# Development of a Pin-on-Disk Wear Testing Machine

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## Abstract

Wear refers to material loss from a solid surface due to its interaction with the environment. It is generally undesirable in machine applications. A wear-testing machine is crucial for effective quality control, good manufacturing practices, and compliance with standards. Therefore, this project developed a pin-on-disc wear testing machine for tribological wear tests. This was achieved through an in-depth literature review of existing wear testing machines; their designs, operational principles, and shortcomings. A comprehensive engineering design and fabrication of a pin-on-disc wear testing machine was then carried out with a construction cost of N428,000.00. The machine was tested and performance evaluation was carried out to assess the wear resistance of nickel aluminium bronze (NAB) with 0% and 8% tin contents following ASTM G99-23 standard. The results revealed that the wear of the specimen increases with the sliding distance and load for all the NAB alloys but, stability is achieved quickly with 8% tin content due to strain hardening. The wear rate reduced from $4 \times 10^{-8}$ kg/Nm and $3 \times 10^{-8}$ kg/Nm at a normal load of 1.6 kg with the addition of 8% tin to the NAB alloy. Thus, the addition of tin to NAB alloy improved the wear resistance of the NAB alloy. Implementing this locally produced wear testing machine is an invaluable tool for students, researchers, and quality control professionals.

***Keywords:*** *Tribology, Design, Wear testing machine, Pin-on-disk, Nickel aluminum bronze*

## 1 Introduction

Wear is the surface damage or material removal from one or both of two solid surfaces in sliding, rolling, or impact motion relative to each other due to surface interactions at asperities between two contacting surfaces [1, 2]. Wear, like friction, is not an inherent material property but a system response, influenced by factors such as surface properties, type of load, motion, speed, temperature, lubrication, and environment [3]. At first, the material at the contact surface may be displaced, thereby altering the properties near the surface of the solid body. Then the displaced material may be detached from the surface and transferred to the mating surface or break loose as wear debris.

Wear is detrimental in most machine components and pairs such as: seals, bearings, cams, and gears [4]. Depending on the tribological system, wear mechanisms include adhesion, abrasion, erosion, fretting, and corrosion. Machine components may need to be repaired or replaced after minimal material removal or if the surface becomes overly rough due to wear. In well-designed tribological systems, material removal from solid surfaces is slow, steady, and continuous. It has been asserted that wear cannot be totally prevented but it can be minimised through modification of the surface properties and geometry of the contacting solids or by application of lubricants [5].

Wear testing is a method for assessing the movement of material from its original or derived location on a solid surface performed by the action of another surface. Wear test is an essential parameter for determining the quality of engineering materials and structural components, and also commonly used as a simple measure of the performance and reliability of material in service [6, 7]. Study of wear in engineering materials and components is crucial because failure of components due to wear has resulted into quite a great deal of money.

The wear testing machine is a crucial tool used in many industries such as manufacturing, engineering, and research and development, to evaluate the durability and workability of materials, coatings, and components under replicated wear conditions. Therefore, the availability of a wear testing machine for materials is the major step to effective quality control and

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good manufacturing practices for good product quality and customer satisfaction [7].

Several laboratory tribotesting equipment have been designed and fabricated for the evaluation of wear such as Pin-on-Disc (POD), Block-on-Ring (BOR), etc. Pin-on-Disc is a popular technique for sliding wear testing. Ogedengbe et al. developed a wear testing device. After the development, they evaluated its performance against an existing wear testing machine. A reliability test conducted revealed that shaft whirling when transmitting power, and the wear rate was found to gradually increase with applied pressure over time [8]. A cost-effective and efficient wear tester (Pin on Disc) used in the metallurgy research field was produced by Nassar and Nassar [9]. The machine was fabricated with locally available materials and components. Wear tests of an A356 alloy on steel using the machine, and evaluated against a standard wear testing machine, showed that the locally fabricated machine was 97% effective.

Uhuami et al. designed and fabricated a dual-working mode Pin-on-Disc wear testing machine. The machine's performance was evaluated by assessing the dry and lubricated wear resistance of Aluminum 6061 against steel at different loads, speeds and time. The results showed that the lubricated surface reduces wear to 54% and the specific wear rate test of the Aluminum was 0.2428 $\times 10^{-3}$ $mm^3/Nm$ [10].

