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TRIBOLOGICAL BEHAVIOR AND LUBRICATION MECHANISM OF FINE PARTICLES IN THE BASE OIL SN500

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Abstract: The using of powders with attractive wear and friction has increased attention industrial sectors and research. In this study the experimental work results of the tribological behavior of base oil SN500 with CuO and ZrO_2 as anti-wear and anti-friction hybrid additives powders at concentrations (0.5, 1, 2 and 4) wt. % were obtained and comparing the results with pure oil. Therefore the effect of normal loads and sliding speed under mixed lubrication were studied according to ASTM G-99 pin on disc and ASTM G-77 block on ring principles for friction and wear measurements respectively. The optimum lubrication concluded on the level of concentration of the hybrid powder was at (2) wt. % by the formation of protected boundary layer in the significantly improved i.e. friction coefficient decreased about (20.8%) and the wear rate about (46%) as compared with the case of using pure lubricant oil.

Keywords: *Lubricating effect, Hybrid additives, Friction, Wear, Tribology.*

السلوك الترايبولوجي والية التزيت لمساحيق مضافة الى زيت نوع SN500

الخلاصة: استخدام المواد بوجود الاحتكاك والبلى اثار انتباه الباحثين والقطاع الصناعي. في هذه الدراسة تم الحصول على النتائج العملية للسلوك الترايبولوجي للزيت SN500 مع CuO و ZrO_2 كهجين لمساحيق مضافة مضادة للبلى والاحتكاك على التوالي وبتراكيز بنسب وزنية (0.5، 1، 2 و 4) ومقارنة النتائج مع الزيت بدون اضافات. وبناءا على ذلك تاثير سرعة الانزلاق والحمل المسلط على الزيت المستخدم مع الاضافات تم دراستها حسب مبدا المواصفة ASTM G-99 مسمار على قرص و ASTM G-77 كتلة على حلقة لقياس الاحتكاك والبلى على التوالي. افضل نتيجة للزيت تم الحصول عليها كانت عند تركيز هجين للمساحيق عند النسبة الوزنية (2%) نتيجة لتكون طبقة حماية ادت الى هذا التحسين بمعنى اخر ان معامل الاحتكاك انخفض حوالي (20.8%) ومعامل البلى حوالي (46%) عند مقارنته مع حالة الزيت بدون اضافات.

1. Introduction

A solid lubricant is powders are used to protect from damage during relative movement and to reduce wear and friction of rubbing surfaces by preventing direct contact between their surfaces even under high loads. Other terms commonly used for solid lubricant are include dry-film lubrication, solid-film lubrication, and dry lubrication. Although these terms refer to solid lubrication takes place under a lubricant

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with solid additives or dry conditions. Mixed lubrication has been employed as a suitable dry lubricant placed with the liquid lubricant in variety of sliding contacts. The main assumption of mixed lubrication is that there are two operative elements, morphological and hydrodynamic. The morphological element refers to the effects of the tribological behavior, chemical, and mechanical properties of the contacting materials. The hydrodynamic element refers to the shearing of layered particles between the sliding tribo-faces [1]. Some of the interesting features of solid lubricants that are adhere to surfaces to forming a protective boundary layer which acts as a lubricant in the sliding contact by absorbing relative surface velocities and are capable of lubricating at high temperatures and prevent wear. Examples of these solid lubricants are copper oxide, graphite, molybdenum disulfide, boron nitride, and ZrO_2 [2]. The study of wear, friction and lubrication has great practical importance, as the performance of many biological, electrical and mechanical systems depends on the values of wear and friction.

Hernandez Battez, et al. [3], studied the effect of CuO, ZrO_2 and ZnO nano-particles as anti-wear additives in lubricant oil. They were observed that all additives exhibited reductions in wear and friction as compared to the base oil. S. Bhaumik and D. Pathak [4], studied the effect of CuO nano-particles and graphite macro particles as anti-wear additives in mineral oil. They were observed that CuO nano-particles and graphite in oil exhibited superior anti-wear properties compared with pure oil, and decrease in the value of specific wear and coefficient of friction. Mengnan Qu, et al. [5], studied tribology performance of sunflower oil containing Cu micro-particle and functionalized liquid as lubricant additives. Cu micro-particle was mixed with functionalized ([EAMIM]F_4) and Polyvinylpyrrolidone. The mixture was then blended with sunflower seed oil. They were observed that the tribological property was improved due to the deposition film of Cu and formation of tribo-chemical products (CuO, Fe_2B, Fe_3O_4, FeF_3, Fe_2O3 and etc.) on the contact surfaces and prevent direct contact. Mohamed K., et al. [6], studied the frictional power losses reducing and the scuffing resistance improving in automobile engine by nano additives as hybrid lubricant. They were investigating the effect of nano-particles of (0.05 wt. % TiO_2 and 0.05 wt. % Al_2O_3) as wear resistance and friction reduction additives in commercial engine oil (5-30W). They were observed that the reduction of friction power losses for the sample used compared to pure oil. In science of materials, wear defined as erosion or material displacement from its premier position onto a solid surface caused by the other surface action. Due to the plastic deformations of material at surface and near surface positions, metals wear are produced and by the particles separation result of wear debris [7]. Many factors of the working environment affected the wear that included rolling, reciprocating, unidirectional sliding, impact load, temperature, speed, different bodies types (solid, gas or liquid) and contact type (multiphase or single phase), in which the multiphase may be combined of (liquid-solid particles gas bubbles) [8]. In fact only a few amount of the contact area between bodies is in actual contact it may be about 0.01% of the apparent contact area and no stresses occur between these real contact areas so the stresses in actual contact areas are surpass the yield strength materials. All of the mechanical energy absorbed by un-lubricated sliding surfaces converts to heats and deformation [9].

