Chapter

Experimental Results of the Tribology of Aluminum in the Presence of Polytron Additive

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Abstract

Friction is an ever-present obstacle that causes energy loss in mechanical parts. To alleviate this nuisance, we carried out experimental studies on a brand new additive called Polytron to assess its role in the minimization of friction and wear. The wear, the volume wear rate, the wear coefficient, and the coefficient of friction of the aluminum surface were measured at room temperature with pin-on-disk tribometer without and with 10% Polytron in Helix oil. In the base oil Helix, their values were found to be 70 μm, 1.28×10^{-3} mm^3/min, 1.27×10^{-10} m^2/N, and 0.012, respectively, which with the incorporation of Polytron additive in the Helix oil correspondingly reduced to 20μm, 6.08×10^{-5} mm^3/min, $4.22 \times 10^{-11} \frac{m^2}{N}$, and 0.004. The experimental verdict points to an ionic character of the additive in that it impregnates the crystal structure of the metal, thereby prompting a hard surface layer which subsequently curtails wear and friction.

Keywords: friction, wear rate, polytron additive, aluminum metal, lubrication, helix oil

1. Introduction

Whenever and wherever two surfaces and/or two parts move against each other in the form of translation, rotation, or oscillation, an opposition is encountered. This opposing or resistive force to motion is described as friction. In fact, friction is an ever-present irritant and is the real source of energy and power losses in every industry and every activity whatsoever. This can be realized in our everyday life and the different industries like automotive, aerospace, agriculture, marine, electronics, and telecommunication, and even the so-called cosmetics industry, and the movements of the human joints are not exempt from this scourge one way or another. The word friction derives from the Latin verb fricare, which means to rub. It is of interest to know that the word tribology, introduced in 1966 by the Jost Report, derives from the Greek word τριβοσ (tribos), which also means rubbing. As indicated by this report, tribology was defined as the science and technology of interacting surfaces in relative motion. Nevertheless, a better definition of tribology might be the science and technology of lubrication, friction, and wear of moving or stationary parts [1, 2]. Even if the term tribology is difficult for the general public to comprehend, the dawn of computer disk drives, micro-devices, and nanotechnology has driven friction science and tribology to the front position. Now, the designers have to deal with the challenge of controlling friction of interacting surfaces in relative motion at sizes far too small for the naked eye to see. This is the nano-mechanical device and nano-tribological regime where the ultimate source of friction is perceived to be van der Waals force and Coulomb force [3–7]. In addition to friction, an associated observable fact with the protracted mechanical motion or rubbing of the mating surfaces is the wreckage of the surfaces and generation of heat and pressure in the surrounding area which will definitely curtail the useful life of the mechanical parts. This scoring of the coupling surfaces is termed as wear. The critical issue is to minimize the amount of wear and friction being produced in any mechanical operation so as to avoid any possible mechanical malfunction. It is hard to stop wear of the surfaces and generation of heat and pressure; but there are different ways to minimize the effects, and one of them is lubrication [7]. A lubricant is any substance that is interposed between two surfaces in relative motion for the purpose of reducing the friction and wear between them. By and large, lubricants can be solids, liquids, or gases; but in any case, they reduce the negative influence in the moving parts. Other than friction reduction, lubricants carry away heat and wear particles as well and can serve as the means to distribute corrosion inhibitors and biocides. Lubricating films should support the pressure between opposing surfaces, separate them, and reduce the sliding or rolling resistance in the interface. To reduce friction, the liquid lubricants are formulated in such a way that chemical species within it react with the surface of the bodies to form lubricative films. This chemical species is named as additive. The function of the additive is to provide a smooth surface plus reduce the amount of wear; that is, they are expected to have antifriction and antiwear properties. For example, calcium sulfonate causes the formation of protective layers on highly loaded surfaces. Phosphorus can react with frictional hot spots on ferrous surfaces and thus can reduce wear and friction. Friction modifiers and antiwear additives to oils are the focus of extensive research in oil companies. The amount of the above-mentioned components and their nano-sized counterparts can vary, depending upon the application, in the range of 1–20 wt% [7–15]. By the same token, it has been noticed that the variation of friction and wear rate depends on various interfacial conditions. There are a number of studies in the literature which report that wear and friction primarily change with load, speed, and/or temperature [16–22], surface roughness [23, 24], type of material or mating component, and other environmental dynamics [25–30]. Yet, a group of researchers argue that friction and wear rate vary with geometry, relative surface motion, surface roughness of the rubbing surfaces, type of the material, system rigidity, stick-slip, lubrication, and vibration and/or type of additive, which means that wear and friction are functions of the specific tribosystem [31–52]. Even then, in many applications, the wear reduction mechanism and quantitative analysis of the additives are not well known and a thorough exploration is still inevitable. A literature survey reveals that there is a peculiar and unexplored additive with the brand name of Polytron which has not been thoroughly investigated by the tribological community. Accordingly, this chapter has been devoted to an academic research on the Polytron additive. Polytron is an oily fluid mixture of petroleum-based chemicals mixed with oxidation inhibitors and detergent chemicals and behaves exactly like a stable grease at ambient pressure and temperature in stark contrast to the conventional lubricants. Polytron additive is petroleum based and thus contains no solid particles; hence, it is compatible with all the lubricants available in the market whether mineral, synthetic, vegetable, or animal. Polytron comprises 80% para and 20% meta polytron. In this chapter, we will focus on the metal treatment concentrate (MTC) trademark of polytron having an inherent ionic/polar nature due to which it is attracted to metallic surfaces and develops a durable polished-like microscopic layer through metallurgical process that can resist wear, extreme pressure, and excessive temperature.

