

# Design, and fabrication of Pin on disc apparatus for investigation of tribological performance of base metal, Alloy, and Polymers against Mild Steel for sliding wear

Ritul Chirde<sup>1</sup>, Pramodini Patil<sup>2</sup>, Atharv Ambavale<sup>3</sup>, Mihir Mulay<sup>4</sup>, Ashwin Chandore<sup>5</sup>

<sup>1</sup>*School of Mechanical and Civil Engineering, MIT Academy of Engineering*

<sup>2</sup>*School of Mechanical and Civil Engineering, MIT Academy of Engineering*

<sup>3</sup>*School of Mechanical and Civil Engineering, MIT Academy of Engineering*

<sup>4</sup>*School of Mechanical and Civil Engineering, MIT Academy of Engineering*

<sup>5</sup>*School of Mechanical and Civil Engineering, MIT Academy of Engineering*

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## Abstract -

Wear is the principal reason and a mechanical failure of parts and it prevails when there are two surfaces in contact with sliding or rotating motion. This document defines the design process for the development of a pin-on-disc (POD) wear test device and the evaluation of tribological characteristics of base metal (copper), alloy (brass), and polymers (Nylon and Teflon) in the implementation of the frictional and wear principle, in other words, wear anomalies on a pin into a circular disc of mild steel while adjusting the motor speed that used a variable frequency drive (which can change the frequency and correspondingly set the speed of the motor) and testing parameters like speed, time, load, and contact geometry. A pin-on-disc wear analyser is crucial when developing new and enhanced applications that can save a fortune. Static structural analysis is been also carried out to assess the well-built POD testing components for enduring stresses and vibrations.

**Key Words:** Adhesive, Friction, Pin on Disc, Tribology, Wear

## 1.INTRODUCTION

The principal reason for mechanical part failure is wearing. Huge economic losses might result from the energy loss brought on by friction as well as the material loss brought on by wear. Wear is a type of mechanical failure that frequently takes place between two surface contact as it has a lot to do with the composition and its qualities as well as the accuracy of manufacturing of the component. Additionally, there is a significant correlation between wear and lubrication and surface contact conditions. Studying wear is done to verify that the device has enough wear resistance to withstand normal operation, minimize wear, and enhance the service life of parts [1,2]. The rubbing between two contacting materials has triggered something of a revolution, and pin-wear testing has become a legitimate scientific field. A substantial surface's exposed face may lose material as a result of pin disc wear tests interfaces with interface materials and the environment [3,4].

The adoption of abrasive testing techniques ASTM G99 As well as ASTM G65 in the industry demonstrates the requirement for abrasive wear monitoring to address issues. Adhesion is a significant source of sliding resistance (friction), and mechanics has demonstrated that it has a role in wear. In the survey of the literature [5] on wear testing, 286

articles and other resources were looked at. It was noticeable when the publications were studied, it became apparent that only a small proportion of them made any mention of any applicability that applied to the wear test discussed in the study. Oscillating tests like POD and revolving tests were among the maximum often cited tests when the prevalence with which various test techniques were mentioned in the research pieces of literature were examined [1].

At all technological levels where the friction of surfaces is involved, the invention and study of pin wear testers are ultimately aimed at minimizing and eliminating losses caused by wear and friction [6,7]. In addition to traditional materials, more complex compound materials (composites) with lower wear rates are preferred since they are relatively valuable and need a longer manufacturing procedure in comparison. Short carbon fibers (CF) are added to the epoxy resin matrix to improve its compressive strength and creep resistance. The wear and tear resistance of a substance is typically thought of as the direct opposite of the wear and tear rate. Numerous experiments have been done on polymer mix for the determination of wear attributes [8].

