The Effect of Speed on Coefficient of Friction in African Plum Oil (*Dacryodes Edulis*) Lubricant

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ABSTRACT---- *One of the major factors influencing the variation of friction between surfaces in contact is the speed; we are faced here with the problem of determining the optimum speed between surfaces in contact in order to improve on the mechanical properties and performance of the entire system. This project investigates experimentally the effect of rotational speed on the (CoF) between aluminum disk test samples in contact with stainless steel pin using plum oil as a lubricant under thin film lubrication conditions. We first extracted plum oil using the manual pressing method and then carried out friction tests on a pin-on-disk tribometer as per ASTM-G 99 standards at room temperature. Rotational speeds between 500rpm and 3000rpm and normal loads of 10N and 20N were deployed as the operating variables and the variation of the (CoF) at predefined rotational speeds and normal loads was studied. Working time for each test was 20 minutes and each test was run twice and average value of friction force calculated. It was observed the CoF decreases with increasing rotational speed from 500rpm-1500rpm speed range and increases with increasing rotational speed from 1500rpm-2500rpm speed range while there is a slight drop from 2500rpm-3000rpm and an optimum speed range attained between 1250rpm-1500rpm where we experienced the least value of coefficient of friction for this specific material combination and test conditions. To further investigate other factors that affect the coefficient of friction and the validity of these results, more studies are needed.*

Keywords---- Friction coefficient, rotational speed, plum oil, lubrication, pin-on-disk tribometer
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1. INTRODUCTION

Study of mechanics of friction and the relationship between friction and wear dates back to the sixteenth century, almost immediately after the invention of Newton's law of motion. It was observed by several authors that the variation of friction and wear rate depends on interfacial conditions such as normal load, geometry, relative surface motion, sliding speed, surface roughness of the rubbing surfaces, and.type of material, system rigidity, temperature, stick slip, relative humidity, lubrication and vibration. Among these factors, sliding speed and normal load are the two major factors that play significant role for the variation of friction and wear rate**(Nikos Kournetas, 2003)** *(Kumar et al., 2006).*

According to **Riyadh A *et al* (2012) and** Wahlstrom *et al* **(2017)** several factors affect the wear equations, such as operational parameters, topography of the surface contact, geometry, speed, load, and coefficient of sliding friction. In addition, material and environmental parameters, various material hardness, temperature, elasticity, breakage, as well as thermal properties, also affect wear. Further, the type and amount of lubrication and surface cleanliness also affect wear, which can cause stoppage in operation (Liew *et al.,* **2014),**(Quinchia,*et al.,* **2014).**The strength of many metals and nonmetals is greater at higher shear strain rates which results in a lower real area of contact and a lower coefficient of friction in a dry contact. On the other hand, high normal pressures and high sliding speeds can result in high interface (flash) temperatures that can significantly reduce the strength of most materials. Yet in some cases, localized surface melting reduces shear strength and friction drops to a low value determined by viscous forces in the liquid layer **(M. A. Chowdhury *et al.,* 2011).**

Part of the observed friction reduction is due to negative slope of the dependence of the friction force upon speed. The friction force is a function of speed and time of contact. For most materials, when the speed increases, friction decreases and when duration of contact increases, friction increases. The dependence of friction on speed may be explained in the following way: When speed increases, momentum transfer in the normal direction increases producing an upward force on the upper surface. This results in an increased separation between the two surfaces which will decrease the real area of

contact. Contributing to the increased separation is the fact that at higher speeds, the time during which opposite asperities compresses each other is reduced increasing the level on which the top surfaces moves. **(Sukirno, R. F. *et al.,* 2009),** (Zhang H *et al.,* **2016),**

In the case of materials with surface films which are either deliberately applied or produced by reaction with environment, the coefficient of friction may not remain constant as a function of load. In many metal pairs in the high -load regime, the coefficient of friction decreases with load. Increased surface roughening and a large quantity of wear debris are believed to be responsible for decrease in friction. It was observed that the coefficient of friction may be very low for very smooth surfaces and/or at loads down to micro to Nano newton range **(M. A. Chowdhury *et al.,* 2012).**