2. Experimental details

2.1 Tribometer machine

Wear tests were conducted on pin-on-disk tribotester (Ducom TR-20LE) wear testing machine. **Figure 1** gives a schematic sketch of the pin and disk while **Figure 2** displays the actual tribometer device.

In **Figure 1**, F_N stands for the normal force that is the load on the aluminum pin whereas F_R represents the resistive force called friction that arises from the sliding contact of the aluminum pin on the steel disk. In **Figure 2**, the pin is firmly attached to the pin support and then linked to the rotating plain disk with the desired load which is usually applied through a pulley system. Lubricant is pumped continuously from the machine. To simplify the contact geometry, a hemispherical pin is used which directly touches the disk surface at the beginning of the experiment. A hygrometer measures the relative humidity of the air in the chamber whereas the rpm of the rotating shaft that supports the disk is measured with the help of tachometer. The variation of friction coefficient with friction time is recorded automatically. Necessary information regarding stainless steel disk and aluminum pin is presented in **Tables 1**–**3**. The aluminum pin is in fact an alloy of aluminum and silicon. In addition, the data sheets for the Helix oil and Polytron additive are given in **Tables 4** and **5**. The data and basic information with reference

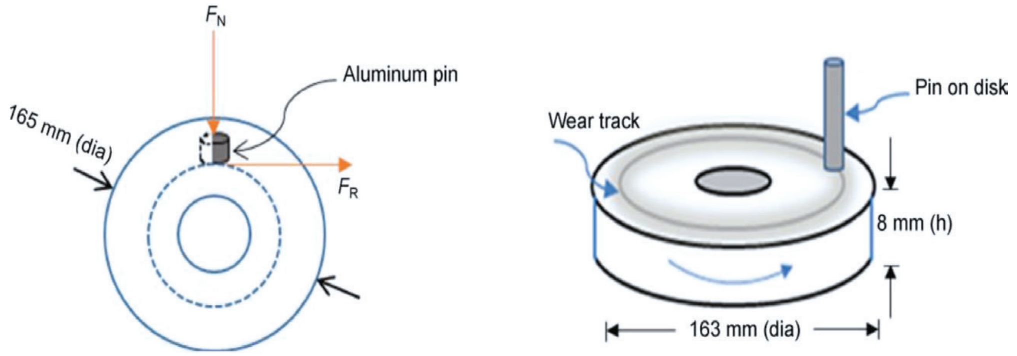

Figure 1.
Sketch of the pin-on-disk. The dimensions of the pin were 32 mm (l) × 10 mm(dia) and dimensions of the disk were 8 mm (l) × 163 mm (dia).