Numerous types of wear and tear prevail in practice, and there has been a significant study about the bracket of these different types of wear and tear. The microstructures of each case are also checked with the help of a microscope to understand further about wear and tear. A usual bracket has been used then which is grounded on the medium that's operating to produce the wear and tear damage [1]. Abrasion is a kind of wear in which substances are harder than abraded surfaces and is happening by wearing, grinding, or rubbing away as a result of friction. As the surfaces of different materials move over each other there is an interaction between the high location which causes wear debris i.e., occasional removal of particles. Fretting happens when there is slight oscillatory tangential relative movement between two contacting surfaces, which are frequently ostensibly at rest. The surface is cleaned of tiny metal flecks, which are subsequently oxidized. In the operation of cutting there is the likelihood that cutting tool and workpiece contact may result in high friction which may lead to the high temperature at the contact regions and the tool diffuses into the workpiece resulting in the phenomena of wear and more precisely to be as diffusion wear.

This document aims to study the tribological performances of metals, base metals, and polymers the POD apparatus is

designed and modeled as the existing models or the apparatus present cost a hefty and the designed model must be durable enough to withstand loads and the environment, hence stationary structural analysis has been done before the development of the model. The reading required for reporting the test results is described to analyze the wear of pin materials.

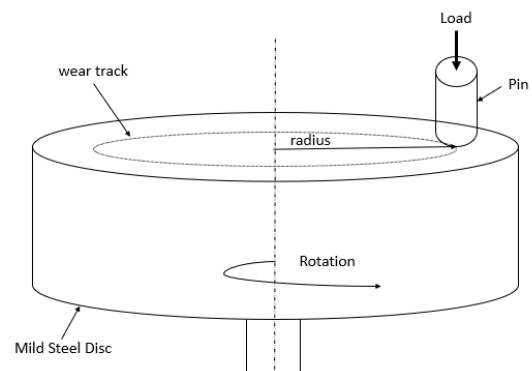
## 2.METHODOLOGY

In order to examine the tribological characteristics the process of wear is been carried out in a controlled manner. For the cover test, two materials are needed. Firstly, the pin tip is deposited vertically into a flat circular disc. The test machine causes the disc to rotate and the pin to be stationarily loaded on it with contact being held or the pin to be revolving on the stationary disc. In either case, the sliding path is the same i.e., the pin will be rotated in a circular motion on the face of the disc. A point, flat or a sphere-shaped indenter, or the pin (test sample) is loaded onto the disc with a precisely known force. The indenter (a point or a ball-shaped from tip) is mounted in the chuck which is attached to the lever and the disc and motor end, where the load in the form of weights is applied on the opposite end of the lever, resulting in the load between pin and disc. The lever is supported at the center termed the fulcrum point with help of bolts assumed to have negligible frictional resistance for smooth movement so that the load applied is accurate. Figure 5 depicts the working model of POD. The disc is coupled to the motor shaft which is removable and the disc mounting has interchangeability. The speed of rotation of the disc will be the same as that of the motor. The direct press fitting method is used to avoid the speed transmission and conversions with the help of mechanical linkages or structures instead a Variable Frequency Drive is used. The VFD can vary the speed of the motor i.e., reduction and increment by adjusting the frequency switch. A POD apparatus proves to have many distinct up points over other methods as the pins have high interchangeability and easy manufacturability because of the less complex shape. Hence pins of various materials from the industry or sometimes for special applications the pin of the required material can be developed and tested [9]. Wear phenomena are also highly dependent on the testing condition. With the help of testing and evaluating parameters, the test is performed to prognosticate the wear performance. Figure 1 describes the general layout of the pin-on-disc tester.