African plum, known scientifically as *Dacryodes edulis*, is an oliferous fruit tree that originates from Central Africa and the Gulf of Guinea and spreads nearly all over the western coast of Africa. It is an evergreen tree attaining a height of 18–40 meters in the forest but not exceeding 12 meters in plantations. It has a relatively short trunk and a deep, dense crown. The bark is pale gray and rough with droplets of resin. The fruit is an ellipsoidal drupe which varies in length from 4 to 12 cm. The skin of the fruit is dark blue or violet, whereas the flesh is pale to light green. The tree flowers at the beginning of the rainy season and bears fruits during 2 to 5 months after flowering. (IA Ajayi *et al*., 2002) (Z Tchoundjeu *et al*., 2002)

The fruits and seeds of this plant have been found to contain reasonable amounts of oil and contains the following acids: palmitic acid (9.06%), stearic acid (15.46%), oleic acid (26.63%) and linoleic acid (30.85%). The physicochemical properties of African plum oil are: average melting point (80°C), refractive index (1.456), viscosity (0.33 poise), free fatty acid (1.100%), saponification value (143.760 mgKOH/g), iodine value (44.079 gI_2/100g), acid value (15.280 mgKOH/g), ester value (128.480) and unsaponifiable matter (53.920%). (KADJI B. *et al.,* 2016) (Asaah,E.K *et al.,* 2010)

In spite of these investigations, the effects of sliding speed on the coefficient of friction are yet to be clearly understood. Therefore, in this study, we will investigate the effect of sliding speed on the coefficient of friction in plum oil lubricant.

2. MATERIALS AND METHODS

The main materials used in this project are: Ripe fruits of African plum, a pin-on-disk tribometer, and aluminum disk test samples.

2.1. Materials Preparation
  ➢ **African Plum**

Ripe fruits of African plum were bought at Makenene along the Bamenda-Yaoundé highway to be used for the oil extraction process. They were washed thoroughly with water inside a bowl in order to remove dirt from it

Figure 1: African Plums *(Dacryodes edulis)*

Plum Oil Extraction Process

We employ the Manual pressing method of oil extraction. This method of extracting oil from plum involves the following stages: washing, preserving in a polythene paper, removal of the pulp, heating the pulp and pressing of the heated pulp. After washing the plums, we put them in a polythene paper making sure it is air tight and under sunlight for about 24 hours. This is done in order to speed up the rate of the pulp getting soft.

(a)   (b)

Fig 2: (a) Packaging of plums in a polythene (b) exposing plums to sunlight

- **Pulp Removal**

After exposing the plums to sunlight and allowing the fruits to get soft, with the use of a knife, the pulp is being removed from the plum fruits and then put inside a pot.

- **Heating the pulp**

We then placed the pot containing the pulp on fire making sure the knob is at the lowest position in order to supply just enough heat needed to dry the little moisture content in the pulp.

- **Pressing the pulp**

The heated pulp is kept for a while to get cold. After which, we put inside a packaging paper having very tiny pores to allow the oil pass through. With a dish placed under the packaged pulp, we pressed the pulp manually with our hand and the plum oil is being collected inside the dish
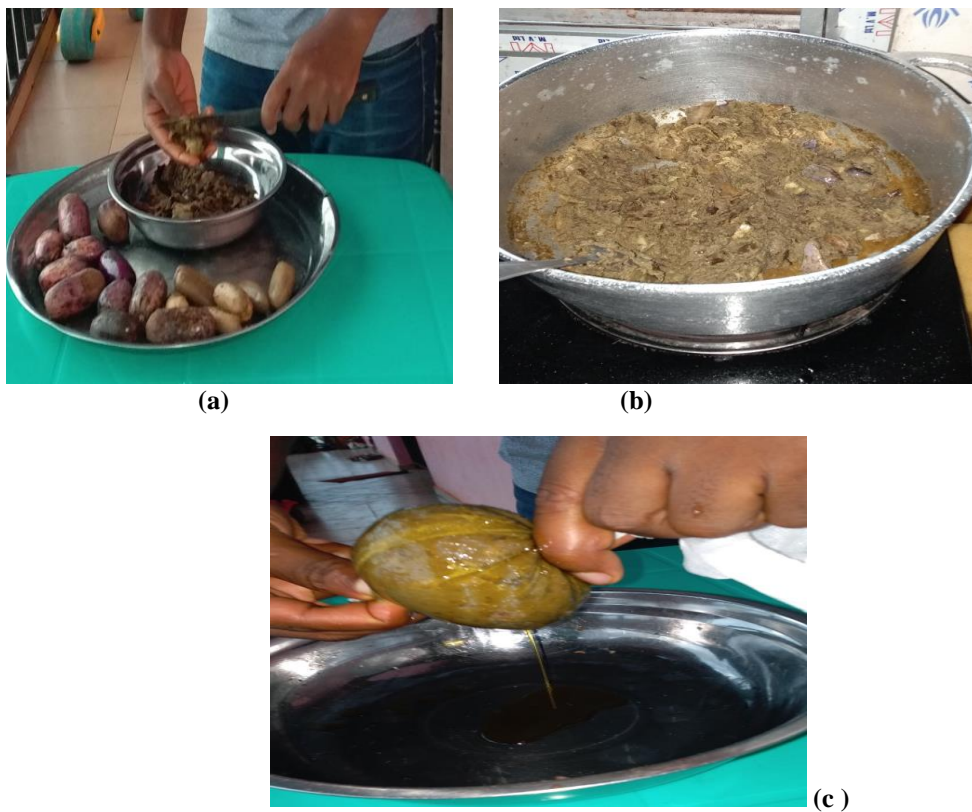