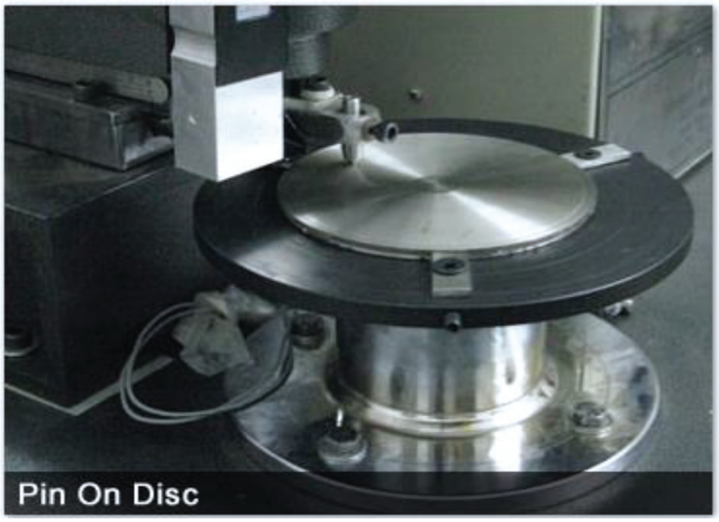

Figure 2.
Pin-on-disk tribotester machine.

Component	Specification/weight percent
Disk dimensions	165 nm (diameter) × 8 mm (height)
Counter bore	M5 holes from bottom × 4 nos.
Counter bore	M5 holes from top × 4 nos.
Holes	M4 tapped holes × 2 nos.
Chemical composition (weight percent)	
Carbon (C)	≤ 0.08%
Silicon (Si)	≤ 1.00%
Manganese (Mn)	≤ 2%
Phosphorous (P)	≤ 0.045%
Sulfur (S)	≤ 0.30%
Nickel (Ni)	≤ 8 –10.5%
Chromium (Cr)	≤ 18.00–20.00%

Table 1.
Specification and composition of stainless steel disk (SUS304) [53–55].

Composition	Min (weight percent)	Max (weight percent)
Silicon	0.4%	0.8%
Iron	—	0.7%
Copper	0.15%	0.15%
Manganese	—	0.15%
Magnesium	0.8%	1.2%
Chromium	0.04%	0.35%
Zinc	—	0.25%
Titanium	—	0.15%
Aluminum	95.85%	98.56%

Table 2.
Chemical composition of aluminum pin (A390) [53–55].

Property	Alloy	
	Aluminum pin A390	**Steel disk SUS304**
Density	2.72 g/cm^3	8000 kg/m^3
Hardness	112.65 VHN	88 HB
Tensile strength	250.00	520 MPa
Yield strength	—	240 MPa
Young's modulus	—	190 GPa
Poisson ratio	—	0.27–0.30

Table 3.
Mechanical properties of the aluminum pin and steel disc [53–55].

Property	Method	Shell Helix Ultra
SAE viscosity grade		5W–40
Kinematic viscosity		
@40 °C cSt	IP 71	81.1
@100 °C cSt	IP 71	14.5
Viscosity index	IP 226	187
Density @15 °C (kg/L)	IP 365	0.856
Flash point PMCC (°C)	IP 34	206
Pour point (°C)	IP 15	–39
HTHS viscosity @ 150°C (mPa s)		3.68

Table 4.
Typical physical properties of Shell Helix Ultra oil (5W–40) [53–55].

Physical/chemical property	Remarks
State	Liquid
Color	Yellowish clear
Smell	Odorless
Specific gravity	60/60 ≈ 1.00
Boiling point range	>300°C
Flash point	>200°C
Viscosity @100 °F	SUS 391
Viscosity @210 °F	SUS 61
Water solubility (T = 20 °C)	Low
Evaporation point	Higher than ether (>34.6°C)

Table 5.
Data sheet of Polytron [53–55].

to aluminum metal, steel disk, Helix oil, and polytron are taken from the research work of Ahmer et al. [53], John [54], and Ahmer et al. [55]. One can guess from **Table 5** that Polytron is marketed in a liquid state and is yellowish in color and, unlike other solid additives, it is odorless. Its flash point is beyond 200 °C whereas its boiling point is further than 300° C and it is scarcely soluble in water.

