4-L-support

5-Electric power jig

6-Wooden platform

***Plate 3: Pictorial view of wear jig***

## 3 Results and Discussion

The results of chemical compositions of As-received Aluminium alloy and Cast aluminium alloy sample used in this experiment are presented in Table 1.

***Table 1: Chemical composition of Aluminium alloy***

| Samples | Al | Si | Mg | Fe | Mn | Cu | Zn | Cr | Ti |
|---|---|---|---|---|---|---|---|---|---|
| As-received aluminium alloy | 98.87 | 0.38 | 0.40 | 0.23 | 0.001 | 0.01 | 0.001 | 0.001 | 0.001 |
| Cast aluminium alloy | 98.44 | 0.32 | 0.29 | 0.16 | 0.001 | 0.01 | 0.001 | 0.001 | 0.001 |

The microstructure obtained from as-received and cast aluminium alloy samples studied under higher resolution metallurgical microscope with digital camera are shown in Plate 4(a-c) and Plate 5(a-c)


*Plate 4: Micro-structure of As-received aluminium alloy sample*

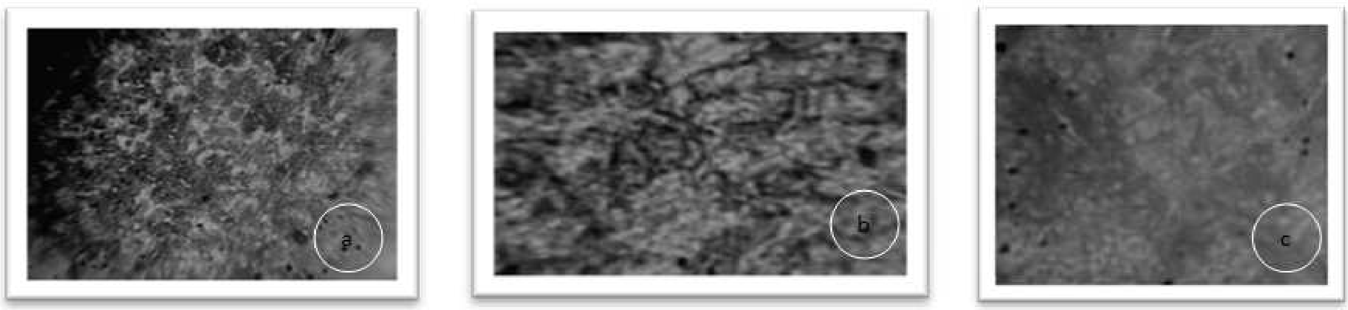



*Plate 5: Microstructure of sand cast eutectic Al-Si Alloy.*

The results of four point hardness tests of Sample 1 (As received alloy AR) and Sample 2 (Cast aluminium alloy AC) are presented in Table 3.

*Table 3: Hardness tests of aluminium alloy samples*

| Samples | Point 1 | Point 2 | Point 3 | Point 4 | Average BHN |
|---|---|---|---|---|---|
| As-received A alloy (AR) | 43.8 | 43.7 | 43.2 | 43.7 | 43.6 |
| Cast Al alloy (AC) | 63.4 | 64.4 | 64.1 | 63.3 | 63.8 |

### 3.1 CHARACTERISTICS OF THE ALUMINIUM SAMPLES

As-received and cast samples were characterised by carrying out the chemical analyses by AAS, and XRD for structural analyses. This is done to ascertain the chemical composition of the sample. The micro-structural examination is carried out to reveal the micro structure of the alloy and to compare the similarities and differences between the grain sizes, phases and structures of as-received and cast samples. The hardness tests of Aluminium alloy samples were determined using Brinell Hardness Testing Machine. The hardness values are compared as means of identifying their behaviour under friction with respect to their composition and micro-structure. With these, some reasons for their corrosion and wear behaviours could be understood.