### 2.1. SIGNIFICANCE OF WEAR TEST IN INDUSTRY OR LABORATORIES

There are several different reasons for performing wear tests [10]. These are based on the operations, practical importance, testing, and finding the failure mode of the pre-existing machine which has sliding or rotating components with contact. The most basic necessity is to gather sufficient information on wear and tear present in the material of the service in use and understand the effect of wear on it. Usually, tribological tests are carried out in the labs so that the environment can be controlled which can either be ambient present conditions or artificially stimulated conditions for the test so that the variations in the microstructures of material due to the frictional effect prevailing can be studied deeply with microscopy. POD test is not used for a single material of

the specimen but it gains significance when there is a comparison between two materials which can be used to determine the more superior one. Thus, due to this, the in-service material can be replaced with factual machine factors for efficient working and longer life cycles. Various prototypes are developed with the help of the wear, frictional i.e., the tribological data, various elemental trials can be conducted to bench new development and final operation in controlled conditional than real in life employment. Troubleshooting is carried out with POD testing i.e.; the test can determine the cause of failure of any machine or service in the application if it failed due to wear.



**Fig -1: Pin on Disc general layout**

Wear tests are crucial in a variety of industrial sectors, including those that process materials, generate materials, and operate with aerospace, packaged goods, vehicle components, and packaging. Abrasive wear mechanisms account for 60 - 63% of the contribution and cover 0.15 – 0.16 % of the outlay of wear as a proportion of the entire turnover of an organization or company, etc. [11].

### 2.2. APPLICATION OF PIN ON DISC WEAR APPARATUS AS PER SIGNIFICANT WEAR PROBLEMS

Common and significant wear problems prevail in the industry and pin-on-disc wear tests can be used in various applications [11]. In the automobile sector where brakes and clutches are the most important components, there is the existence of wear, to be more precise adhesive wear as there is contact sliding amongst metals and nonmetals. In implementations, the wear of metal parts in contact with a series of other solid structures is based on adhesive and abrasive wear, but the components of the wear process are constantly been updating in the cylinder liner and piston rings so that the technology keeps on upgrading with good quality and high strength materials. Alongside this hip joints and dry rubber, bearings are also a part of a wear problem.

Tools used in the manufacturing of stamping tools, press tools, sintering dies, cutting tool blades, etc need to be checked for wear phenomena to increase their working life which will ultimately reduce the recurring purchase costs and maintenance costs of them. Additionally, in Digger teeth, Rotors of powder mixes, and Extrusion dies for bricks and penstocks where the wear of an exposed face by hard patches in a compliant bed of material and it's caused due to significant characteristics of Abrasion, with the force of

abrasive continuously renewed by the movement of the bed of material and Pivot legs in construction instrument.

The prime uses of aluminum alloy forming techniques are applied for aerospace sector applications due to its favorable material characteristics of having considerable strength and less weight. However, it is been seen that in the last few decades there are advancements in the manufacturing core sector and machining techniques have shifted their focus to less harmful environmental procedures by diminishing or eliminating the usage of cutting tools for highly precise and accurate manufacturing. POD tests are also important for Scraper blades in plaster mixing machines. Shaft seals for fluids containing abrasives where the wear of metal shells in collective rubbing contact, with abrasive patches, present and is a type of three-body abrasion (solid abrasive-solid) with an ongoing force of new abrasive pits [12].

As cutting tools are in direct contact with the workpiece there exhibits amplification of the wear in this process of conventional manufacturing technique, resulting in deviations from initial project constraints [13,14]. Thus, to ensure final tolerances, it is crucial to maintain the cutting tool's original geometry for as long as feasible [15].

The important reason for the preliminary study on the tribological performance between two product machines and the tools which are necessary for such scenarios is to retain precise and strong influence on the process constraints and set stronger and greater performance standards.

### 3. DESIGN PROCESS OF PIN ON DISC

#### 3.1. MODEL DEVELOPMENT

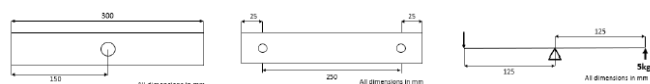
The fabricated model strongly resembles the cad model developed. The material used here for the model is Mild steel due to its mechanical properties which are listed in Table 1.