2.2 Materials and chemicals

The experimental work was performed in the Tribology Laboratory of Universiti Kebangsaan Malaysia, UKM,at ambient temperature (300 K) and pressure (760 mmHG) and approximately 70% relative humidity. Helix oil was chosen as representative base oil for the experiment and its brand 5W–40 was supplied by Shell Oils. The additive was Polytron MTC which was supplied by the Malaysian Association of Productivity. We used soft aluminum-silicon alloy A390 and stainless steel SUS304 as pin and disk material, respectively. Separate test runs were taken for the base oil stock and the 10% polytron additive plus the base oil stock. The runs were executed for 240 min in each case and the wear rates of the pin were then calculated from the measured weight loss. The mass and volume of the pin

Test variable	Assessed value
Before the wear run	
Material of the wear disk	Stainless steel S304
Diameter of the wear disk	80 mm
Mass of the pin	6.4480 g
Length of the pin	32.00 mm
During the wear run	
Speed of the wear disk	500 rpm
Time allocated	240 min≈ 14,400 s
Sliding speed	2.09 m/s
Sliding distance	30.163 km ≈ 30,163.2 m
After the wear run	
Mass of the pin	6.4470 g
Length of the Pin	31.981 mm

Table 6.
Recorded data of the wear test for helix base oil (5W–40).

Test variable	Assessed value
Before the wear run	
Quantity of Helix plus Polytron	2000 mL
Load	196.2 N
Material of the pin	Al■Si alloy A390
Pin diameter	10.00 mm
Length of the pin	32.00 mm
Material of the wear disk	Stainless steel SUS 304
Diameter of the wear disk	80 mm
During the wear run	
Speed of the wear disk	500 rpm
Time allocated	240 min≈ 14,400 s
Sliding speed	2.09 m/s
Sliding distance	30.163 km ≈ 30163.2 m
After the wear run	
Mass of the pin	6.4472 g
Length of the pin	31.996 mm

Table 7.
Recorded data of the wear test for the Helix oil plus 10% polytron.

were measured both before and after running the experiment and the data set are presented in **Tables 6** and 7.

2.3 Procedure and calculations

In the experiment, an aluminum pin having a diameter of 10 mm was slid against the steel disk. The applied load was 20.0 kg. In the first instance, 100%

Helix oil was used and its volume in the graduated cylinder was 2000 mL. In the second instance, 90% Helix oil having a volume of 1800 mL was mixed with 10% polytron additive which amounted to 200 mL volume of polytron. Before running the test, the disk was completely covered with the lubricant by keeping a steady flow rate of the lubricant at nearly 0.5 mL/min. The wear volume was calculated from the diameter of the wear scar generated by the pin. Typical wear versus time curves were obtained with the help of MatLab software and were polynomially fitted in order to decide the data trend.

Wear process is in general quantified by the wear rate. Wear rate is defined as the volume or mass of material removed per unit time or per unit sliding distance. In order to determine the extraordinary contribution of the polytron additive in the helix lubricant, we calculated three key tribological parameters, namely, mass wear rate, volume wear rate, and wear coefficient. The defining equations for these parameters are specified by Eqs. (1–3) as written down below [56].

$$\text{Mass wear rate} = m/t \tag{1}$$

$$\text{Volume wear rate} = V/t \tag{2}$$

$$\text{Wear coefficient }(k) = (V \times H)/(N \times S) \tag{3}$$

Eq. (3) is the famous Archard equation of tribology.

The coefficient of friction μ is obtainable from the experimentally obtained data. The popular defining expression for the coefficient of friction is like that described by Eq. (4).

$$\mu = F_R/N \tag{4}$$

In the above equations, the variable m stands for the worn out mass of the aluminum pin, t represents the time span of the experimental run, V refers to the worn out volume of the pin called the wear volume, H points to the hardness of the sliding pin, F_R is the tangential resistive force between the pin and the disk and is termed as friction force, N is the normal load, and S is the sliding distance on the disk. It is to be noted that the friction coefficient μ is a convenient way to characterize the resistance to relative motion between the surfaces, but it is not a material property nor is it a physical constant. The effect of the polytron additive on different tribological parameters in the experiment and the computed values from the above-mentioned equations are recorded in **Table 8**.

Parameter	**Helix base oil (100%)**	**Helix oil (90%) plus Polytron (10%)**
Wear	70 μm	20 μm
Mass wear rate	3.33×10^{-3} mg/min	8.33×10^{-4} mg/min
Volume wear rate	1.28×10^{-3} mm^3/min	6.08×10^{-5} mm^3/min
Coefficient of friction	0.012	0.004
Wear coefficient (k)	—	4.22×10^{-11} m^2/N
Total mass loss	0.7992 mg	0.1992 mg
Total volume loss	0.3079 mm^3	0.01459 mm^3

Table 8.
Computed tribological parameters for the aluminum pin.