The present study aims to develop a wear testing machine (Pin-on-Disc), with a high percentage of local content, which can be used for adhesive wear studies in laboratories. [17].

## 2 Methodology

### 2.1 Description of Machine

As shown in Figure 1, the Pin-on-Disc wear testing machine comprises the following main components: A disc, pin holder, load (weight) holder, load cell, load cell holder, lever arm, lever arm guide, electric motor, data logger, machine frame, and cover sheet.

### 2.2 Design Consideration

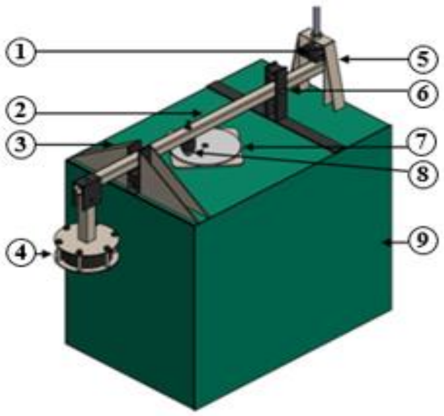
When designing the pin-on-disc wear testing machine, specific considerations were given to availability of local materials (high local content) with appropriate physical, chemical and mechanical properties for the machine components, convenience of operation (ergonomics) and safety, reliable measurements and data acquisition, cost-effectiveness, and maintenance of the machine.

### 2.3 Design Analysis

#### 2.3.1 Lever arm

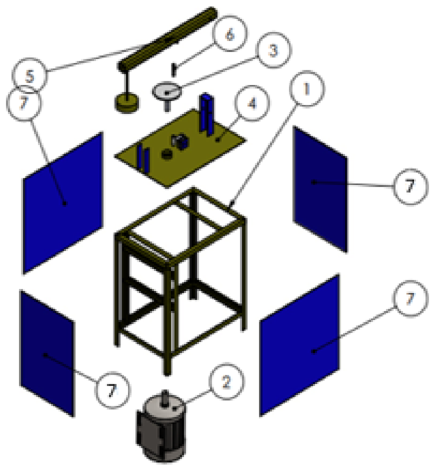
The free body and the split diagrams of the forces acting on the lever arm are as shown in Figure 2. The pivot point is taken as a hinge point.

Maximum bending moment is acting in the middle, and lever arm loading is symmetrical. It has zero shear force. The lever arm has adequate strength and capacity to withstand the highest shear load of 20 N without failure.



| S/N | Component |
|---|---|
| 1 | Load cell |
| 2 | Lever arm |
| 3 | Lever arm guide |
| 4 | Weight holder |
| 5 | Load cell holder |
| 6 | Pivot pin |
| 7 | Disc |
| 8 | Wearing pin |
| 9 | Cover sheet |

(a)



| S/N | Component | Description |
|---|---|---|
| 1 | Frame | Mild steel |
| 2 | Electric motor | Induction motor |
| 3 | Disc holder | Mild steel plate with shaft |
| 4 | Wear top cover | Mild steel plate |
| 5 | Load press bar | Mild steel pipe |
| 6 | Pin | Stainless steel r |
| 7 | Cover sheet | Acrylic plastic |

(b)

Figure 1: (a) Schematic diagram of the wear testing machine and (b) Expanded details of the designed Pin-On-Disc wear testing machine

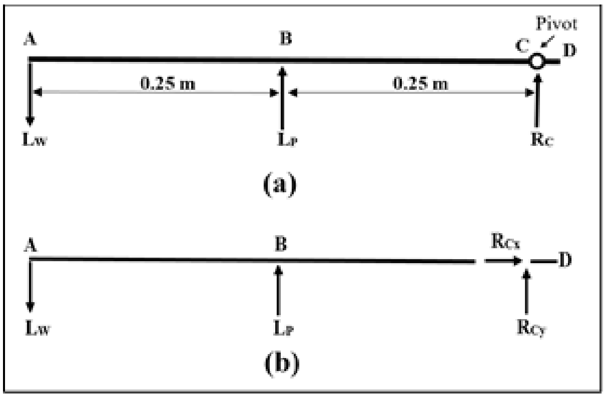



Fig. 2: (a) Free body diagram and (b) Split diagram of the lever arm

2.3.2 Pivot pin

The design stress of the pivot pin is taken as 25% of the shear stress of mild steel (300 MPa):

$$Stress = \frac{Force}{Area} \quad (1)$$

The diameter of the pin is designed as 10 mm.