**Table -1: Properties of Mild Steel for Frame Development**

| Material   | Phase Present | Tensile Strength (Ultimate) | Brinell Hardness Number | Capacity to conduct heat  |
|------------|---------------|-----------------------------|-------------------------|---------------------------|
| Mild Steel | Solid         | 400 to 550 Mega Pascals     | 120 BHN                 | 515 Joules/ grams. Kelvin |

#### 3.1.1. LEVER

For the application of force on the pin force analysis of the Lever is been carried out. Figure 2 shows the overall length of the lever and the distance of the fulcrum.



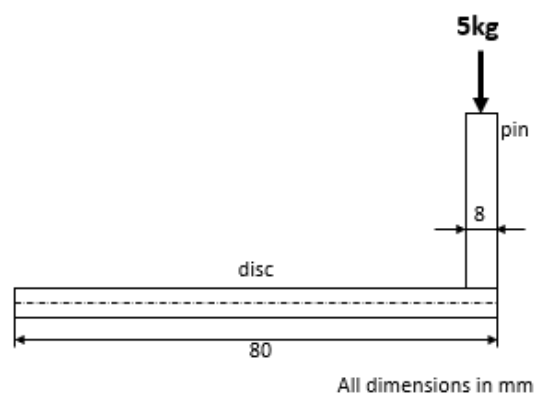
**Fig -2: Distances of the fulcrum**

The schematic diagram of Class 1 in Figure 3 which resembles a Lever by taking moment action on both sides of the lever is equal and it can be expressed as,

Applied Load  $\times$  Distance between weight and fulcrum = Pin Load  $\times$  Distance between pin and fulcrum, considering for maximum loading condition we have,

$$5 \times 125 = F_1 \times 125$$

$$\text{Pin Load} = 5\text{kg}$$



**Fig -3: Schematic diagram for motor torque**

#### 3.1.2. REQUIRED MOTOR

Torque Calculations for rotating the disc against the applied load on the pin. The schematic diagram is in Figure 3.

Diameter of the disc specimen = 100 mm (upper limit specified [18]), Pin specimen diameter = 8mm (range 2 mm – 10 mm [18])

Coefficient of friction between steel and steel = 0.5,  $F$  = maximum force that can be applied on the pin = 5kg = 49.05 N

$$\text{Motor torque required} = F \times (1002 - 4) \times u$$

$$\text{Required torque} = 49.05 \times 46 \times 0.5, \text{ Required motor torque} = 1128.15 \text{ N.mm} = 1.128 \text{ N.m}$$

Therefore, the Motor selected for this purpose is Kissan Electric Co. Faridabad (India) 3 phase motor, 0.5 Hp, 1440 rpm, foot mounted with the torque of 3.32 N.m

#### 3.1.3. CONTROLLING THE SPEED OF THE DISC

For varying the rpm of the motor, we have used the Variable frequency drive. For varying speeds of the disc between 60 r.p.m – 600 r.p.m. It will reduce the rated rpm of the motor which was 1400 rpm. The VFD is a standardized way of varying the rpm with the help of varying frequency. Delta VFD004EL21W-1 is used here and is shown in Figure 4



Fig -4: VFD [16]

### 3.1.4. LOAD

Deadweights are standardized laboratory dead weights and the pulley used is of aluminum which has a maximum load capacity of 7 kg

### 3.1.5. MODEL

The wear test rig is fabricated using the Mild steel of L section 50 mm width 50 mm height and 5 mm thickness. Figure 5 (a) and (b) represent CAD Model and Fabricated Model respectively.



Fig -5: (a) CAD Model and (b) Fabricated Model

## 3.2. VALIDATION USING STATIC STRUCTURAL ANALYSIS

The lever is the most important part of the design as it has to sustain the loading and unloading of applied load thus so at 50

N, the static structural analysis test results are obtained. The stress induced in the lever by fixing the fulcrum and opposite end of the pin side and the displacement results of the lever are in Table 2 and Table 3 respectively, while both parameters are depicted in Figure 6 -a and Figure 6 -b

Table -2: Stress Analysis Result

| Name    | Type                  | Min                       | Max                       |
|---------|-----------------------|---------------------------|---------------------------|
| Stress1 | VON: von Mises Stress | 1.748e+04N/m <sup>2</sup> | 1.919e+07N/m <sup>2</sup> |

The displacement of the lever at 50N is in Table 3 and Figure 6.