3. Results and discussion

The experimentally obtained data and their polynomial fits for the wear behavior of the aluminum metallic pin are displayed in **Figures 3** and **4** for two different configurations in which the experiment was carried out. The adopted test configurations in the experiment were: aluminum pin versus Helix oil-on-steel disk, tagged as AHS configuration, and aluminum pin versus 10% polytron plus 90% Helix oil-on-steel disk, which will be referred to as the APS configuration in the forthcoming discussion.

Figures 3 and **4** show the plot of the wear pattern of the aluminum pin with the passage of time and then the sliding distance on the steel disk of the experiment under consideration. The red line represents wear in the AHS configuration whereas the blue line symbolizes the wear in the APS configuration. It is very much clear from this plot that the polytron additive provides excellent let-up the wear of the tribosystem consisting of an aluminum pin on a steel disk interposed by an oil film of 10% Polytron and 90% Helix. It shows that that the wear in the AHS configuration starts from 70 micron and then stabilizes at approximately 65 micron, but in the APS

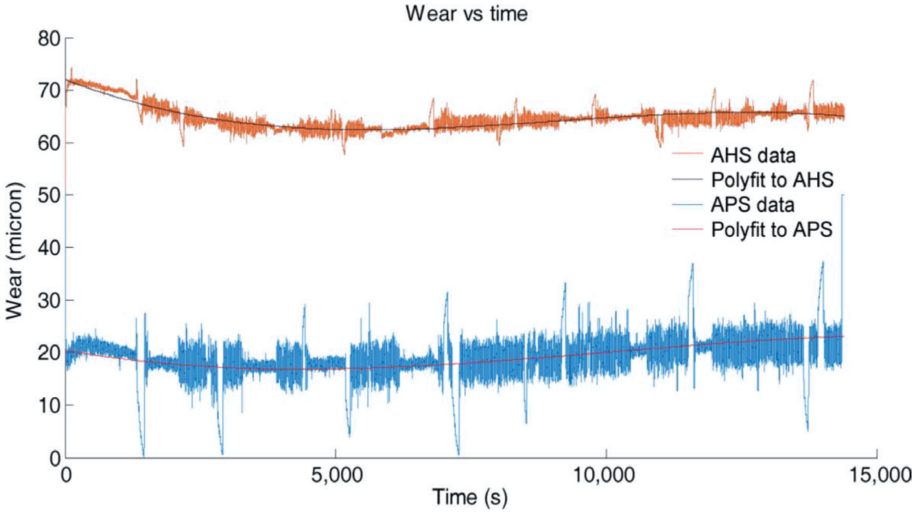

Figure 3.
Graph of the wear of aluminum pin against time in the AHS and APS configurations. The time for the experiment was 240 min.

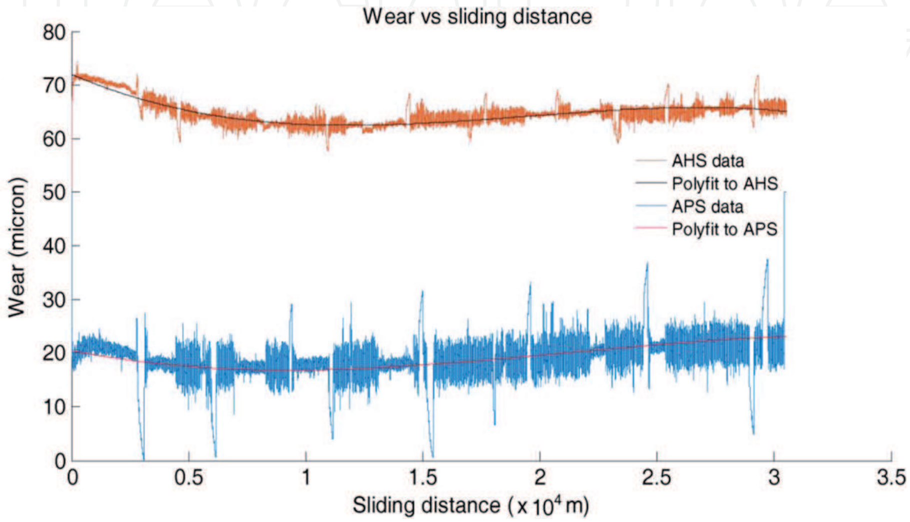

Figure 4.
Graph of the wear of aluminum vs. sliding distance in the AHS and APS configuration. The sliding distance for the experiment was 30.163 km.