2.3.3 Shaft

The shaft shear stress is designed based on the maximum shear stress theory (Guest's theory), normally used in stress analysis of ductile materials like mild steel. This is given as [11, 12]:

$$\tau_{max} = \frac{1}{2}\left(\sigma_b{}^2 + \tau^2\right)^{\frac{1}{2}} \quad (2)$$

Where: $\tau_{max}$ is the maximum shear stress (N/m$^2$), $\sigma_b$ is shear stress (N/m$^2$) and $\tau$ is shear stress (N/m$^2$).

$$\sigma_b = \frac{32M_b}{\pi d^3} \quad (3)$$

Where: $M_b$ is the bending moment (Nm) and $d$ is the shaft diameter (m).

$$\sigma_b = \frac{16T}{\pi d^3} \quad (4)$$

where: $T$ is torque (Nm).

Combining the equation as applying ASME Code Equation for solid shaft [11].

$$d = \sqrt[3]{\frac{16}{\pi \tau_{max}}\left[(K_b M_b)^2 + (K_t T)^2\right]^{\frac{1}{2}}} \quad (5)$$

where: $K_b$ and $K_t$ are combined shock and fatigue.

2.3.4 Electric motor

The relationship between the maximum torque transmitted by the shaft and the power of electric motor is given as [11]:

$$T = 9.55 \times \frac{P \times 60}{2\pi N} \quad (6)$$

Where: $T$ is the maximum torque transmitted (Nm). P is the electric motor power (W) and N is the speed of the electric motor (revolutions per minute).

From the design analysis, a 0.5 HP induction electric motor was selected to power the wear testing machine for reliable performance.

2.3.5 Control and data logger

A programmable Arduino Uno microcontroller connected and controlled the speed sensor, load cell, thermocouple and electric motor. The control board also includes an LCD (Liquid crystal display) screen, shown in Figure 3, which makes the testing process controllable, efficient and user-friendly. It displays information such as wear rates, load and time, and helps the user to monitor and control these set of information. It has a memory card port that makes information storage and retrieval possible.


Figure 3: The display on the control board interface of the wear testing machine.

## 2.4 Construction of the Wear Testing Machine

The following constructional operations will be carried out: marking out and cutting of materials, drilling, welding, filing and smoothing, painting and assembly of the machine. The important machine components that were constructed include the frame, pivot pin, load cell holder, lever arm, lever arm guide, weight holder, disc, wearing pin and cover sheet. However, the load cell, electric motor and data logger were purchased. The assembled wear testing machine is shown in Figure 4.

Figure 4: The wear testing machine.

## 2.5 Mode of Operation of the Machine

The prepared pin specimen is mounted in a holder and the disc specimen on a rotating platform or disc holder to ensure precise alignment and positioning for consistent contact during wear testing. The machine is switched on, a desired normal force (load) is then applied to the pin through the loading mechanism integrated. If the test is to be conducted under lubricated conditions, the test lubricant would be supplied to the pin-disc contact interface. The wear testing is executed by setting the timer and speed and then pressing the start button on the control panel. The pin would be brought into contact with the rotating disc under the specified load. As the disc rotates, the pin slides against it, generating frictional forces. This sliding action causes wear on both the pin and disc surfaces. Data are recorded continuously throughout the test duration using sensors and measurement devices integrated into the wear testing machine. After the test, relevant readings including speed of the disc, duration of the test, temperature, load and length of the pin during the test are collected from the data logger for further analysis to compute the frictional forces, wear volume, wear rate and specific wear rate. The analysis of these data would help to understand the wear resistance and frictional behaviour of the test materials.