The results of chemical compositions of as-received Aluminium alloy and Cast aluminium alloy sample used in this experiment are presented in Table 1. The analysis shows that 98.87 %Al, 0.38 %Si, 0.40 %Mg, and 0.23 %Fe were present in the as-received aluminium alloy; 98.44 %Al, 0.32 %Si, 0.29 %Mg, and 0.16 %Fe were present in the cast aluminium alloy while equal amount of 0.001 %Mn, 0.01 %Cu, 0.001 %Zn, 0.001 %Cr and 0.001 %Ti were obtained in both as-received and cast aluminium specimens.

The eutectic Al-Si microstructures obtained from the cast aluminium alloy samples studied using higher resolution metallurgical microscope with digital camera under x200, x400, x800 are shown in Plates 4(a-c) and 5(a-c). The microstructure of as-received aluminium alloy sample has more coarse grains than the cast aluminium alloy sample. This is reflected in the result of hardness tests obtained on the as-received aluminium alloy (control sample) and Cast aluminium alloy in Table 3. The average BHN obtained from the as-received aluminium alloy sample is lower as compared with the cast aluminium alloy examined under the same conditions. From these results, the wear behaviours could be understood since fine grained microstructure would produce produced hard material in the cast alloy.

### 3.2 WEAR TEST OF ALUMINIUM ALLOY SAMPLES WITH AND WITHOUT HYDRAULIC OIL.

Figures 1-4 illustrate the wear rate study of AR and AC aluminium alloy samples with and without hydraulic oil. The figures show the variation in the wear cycle and wear loss of as-received and cast aluminium alloy samples with and without hydraulic oil. Figure 1 shows obviously that both AR and AC aluminium alloy samples have higher wear loss without hydraulic oil than with hydraulic oil. It is shown in Figures 2 and 3 that AC has lower wear rates than AR the under wear tests, with and without hydraulic oil. The wear loss and wear rate of AR and AC increase steadily with the increase in the wear time from zero to 134750 wear cycle above which there is sudden sharp increase in the wear loss and wear rate of both samples under test. The resistance to wear of AR and AC under test with hydraulic oil is much higher that the counterpart AR and AC without hydraulic oil. Likewise, the resistance AC to wear under test with hydraulic oil is much higher that the counterpart AR with hydraulic oil.

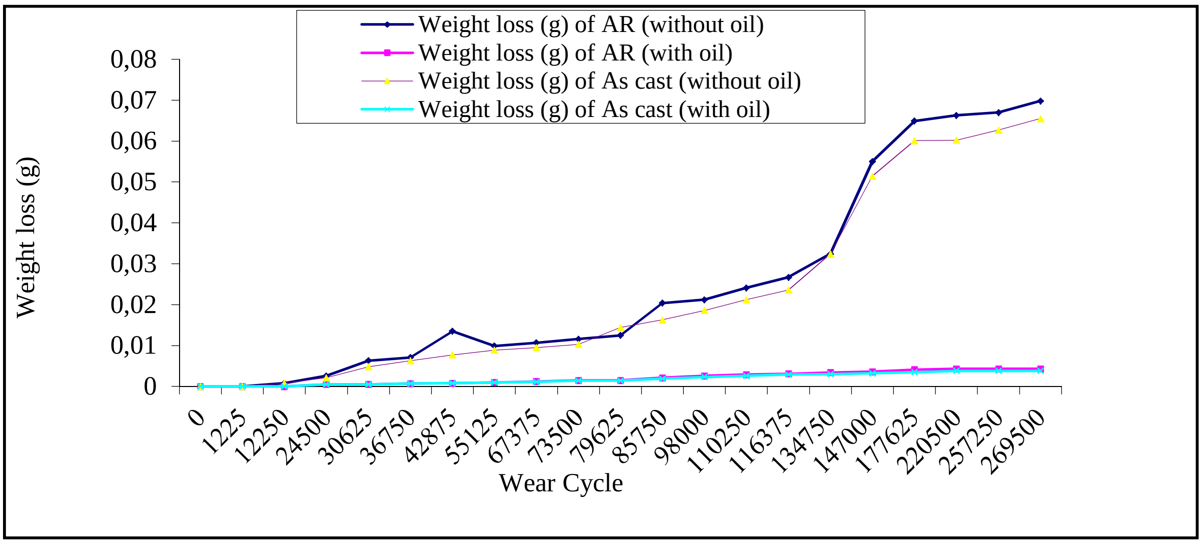



*Figure 1: Wear loss of As-received and Cast aluminium alloys with and without oil*