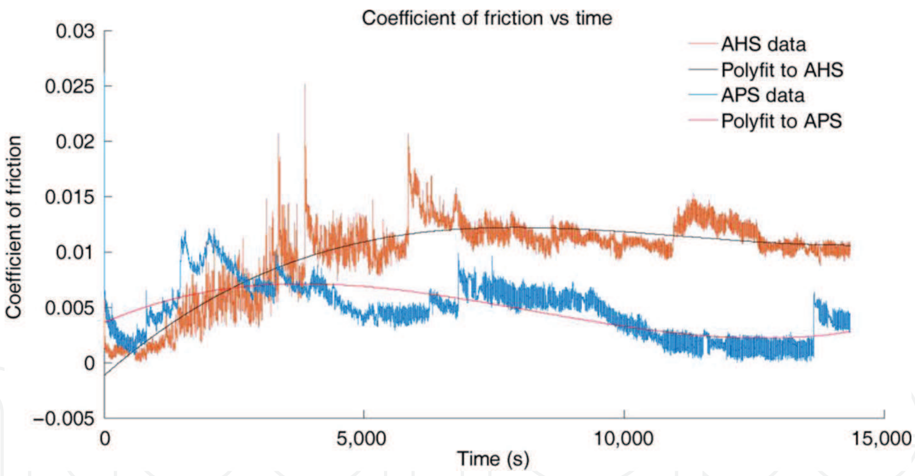

Figure 5.
Evolution of the COF with time in AHS and APS configuration. The experimental time was 240 min.

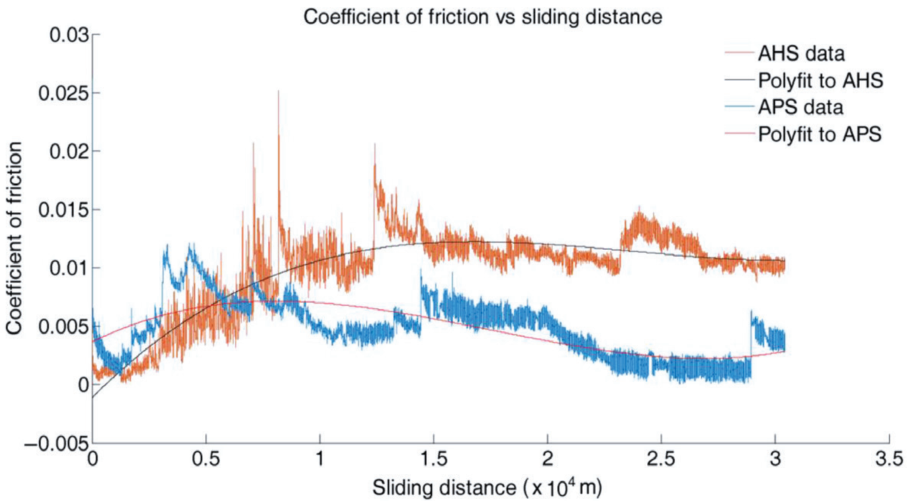

Figure 6.
Evolution of COF with sliding distance in the AHS and APS configuration. The sliding distance for the experiment was 30.161 km.

configuration wear stays at nearly 20 micron. Then, for the same two configurations and under the same experimental conditions, the evolution of the coefficient of friction μ with reference to time span and sliding distance has been plotted as shown in **Figures 5** and **6**.

It is perceivable from the graph of **Figures 5** and **6** that in the AHS format, the initial value of the friction coefficient is almost zero and increases almost linearly to a value of 0.012 in a time span of 100 min of rubbing after which COF stands stable at this very value. The low value of μ in the initial stage of rubbing is probably due to the presence of a layer of foreign material on the disk surface which may be due to some moisture or oxide of the aluminum metal because it readily oxidizes in air. Conversely, in the APS setup, the coefficient of friction starts from a value of 0.005 and then further declines to virtually 0.004. It is recognizable that polytron reduces the wear of the aluminum pin significantly and one can predict that the ratio in the
APS configuration is effectively more than 30% in comparison with AHS configuration. Despite the fact that in our experiment the normal force and sliding distance had very large values in difference with other experimenters, nevertheless the evolved coefficient of friction had negligibly small value when meager 10% polytron was added to 90% helix which in turn endorsed the positive contribution of the polytron in friction minimization. These findings in our tribological