## 3 Performance Evaluation

### 3.1 Experimental test

The machine was used to carry out an experimental wear test on nickel aluminium bronze alloy (NAB) in the Tribology Laboratory, Department of Mechanical Engineering, Ekiti State University, Ado-Ekiti. In a typical tribocouple, the softer of the two materials wears against the harder. In this case, the pin got worn against the disc. The pin is a nickel aluminium bronze alloy (NAB) with varying constituents, while the disc is stainless steel. The constituents of each specimen are indicated as follows:

Specimen A: nickel aluminum bronze alloy (86% copper, 0% tin, 10% aluminum, 4% nickel)

Specimen B: nickel aluminium bronze alloy (78% copper, 8% tin, 10% aluminium, 4% nickel)

The wear test was carried out according to ASTM G99-23 standard. Each specimen was weighed using a weigh balance before each test and the length before wear was also taken using a Vernier height gauge. The tip of the pin and the surface were cleaned before each wear test, and the pin was then loaded into the work holder. The machine was loaded with a known load (1.5 kg and 1.6 kg) before each test and each specimen was worn for intervals of 60, 120 and 180 seconds. After each wear, recorded parameters like the load, time, mass and height were obtained from the machine for further analysis.

The mass loss during the test is calculated as:

$$\Delta w = w_b - w_a \quad (7)$$

where: $w_b$ (g) is the weight of sample before wear and $w_a$ (g) is the weight of sample after wear.

Wear rate is computed as:

$$W_r = \frac{\Delta w}{\rho \times S_d} \quad (8)$$

where $\Delta w$ is change in Mass, $S_d$ is sliding distance and p is pressure or load.

The sliding distance is given as:

$$S_d = 2\pi RNT \quad (9)$$

where R is the radius of the rotating disc, N is the number of revolutions, and T is the time.

The results of the experimental test carried out on two different specimens using the wear testing machine for the wear performance evaluation of the specimen are presented in Table 1.

Table 1: Wear results for specimen A And B

| Time (sec) | Height (cm) | Weight (g) | Speed (rpm) | Temp (ºC) | Depth (mm) |
|---|---|---|---|---|---|
| ***Specimen A at 1.5 kg*** | | | | | |
| **Initial** | 5.30 | 26.976 | 2500 | 34 | 134 |
| **60** | 5.30 | 26.899 | 2350 | 36 | 135 |
| **120** | 5.21 | 26.710 | 2000 | 38 | 137 |
| **180** | 5.15 | 26.592 | 1878 | 44 | 140 |
| ***Specimen A at 1.6 kg*** | | | | | |
| **Initial** | 5.15 | 26.592 | 2100 | 31 | 134 |
| **60** | 5.07 | 26.291 | 1950 | 35 | 136 |
| **120** | 4.91 | 25.931 | 1760 | 39 | 138 |
| **180** | 4.20 | 25.725 | 1600 | 43 | 142 |
| ***Specimen B at 1.5 kg*** | | | | | |
| **Initial** | 5.54 | 28.321 | 3057 | 33 | 135 |
| **60** | 5.46 | 28.124 | 2860 | 36 | 137 |
| **120** | 5.29 | 28.012 | 2750 | 38 | 139 |
| **180** | 5.04 | 27.914 | 2570 | 44 | 142 |
| ***Specimen B at 1.6 kg*** | | | | | |
| **Initial** | 5.04 | 27.914 | 3500 | 31 | 135 |
| **60** | 4.97 | 27.708 | 3140 | 33 | 137 |
| **120** | 4.79 | 27.512 | 2750 | 36 | 140 |
| **180** | 4.51 | 27.394 | 2400 | 42 | 143 |

### 3.2 Mass Loss

The graphic representative of wear (mass loss) for specimens A and B at different load and wear time during the wear test is presented in Figure 5. It could observed from the figure that both specimens A and B show increasing mass loss with increase in sliding period. This is agreement with Abed [13] and Ilangovan & Sellamuthu [14]. Moving from low to higher load also causes more wear at different load. At the load of 1.5 kg specimen B consistently shows higher mass loss than specimen A. Specimen A's mass loss increases more steadily throughout the test. At 60 seconds of the test, specimen B has lost about 0.2 g, while specimen A has lost only about 0.05 g, and at the end of the test (180 seconds), specimen B has lost about 0.41 g, while specimen A has lost about 0.39 g. The gap in mass loss between A and B narrows towards the end of the test.