Table -3: Displacement analysis results

| Name          | Type                        | Min         | Max         |
|---------------|-----------------------------|-------------|-------------|
| Displacement1 | URES-Resultant Displacement | 0.000e+00mm | 4.572e-02mm |

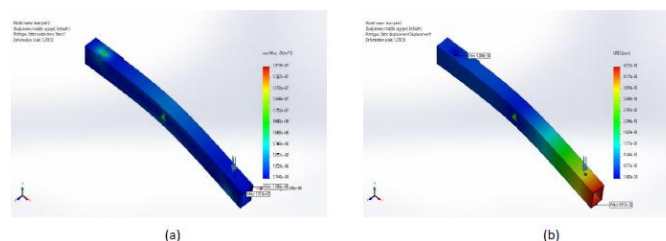


Fig -6: (a) Stress Analysis and (b) Displacement Analysis

Other components of the body are selected considering the vibration of the motor and weight. From the above readings, it is noticeable that there is not much deflection of the lever against the applied load for up to 50N and letting the test be carried out under 30N for the POD test.

## 4. TEST METHOD

- Before the POD wear test, the disc and pin specimen should be cleaned properly. There should be no presence of foreign particles on the specimens. Appropriate cleaning solutions can be used which are not chlorinated and are not forming any film on the specimen. There should be no traces of the cleaning fluid.
- As the specimen is cleaned properly with no traces of any external particle, it should be properly measured in terms of length and weight.
- The disc with mount should be properly coupled to the motor shaft and it should be perpendicular enough to the revolution axis so that there are no runout errors.
- A chuck is attached to the lever for holding the pinned specimen which is the main part to be tested against the disc. The pin should be perpendicular to the disc surface. At the contact of the pin and disc, adjustments can be made so that they both are mutually perpendicular to each other.
- A counterweight should be applied on the other end of the lever which will press the pinned specimen against the rotation disc.
- POD test must begin only when the specimens are perpendicular and in contact with the applied loads.

- The necessary test parameter and experimental reporting parameters should be preserved for deriving the conclusion. The specimens should be noted for any wear scars.
- As there is a continuous rotation of the disc and constant application of load as the pin presses over it there is a rise of normal stress and shear stress which can cause the plastic deformation of the material from the surfaces as well as surface hardening in this process of frictional pair contact [12].

#### 4.1. FORMULAS AND REPORTING FOR THE EXPERIMENTAL PROCEDURE

The resistance of wear is the phenomenon in which the results are obtained by checking the weights of the specimen prior to and after the POD tester to be used in the application where the performance of tribology is of utmost importance [17]. This is given by:  $D(W) = W_i - W_f$ , where,

$D(W)$  is the change in wear of the specimen to be examined,  $W_i$  is the weight of the pin specimen prior to the POD test,  $W_f$  is the weight of the pin specimen after the POD test,

Similarly, the reading of change in length is taken into consideration. At two demonstrative locations on the pin tip and the circular disc surface, the measurement of wear scar should be measured and then the final reading should be their mean. In some scenarios where the wear is rigorous on both the parts viz. pin and circular disc, it becomes utmost necessary to measure the wear dept profile on both the parts. Stylus profiling calculates the change in dimension which ultimately is the loss of volume due to wear and is one of the best methods in this case as it will be put into service for determining the accurate post-test shape. Changes in the linear dimension of both the pin and disc of the samples help gain knowledge of the material loss. With the help of appropriate densities of both pin and disc, the change in mass can be determined. Mass-to-volume loss conversion can be carried out with the formula stated [17].