(a)   **(b)**

(c)

Figure 3: (a) Pulp removal, (b) Heating the pulp,(c) Pressing of pulp for plum oil extraction

We then employ the plum oil extracted as a lubricant in carrying out our friction tests at various speeds as described in the following section.

Pin-On-Disk Tribometer testing

Experiments have been carried out on a pin-on-disc tribometer at various speeds ranging from 500rpm to 3000rpm as per ASTM-G99 standard at room temperature as shown in the figure below. The pin-on-disk tribometer used for this study was designed for high precision measurement of friction, wear and lubrication. In the plum oil lubricated test of a stainless steel pin-to-an aluminum disk test sample contact, sliding occurs between a static partners (pin) that is loaded onto a rotating disk with a precise known normal load. Variation of the rotating speed is possible, to suit test conditions.
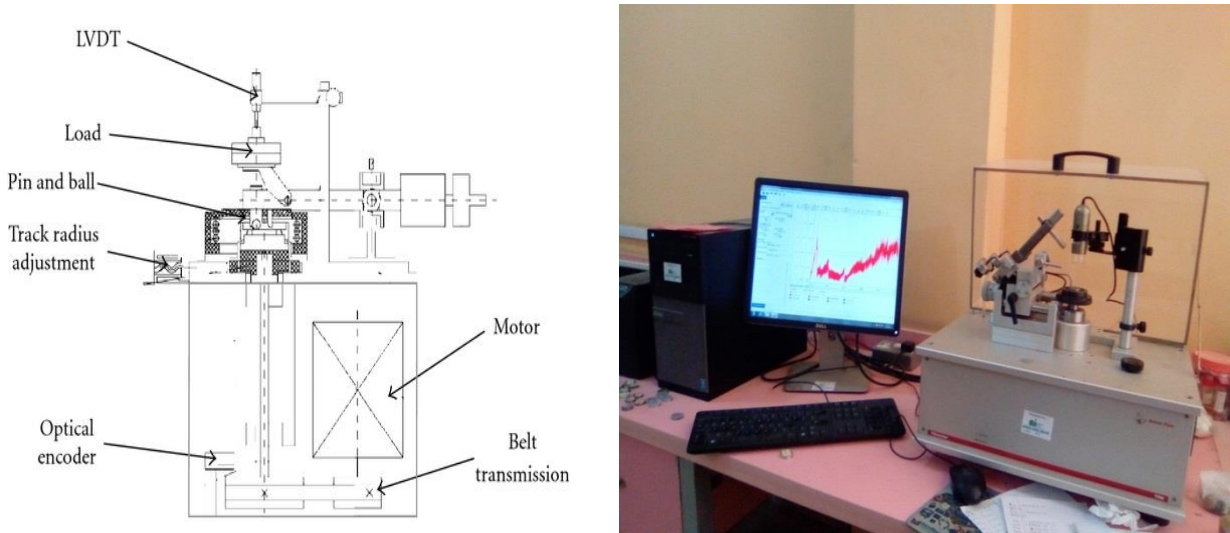
Figure 4: Schematic diagram of the pin-on-disc tribometer

Table 1: Technical Specifications of the Pin-On-Disk machine

S. N^O	PARAMETER	RANGES
1	Normal Load (dead weight/s)	Up to 60N
2	Friction force	Up to 20N
3	Rotational speed (pin on disc)	0.2rpm-3500rpm
4	Linear speed	100mm/s
5	Linear stroke	60mm
6	Disk diameter	Up to ☞60mm
7	Maximum Torque	450N-mm
8	Electrical power	0.5HP DC Motor
9	Relative Humidity level	15% to 95%
10	Environment	- Dry or lubricated
		- Room temperature or heated up to 37°C