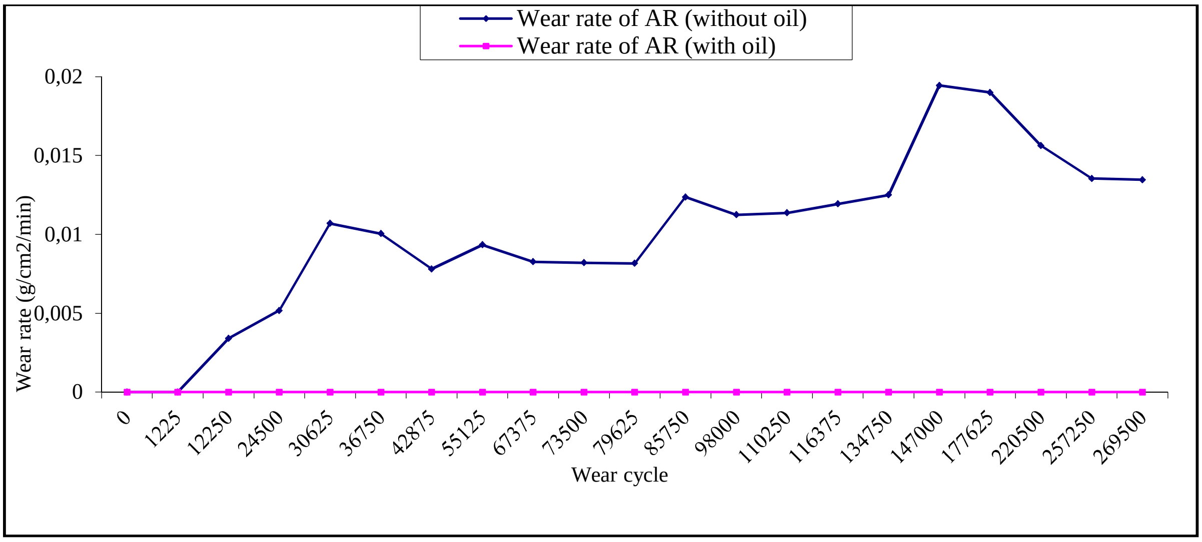



*Figure 2: Wear rate of As-received aluminium alloy with and without oil*

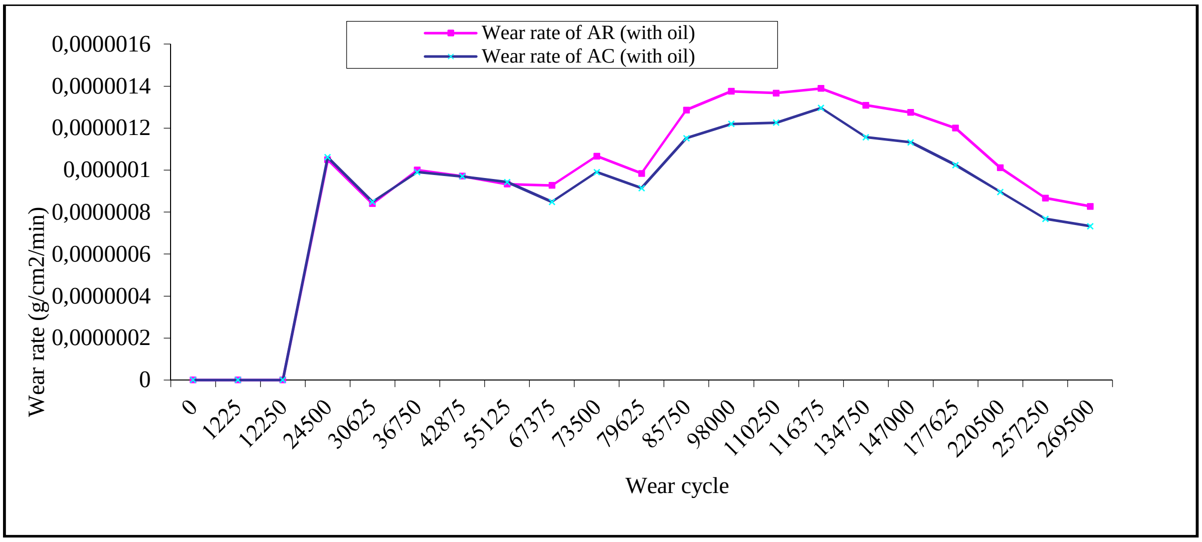



*Figure 3: Wear rates of As-received and cast aluminium alloys with oil*

The trend of the wear rate with respect to increasing wear cycle was studied using the experimental data generated from the experiment. The best fit models for the trend using MS excel application were of polynomial equations to power 2 relating the wear loss and wear rates of AR and AC to wear cycle tested with and without hydraulic oil respectively.

The models developed for the wear rate from the study are:

AR wear rate with oil $$M_{n1} = -8E\text{-}09c^2 + 2E\text{-}07c - 3E\text{-}07 \quad (7)$$

AC wear rate with oil $$M_{n2} = -8E\text{-}09c^2 + 2E\text{-}07c - 2E\text{-}07 \quad (8)$$

AR wear rate without oil $$M_{n3} = -3E\text{-}05c^2 + 0.001c - 0.000 \quad (9)$$

AC wear rate without oil $$M_{n4} = -3E\text{-}08c^2 + 1E\text{-}06c - 3E\text{-}07 \quad (10)$$

Where $0 \leq c \leq 269500$, c = wear cycle, $M_{n1}$, $M_{n2}$, $M_{n3}$ and $M_{n4}$ are the wear rates (in g/cm$^2$/min) of as-received AR and cast aluminium alloy AC with respect to wear cycle tested with and without hydraulic oil respectively. Similar trend of wear rate equations were defined by the two samples during the tests with and without hydraulic oil.

The model equation 7 for the wear of AR without oil is avoided while model equation 8 for the AR with oil is the traditional condition under which the hydraulic master brake operates.

Model equation 9 and model equation 10 are both applicable under the condition where there is need for the replacement of less wear resistant AR while model equation 10 could be applied to reduce fretting corrosion and tribocorrosion effects on the application of cast aluminium alloy in service.