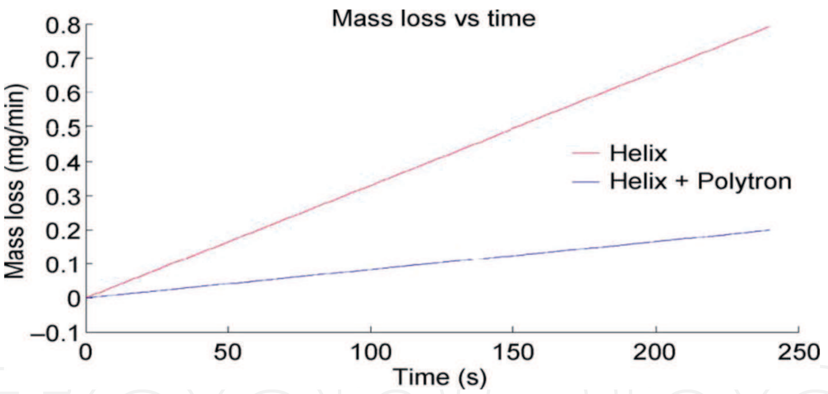

Figure 7.
Graph of the mass loss of aluminum pin vs. time for the AHS and APS configuration. The time of the experiment was 240 min.

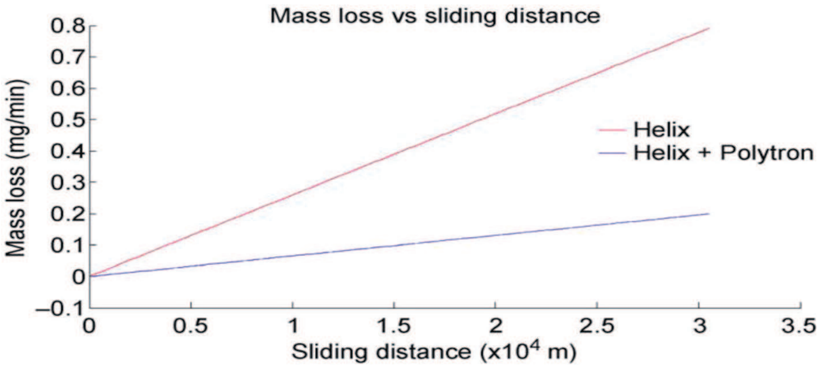

Figure 8.
Experimental graph of the mass loss of aluminum pin vs. sliding distance in the AHS and APS configuration. Sliding distance for the experiment was 30.161 km.

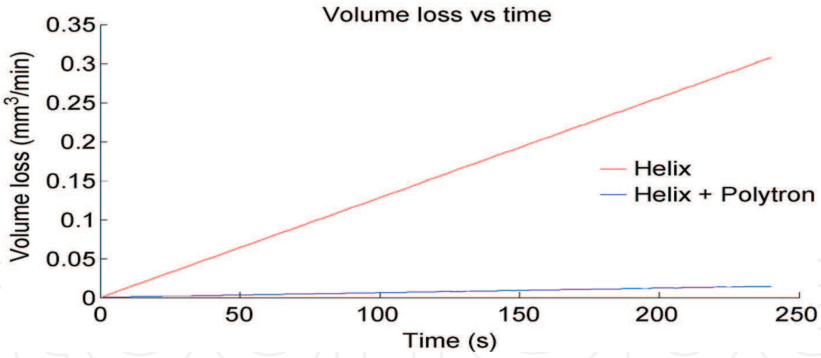

Figure 9.
Graph of the volume loss of aluminum pin vs. time in the AHS and APS configuration. Time for the experiment was 240 min.

experiment with polytron additive in Helix oil are significantly superior in comparison with the findings of other researchers like Nuruzzaman and Chowdhury [57], Bhushan and Kulkarni [58], and Le and Lin [59].