The pin is cylindrical with a diameter of 10 mm, a height of 20 mm and made of stainless steel material SS-304, fitted on a holder which is subsequently fitted with an arm. The arm is pivoted with a separate base in such a way that the arm with the pin holder can rotate vertically and horizontally about the pivot point with very low friction. The Pin holder is designed including the facility of putting dead weight on it so that required normal force will act on the test sample through the pin. We applied normal loads of 10N and 20N.

The circular aluminum test sample (disk) has a diameter of 60 mm and a thickness of 6 mm and is fixed on a rotating plate (table) having a long vertical shaft welded from the bottom surface of the rotating plate. The shaft passes through three close-fit bush-bearings which are rigidly fixed with three-square plates such that the shaft can move only axially and any radial movement of the rotating shaft is restrained by the bush.

Sliding velocity can be varied by two ways (i) by changing the rotation of the shaft and (ii) by changing the radius of the point of contact of the sliding pin.

A half-horsepower motor is mounted vertically to rotate the shaft with the table on a separate base having rubber damper. This separate base was used to reduce the effect of vibration of the motor, which may transmit to the main structure. The speed of the motor is varied as required by using an electronic speed control unit.

Each test was run two times at a particular speed for 20 minutes and the average values of friction force calculated. Different pin and disk samples were used in all tests.

We apply plum oil lubricant evenly on the surface of the friction pairs before the test, when the test is being carried out, no more lubricant is added.

The test machine is started in the 50 rpm speed rotation for 3 minutes, during the period not to load, to ensure that the contact can be formed in a uniform lubricant film, and then smoothly to the test load to the specified value. We record the values of frictional force during the last 10 minutes of the test since the values are more stable and accurate.

To perform the test, the pin specimen was cleaned with methylated spirit and inserted into the pin holder which was mounted on a stiff cantilever arm of the tribometer designed as a frictionless force transducer. The disk was also secured in place with the disc holder.

Rotational speeds and the pin distance from the disk center were fixed. An initial load of 2N was used to start up the experiment which ran approximately up to 3 minutes. The loads were later increased to 10N and 20N.

As the disk was rotated by the motor, the resulting frictional forces acting between the pin and the disk were measured by very small deflections of the lever using an LVDT sensor.

3. RESULTS AND DISCUSSION

To know the effect of speed on the coefficient of friction in plum oil lubricant, each of the test samples were tested at normal loads of 10N and 20N at rotational speeds ranging between 500rpm and 3000rpm and the pin distance from the disc center was fixed. Typical friction data recorded are presented in the following tables.

A) COF TESTING AT 10N

Table 2: Friction test values at predefined speeds

Speed (rpm)		500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000
Friction Force(N)	1st Run	1.75	1.72	1.72	1.69	1.66	1.67	1.71	1.73	1.77	1.74	1.71
	2nd Run	1.75	1.73	1.72	1.68	1.65	1.68	1.71	1.74	1.78	1.75	1.72
	Average value	1.75	1.73	1.72	1.69	1.66	1.68	1.71	1.74	1.78	1.75	1.72