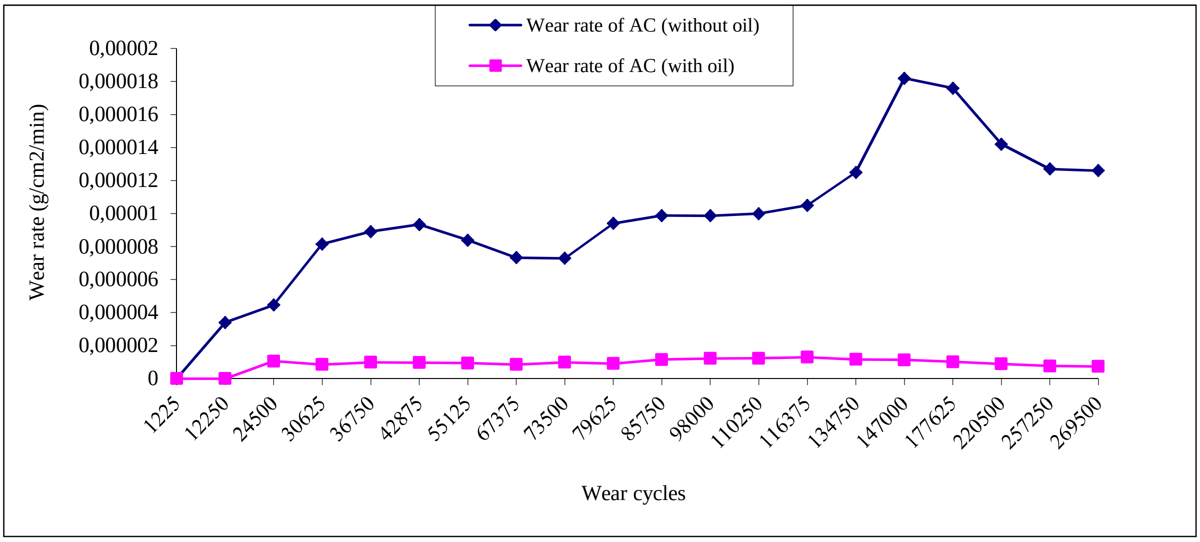



***Figure 4: Wear rates of cast aluminium alloys with and without oil***

Micrographs of as-received and cast aluminium alloy samples before and after wear tests are shown in plates 6-8 below.

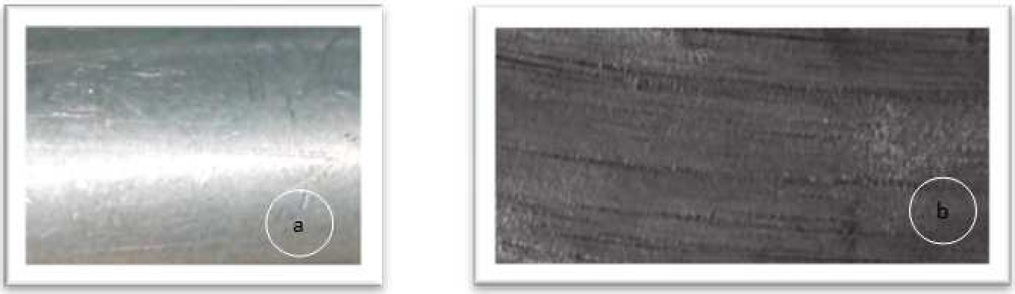



***Plate 6: As-received surfaces (a) before and (b) after wear test in hydraulic oil***


***Plate 7: As cast surfaces (a) before and (b) after machining (turning) on lathe***


***Plate 8: Machined as-cast surface after wear tests (a) with oil and (b) without oil***

## 4 CONCLUSION

The test results show cast aluminium alloy behaves relatively better than the as-received aluminium alloy specimen in oil. It is significant that the oil functions as lubricant on the alloy under test, hence the common deteriorations experience from the cast alloy under service must have aggravated from the chemical adulterations in the oil. A thin film of more wear and chemical resistance would bring effective and significant tribological and corrosion protection or even both to the surface.

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## 6 APPENDIX

***Table 2: Properties of hydraulic fluid (brake oil)***

| **Composition / Information on Ingredients** | |
|---|---|
| Ingredient Name<br>Alkylene Glycols<br>Trade Secret Inhibitor Package | % wt *or* % vol<br>5-20<br><3 |
| **Physical and Chemical Properties** | |
| Physical State | Liquid |
| Appearance and Odour | Yellow to amber liquid with a mild odour. |
| Vapour Density (Air = 1): | >1 |
| Density: | 8.33 to 9.02 lb/gal |
| Specific Gravity ($H_2O$ = 1, at 4 °C): | 1.000 to 1.070 |
| pH | 10.0 – 11.5 |
| Water Solubility: | Soluble |
| Boiling Point: | (248.9 °C) |
| Chemical name | DOT 3 brake fluid |
| Chemical Formula | Not applicable, this product is a mixture of glycols / glycol ethers |

*Source: Manufacturer-Dot Chemicals, Inc. Texas*

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