Loss in volume,  $\text{mm}^3 = \text{mass loss, grams} / \text{density gram/cm}^3 \times 1000$

When the wear test is carried out between specimens and there is a significant transfer of material between them without loss from the system in such cases the test result should be discarded and the test reporting should not be used and it will not reflect the adequate volume and mass loss and thus it will not show the accurate reading or wear severity.

#### 4.2. EXPERIMENTAL TEST SPECIMEN PREPARATION

POD is been carried out in open systems at ambient available conditions and in some instances, the test conditions are altered to high temperatures and diverse environments conditions for the required application of the specimen in service. The insisted test conditions at the ambient

environment where is the load which is been applied on the pin which will ultimately put a force on the disc, the speed on the motor which will rotate the circular disc. All the parameters of POD and specimen preparation are as per the standards mentioned in [18] Test condition – Load to be applied on the pin, Speed of motor (rotation of disc), pin tip i.e., the contact (flat-ended pin, chamfered pin or rounded pin or ball (up to 10 mm diameter), duration of the test. and measurements made are of Change in length of the pin, reduction in the weight of the pin, and examination of worn surface. The mild steel disc which is put into rotation on the motor has a thickness of 10mm and a diameter of 100 mm. In order to study the friction properties, experimented with the atmospheric condition which was 24 degrees Celsius, and Relative Humidity at 90 %.

#### 5. TEST RESULTS

The volume of wear of the pin and the loading force which is been applied with the help of counterweights and class 1 lever had roughly directly proportional positive co-relationship between each other. As the actual contact area between the pin specimen and the circular rotating disc increases, there are chances of increasing in the plastic deformation of the pin.[19]. In the standard ASTM International, ASTM G99-04 the frictional effects of the pin are expressed in terms of the pins' materials volume change/loss in  $\text{mm}^3$  which is the function of the sliding length on the pin [20]. The effects on pin specimen in terms of length and weight are:

Parameter (A) - The duration of the disc rotation was set to 120 seconds at 695 rpm at 50Hz frequency in VFD for the weight of 1831 grams which will result in a force of 17.956 N on the disc with help of a pin and lever. The pins have a diameter of 6mm. The disc has a diameter of 100mm and a thickness of 6mm. The wear track diameter is 80mm. The results are as follows.

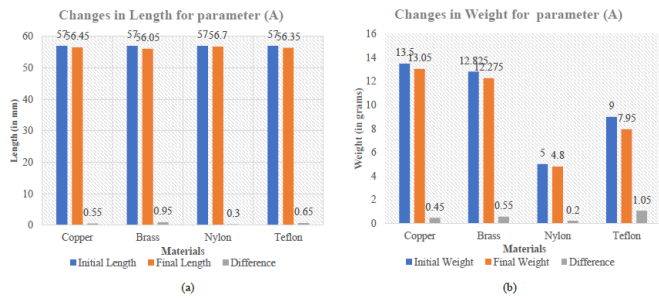
The reduction in lengths is in Table 4 whereas weight loss results are in Table 5 whilst both are graphically represented in Figure 7 (a) and Figure 7 (b) respectively.

**Table -4:** For test Parameter (A) reduction in length (in mm)

| Material       | Copper | Brass | Nylon | Teflon |
|----------------|--------|-------|-------|--------|
| Initial Length | 57     | 57    | 57    | 57     |
| Final Length   | 56.45  | 56.05 | 56.7  | 56.35  |
| Difference     | 0.55   | 0.95  | 0.3   | 0.65   |

**Table -5:** For test parameter (A) reduction in weight (in grams)

| Material       | Copper | Brass  | Nylon | Teflon |
|----------------|--------|--------|-------|--------|
| Initial Weight | 13.5   | 12.825 | 5     | 9      |
| Final Weight   | 13.05  | 12.275 | 4.8   | 7.95   |
| Difference     | 0.45   | 0.55   | 0.2   | 1.05   |



**Fig -7:** (a) Variations in Changes in Length and (b) Variations in Change in Weight

Parameter (B) - The duration of the disc rotation was kept to 150 seconds for the weight of 2751 grams which will result in a force of 26.9781 N on the disc with help of a pin and lever. The pins have a diameter of 6 mm. The disc has a diameter of 100mm and a thickness of 6mm. The wear track diameter is 80mm. The results are as follows.