Table 3: Coefficient of Friction calculations

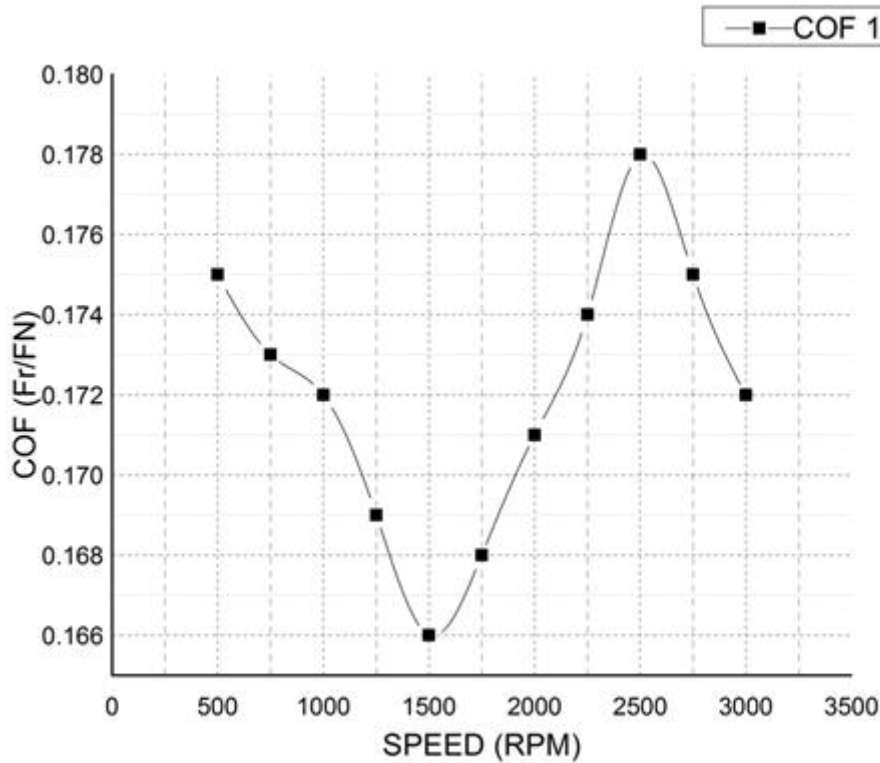| Average value of Friction Force(N)	1.75	1.73	1.72	1.69	1.66	1.68	1.71	1.74	1.78	1.75	1.72
Normal load(N)	10	10	10	10	10	10	10	10	10	10	10
COF= F_r/F_N	0.175	0.173	0.172	0.169	0.166	0.168	0.171	0.174	0.178	0.175	0.172

Figure 5: Plot of Speed against COF at 10N normal load

From table 2, table 3 and Figure 5 it was observed in the interval of 500 -1500 rpm speed range that the coefficient of friction decreases as speed increases. The decrease of friction coefficient of aluminum disk with the increase of rotational speed is due to the change in the shear rate. The strength of this material is greater at higher shear strain rates which results in a lower real area of contact hence a lower coefficient of friction. The minimum value of coefficient of friction is reached at 1500 rpm.In the interval 1500 – 2500 rpm speed range, the coefficient of friction increases as speed increases. This is because, under the high speed, the friction heat fast, make the friction pair surface temperature increases rapidly, the lubrication film is easy to be destroyed, make direct contact with the metal and metal state of dry friction, so the friction coefficient is higher. **(Ponnekanti *et al*., 2015) (Ashwani Kumar *et al*., 2008)** There exists a small decreasing trend in the coefficient of friction as speed increases in the 2500-300rpm speed range. This is mainly because with the increase of speed, temperature on the surface of the friction pair surface may have softened which results to a relatively low coefficient of frictions. These results were similar to (Jian-ji WANG *et al*., 2017) and (M. A. Chowdhury *et al*., 2011). (Philippe Vergne, 2018). (Sliney, H.E. 1978):

B) COF TESTING AT 20N

Table 4: Friction test values at predefined speeds

SPEED (RPM)		500	750	1000	1250	1500	1750	2000	2250	2500	2750	3000
Friction Force(N)	1st Run	3.38	3.36	3.33	3.3	3.29	3.32	3.35	3.37	3.4	3.38	3.36
	2nd Run	3.38	3.35	3.33	3.31	3.28	3.31	3.34	3.37	3.39	3.37	3.34
	Average value	3.38	3.36	3.33	3.31	3.29	3.32	3.35	3.37	3.4	3.38	3.35