To further clarify the effect of polytron additive, we examined the mass and volume losses of the aluminum pin with regard to time as well as sliding distance and separate graphs were drawn for both the AHS and APS configurations. The comparison plots for the mass losses are shown in **Figures 7** and **8** while the comparison graphs for the volume losses are illustrated in **Figures 9** and **10**. A deep examination of all the figures reveals that the mass as well as volume loss cannot be controlled with Helix oil alone; rather, it will damage the contact surfaces in a

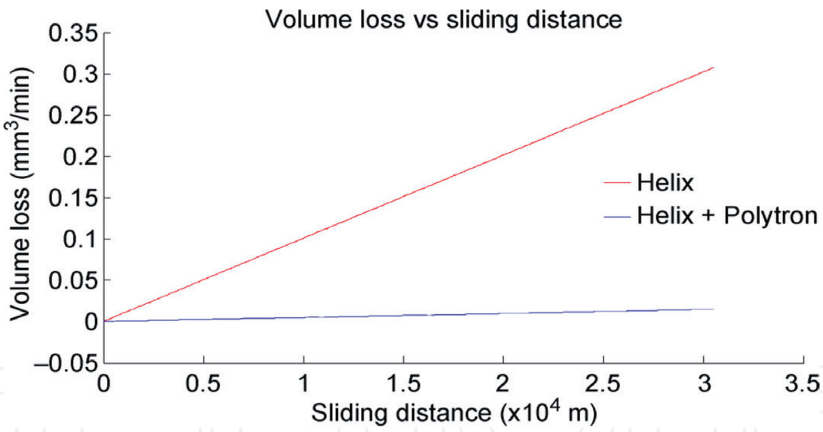

Figure 10.
Graph of the volume loss of aluminum vs. time in the AHS and APS configuration. The sliding distance for the experiment was 30.161 km.

short while, whereas only a scanty addition of 10% of Polytron reduces the mass as well as the volume losses to almost zero level. This is a tremendous change and is visible to the naked eye and directly identifies the supreme antifriction and antiwear capability of the polytron additive. This observation with the addition of polytron additive is fairly divergent with the high wear rate results of researchers like Suarez et al. [60] who studied the popular ZDDP additive in mineral oil stock.

In the same vein, the tribological parameters in our research work are much better than those of Anand et al. [61] who used phosphonium ionic liquid additives in diesel engine lubricants. More to the point, the experimental predictions in our research effort on wear and friction minimization are even far superior to the findings of Chen et al. [62] and Su et al. [63] who used nano-additives in different lubricating media. With an advantage, the calculated values of mass and volume losses of the aluminum pin show that polytron additive attenuates the mass wear rate by an order of magnitude while the volume wear rate of aluminum is alleviated by two orders of magnitude and these outcomes in sequence yield just a nominal value for the wear coefficient as can be noticed from **Table 8**. This outstanding performance identifies that polytron had the capability of permeation into the metal crystal structure of aluminum and subsequent adherence to the metallic surface as an unbreakable surface film that diminished the wear of aluminum surface and consequently curtailed friction between the rubbing surfaces of aluminum and steel.

4. Conclusions

1. The wear of the aluminum metal surface in the Helix base oil was circa 70 μm. The addition of 10% of Polytron additive declined the wear to 20 μm, representing an excess of 2/3 decrement in the wear of the metal.

2. The mass wear rate of the aluminum pin in the Helix base oil was 3.3×10^{-3} mg/min which decreased by an order of magnitude in the Helix plus Polytron mixture, attaining a value of 8.33×10^{-4} mg/min.

3. The mass wear rate of the aluminum pin in the Helix base oil was 1.28×10^{-3} mm^3/min and it decreased by two orders of magnitude in the Helix plus Polytron mixture by assuming a value 6.08×10^{-5} mm^3/min.

4. The value of the coefficient of friction in the Helix oil was estimated at 0.012 which trimmed down to an extremely low value of 0.004 in the combination of 10% polytron additive and 90% Helix oil.

5. Polytron, due to its polar nature, proves to be an effective antiwear additive in the Helix base oil and hence can intrinsically reduce friction by orders of magnitude in mechanical processes and consequently prolong the life span of mechanical parts and, in turn, contribute to considerable fuel and oil economy.

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Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Nomenclature

MTC	metal treatment concentrate
F N	normal force/(load)
F R	resistive force/friction
TCP	tricresylphosphate
ZDDP	zinc dialkyl-diethylthiophosphate
μ	coefficient of friction (COF)

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