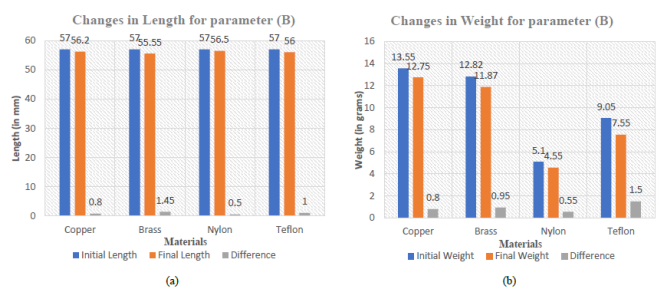
The reduction in lengths is in Table 6 whereas weight loss results are in Table 7 whilst both are graphically represented in Figure 8 (a) and Figure 9 (b) respectively.

**Table -6:** For Test parameter (B) reduction in length (in mm)

| Material       | Copper | Brass | Nylon | Teflon |
|----------------|--------|-------|-------|--------|
| Initial Length | 57     | 57    | 57    | 57     |
| Final Length   | 56.2   | 55.55 | 56.5  | 56     |
| Difference     | 0.8    | 1.45  | 0.5   | 1      |

**Table -7:** For Test Parameter (B) reduction in weight (in grams)

| Material       | Copper | Brass | Nylon | Teflon |
|----------------|--------|-------|-------|--------|
| Initial Weight | 13.55  | 12.82 | 5.1   | 9.05   |
| Final Weight   | 12.75  | 11.87 | 4.55  | 7.55   |
| Difference     | 0.8    | 0.95  | 0.55  | 1.5    |



**Fig -8:** (a) Variations in Changes in Length and (b) Variations in Change in Weight

Parameter (C) – The duration of the disc rotation was kept to 180 seconds for the weight of 3660 grams which will result in a force of 35.89 N on the disc with help of a pin and lever. The pins have a diameter of 6 mm. The disc has a diameter of 100mm and a thickness of 6mm. The wear track diameter is 80mm. The results are as follows.

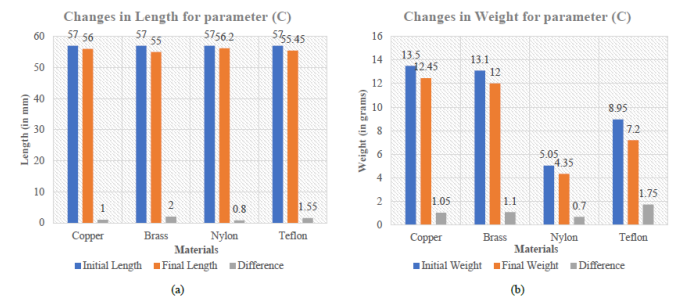
The reduction in lengths is in Table 8 whereas weight loss results are in Table 9 whilst both are graphically represented in Figure 9 (a) and Figure 9 (b) respectively.

**Table -8:** For Test parameter (C) reduction in length (in mm)

| Material       | Copper | Brass | Nylon | Teflon |
|----------------|--------|-------|-------|--------|
| Initial Length | 57     | 57    | 57    | 57     |
| Final Length   | 56     | 55    | 56.2  | 55.45  |
| Difference     | 1      | 2     | 0.8   | 1.55   |