However, the behaviour of specimens A and B is reversed under the higher load of 1.6 kg compared to a load of 1.5 kg. Specimen A now shows consistently higher mass loss than specimen B. Specimen A's mass loss increases at a higher rate throughout the test. At 60 seconds, specimen A has lost about 0.3 g, while specimen B has lost about 0.2 g.

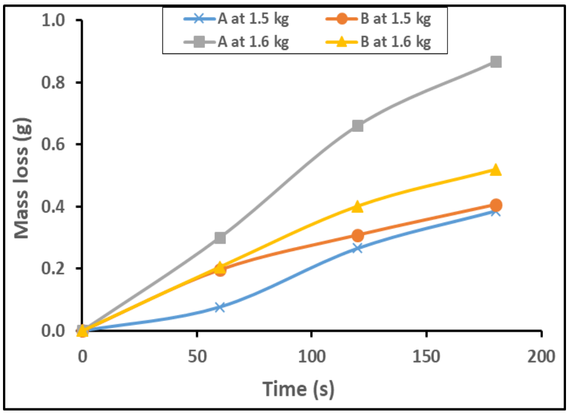



Figure 5: Wear of specimens under different loads and times

Mass loss for specimen A remains higher than specimen B throughout the test at high applied load. The gap in mass loss between A and B widens towards the end of the test which illustrates that A lost more mass than B. By the end of the test (around 180 seconds), specimen A has lost about 0.88 g, while specimen B has lost about 0.52 g. The reduction in wear can be attributed to the level of oxide formation due to tin in the NAB. This observation is in agreement with the findings of [15, 16].

### 3.3 Wear Rate

The wear rate of specimens A and B under different loads and periods is depicted in Figure 6. It was noted that there was an initial increase in the wear rate due to work hardening which is occasioned by the formation of protective layer on the metal specimen by stainless steel, and this which increases the occurrence of wear rate at the initial period. This shows consistency with previous studies that reported that objects pulled from the can cause wear [16].

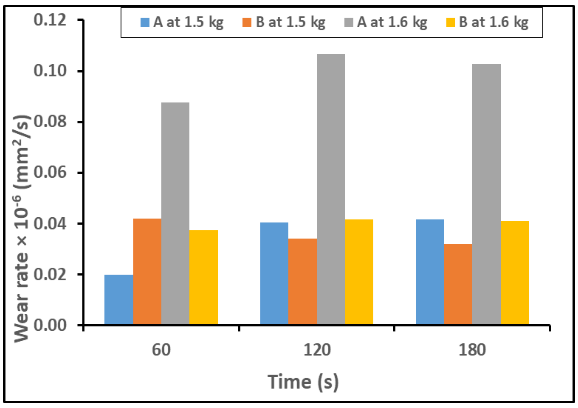



Figure 6: Wear rate of specimens under different loads and times

It was later observed that there was a slight decline towards the later end of the testing period because of the disassociation that occurs on continuous exposure of the material to the stainless support. This is due to the specimens experiencing an increase in the work hardening as also asserted by previous studies to be the result of change in grain structure of specimen due to continuous wearing [16, 17].

This specimen B experienced a decrease in the wear rate compared to specimen A, especially as the sliding period increased due to the hardness which was further aided by the addition of tin in NAB alloy [18]. With tin inclusion in tin in the NAB the wear rate high consumption dropped by approximately 60%. The observed decrease in wear rate in the alloy with tin addition can be deduced to improve in hardness of NAB due to tin addition, and it has been reported that wear resistance is inversely proportional to the hardness [16, 19, 20].

## 4 Conclusion

The concept of a locally produced pin-on-disc wear testing machine with high local content was successfully realized through an in-depth literature review of existing wear testing machines. This was followed by comprehensive engineering design, fabrication and assembly of the machine. This has shown that it is feasible to produce a pin-on-disc wear testing machine with high local content, and local production of wear testing machines will reduce dependence on expensive imported machines. Wear performance of NAB carried out using the machine showed that wear rate increased initially and later on maintain an equilibrium which have been deduced to be as a result of work hardening of the specimens as time increases for NAB alloy with and without tin in its constituent. Addition of tin to NAB alloy improved the wear resistance of NAB alloys. Further research work will focus on the development of other types of wear testing machines suitable for wear research.

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