Table 5: Coefficient of Friction calculations

Average value of Friction Force(N)	3.38	3.36	3.33	3.31	3.29	3.32	3.35	3.37	3.4	3.38	3.35
Normal load(N)	20	20	20	20	20	20	20	20	20	20	20
COF= Fr/F$_N$	0.169	0.168	0.167	0.166	0.165	0.166	0.168	0.169	0.17	0.169	0.168
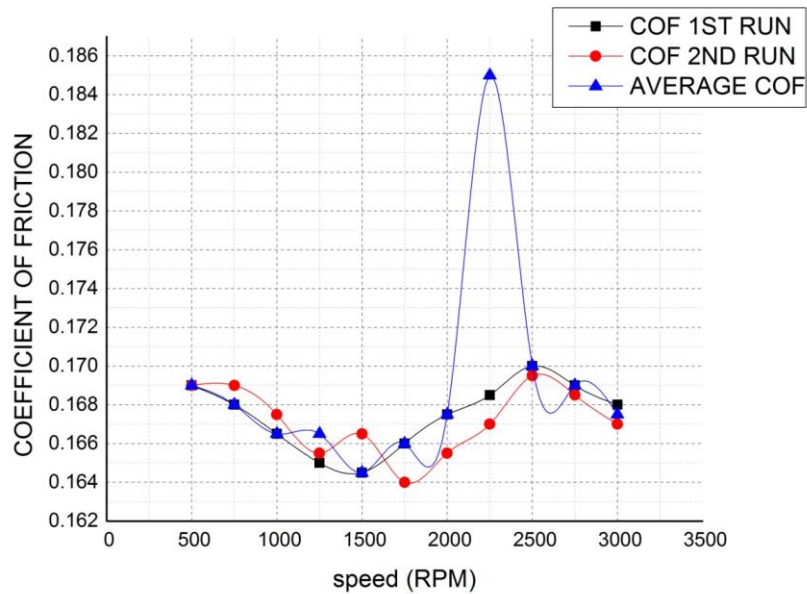
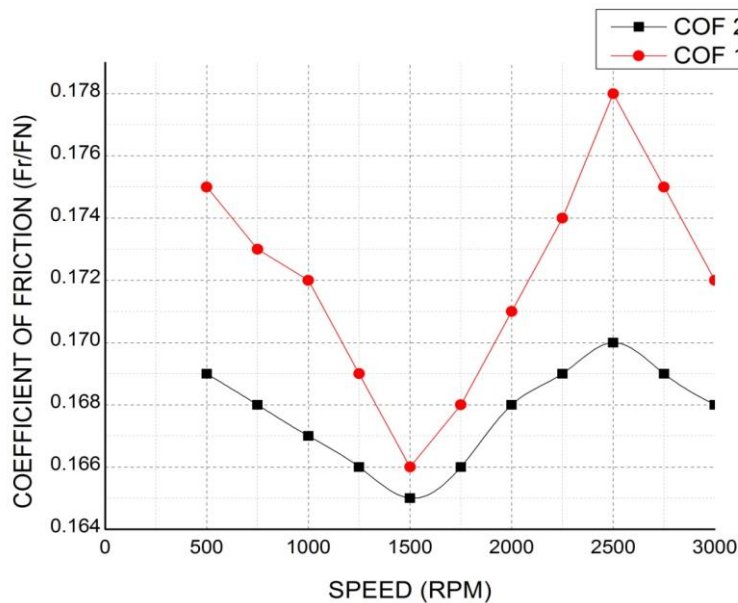**Figure 6:** Plot of Speed against COF at 20N normal load

Figure 7: Plot of Speed against COF at 10N and 20N normal loads

Under different rotational speeds, the corresponding friction forces were measured and coefficient of friction values calculated. The plots of speed against coefficient of friction in figure 6 reveals that speed is significant for the influence of coefficient of friction. Indicates that coefficient of friction decreases with the increase of normal load. Increased surface roughing and a large quantity of wear debris are believed to be responsible for the decrease of friction with the increase of normal load this concords with the finding of (Nikos Kournetas, 2003), (Sharma *et al.,* 2009) and (Liew, W.Y.H; *et al.,* 2014).

4. CONCLUSION

In this study, we have been able to extract plum oil using the manual pressing method and the oil extracted was applied as a lubricant in carrying out friction tests on a pin-on-disc tribometer of aluminum disk test samples and stainless steel pin material combination at various speeds ranging from 500rpm to 3000rpm. This has been done to map the CoF dependence on speed variation.

Results obtained clearly indicates a highly significant relationship between rotational speed and coefficient of friction with an optimum speed range attained between 1250rpm-1500rpm where we experience the least value of coefficient of friction between this particular material combination. Therefore, maintaining rotational speed within this range, friction and wear may be kept to some lower value to improve mechanical processes in machines.

It can be concluded from the results of this present study that the CoF decreases with increasing rotational speed from 500rpm-1500rpm speed range and increases with increasing rotational speed from 1500rpm-2500rpm speed range while there is a slight drop from 2500rpm-3000rpm for this specific material combination and test conditions. We also notice that the coefficient of friction decreases with the increase of normal load.

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6. NOMENCLATURE

ASTM   : American Standard for Testing and Materials

Rpm   : Revolutions per minute

CoF   : Coefficient of Friction

F_f : Average friction force

FN   : Normal load

LVDT   : Linear Variable Differential Transformer

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