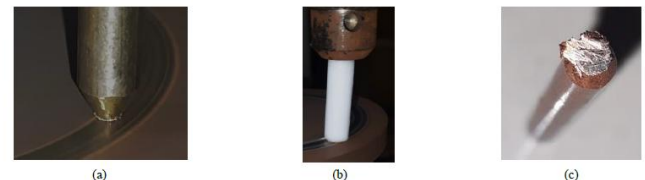
**Table -9:** For Test parameter (C) reduction in weight (in grams)

| Material       | Copper | Brass | Nylon | Teflon |
|----------------|--------|-------|-------|--------|
| Initial Weight | 13.5   | 13.1  | 5.05  | 8.95   |
| Final Weight   | 12.45  | 12    | 4.35  | 7.2    |
| Difference     | 1.05   | 1.1   | 0.7   | 1.75   |



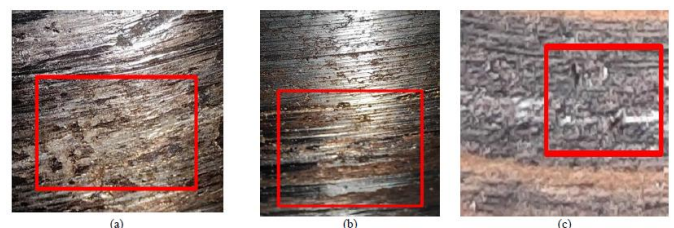
**Fig -9:** (a) Variations in Changes in Length and (b) Variations in Change in Weight

The pins' values for weight loss and volume and weight loss increased with sliding length at the increase in timing at constant speed on disc rotation at 695 rpm in this case showing a directly proportional relationship and harmonizing with earlier research findings [19]. Figure 9-a depicts the experimental photo of a pin pressed against a rotating disc.



**Fig -10:** (a) Experimental photo of copper pin pressed against the disc, (b) Polymer pin pressed against the disc, and (c) Brass Pin tip after test

It is been noted that the polymers Nylon and Teflon have shown a flexure against the rotating mil steel disc. Figure 9-b shows Nylon has more flexure and there is an inclination of 0.75o to 1o from its lateral axis with a time duration of 120 seconds for an applied load of 26.9781 N. Additionally, there is powder material erosion from the pins' surface contact with the disc of Teflon polymer at 26. 9721N.



**Fig -10:** (a) Copper pin against mild steel disc, (b) Brass pin against mild steel disc, and (c) Pits on mild steel

Figure 10 (c) shows the heavily damaged pin tip of brass at Parameter -C. For higher loads, Figure 11 (a) depicts that the copper pin's small particles were stuck in the direction of the wear track of the mild steel disc, Brass pin eroded material is visible in Figure 11 (b) and Figure 11 (c) shows pits occurring on the mild steel disc due to brass.

## 6. CONCLUSION

As the test is been carried out for base metal copper, brass alloy and nylon, and Teflon from the polymer category. With this study, there is more change in volume, reduction in length, and weight of brass alloy for all the test parameter conditions at applied loads compared to other pin materials. Pitting arose when the load is increased. Although for polymers, Nylon has shown fewer deviations in length and weight compared to Teflon. Thus, showing that the material is a good alternative in the application again the material which has characteristics or BHN similar to Mild Steel. The wear volumes are thus appreciatively identified with the loading forces when speed is constant. Pin-on-disc wear apparatus is the crucial approach and underlying means for carrying the wear performance evaluations, additionally with details study the plasticity of material in the application can also be estimated. POD test results provide great benefactions for gauging innovation methodologies for increasing the life cycle of the component in service and achieving greater service efficiency and effectiveness of the materials as there is an increase in force on it. Hence, wear testing is the system for analyzing the friction or erosion due to rotation or action of rubbing of two surfaces which leads to the relegation of the materials from their primary form. Material which doesn't work well in friction and wear phenomena is important for this mechanical test as the factual results can be witnessed. As there is an increase in weight the load also increases between the pin and disc; The pin and disc get pressed and thus the effects of load on adhesive wear were egregious due to this friction prevailing in such conditions giving rise to pits. The openness of a wear and tear testing machine and its practical results are the step towards effectual quality control and sound manufacturing practice with acceptable materials in application.

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