2. Experimental work

2.1. Materials used

In this study, the SN500 base oil was used as liquid lubricant. Additives powders of CuO and ZrO_2 of particle size (45µm) as a hybrid, were mixed of same amount with the SN500 by using magnetic and power sonic stirrers to get the optimum distribution of the particles in the oil.

2.2. Friction Test

This test was carried out by using MMW-1A vertical universal friction testing machine according to ASTM G-99 pin on disc test principle [10]. The test was carried out at constant sliding speed (500 rpm), constant load (50 N), constant test time (15 min), different additives concentration, and at room temperature. CK50 steel was used for preparing all the samples in cylindrical (pin) and ring shapes with dimensions (5x15) mm and (16x32x10) mm respectively as shown in “Fig. 1”. “Table 1” illustrates the chemical composition of the experimental samples used.

Figure 1. Vertical universal friction testing machine (MMW-1A), samples and samples fixture

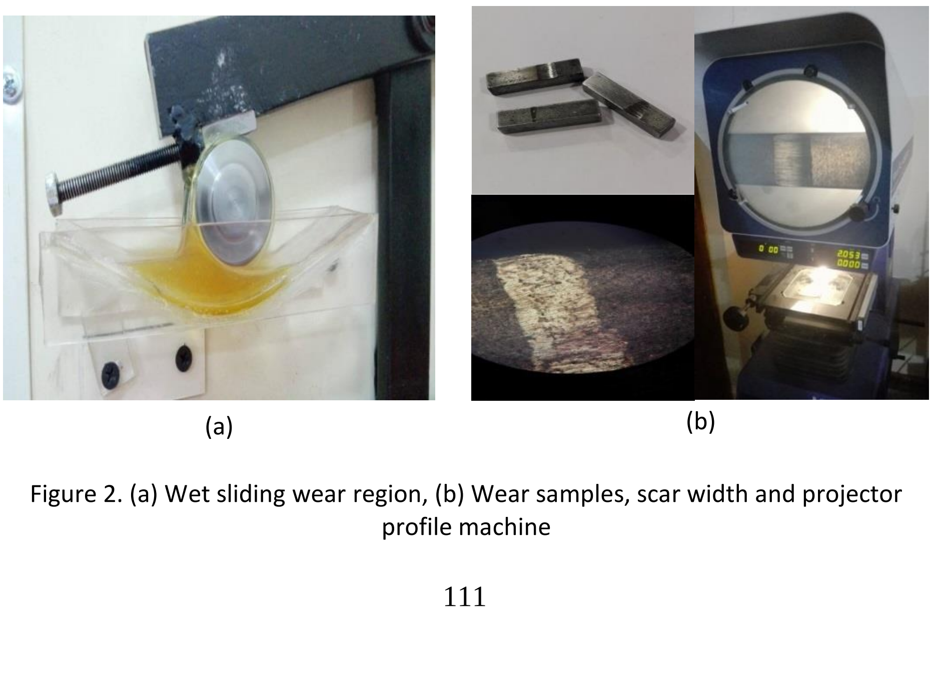
Table 1. Chemical composition of experimental samples metal

Element	Content (%) of nominal [11]	Content (%) of actual
Iron	From 95.195 to 96.33	Bal.
Carbon	From 0.370 to 0.430	0.512
Molybdenum	From 0.200 to 0.300	0.004
Manganese	From 0.600 to 0.800	0.692
Nickel	From 1.65 to 2.00	0.026
Phosphorous	Up to 0.0350	0.017
Silicon	From 0.150 to 0.300	0.235
Sulfur	Up to 0.0400	0.023
Chromium	From 0.700 to 0.900	0.056

2.2. Wear Test

The block on ring principle was used at room temperature to examine the volume losses sliding wear characteristics in wear testing apparatus according to ASTM G-77 [10] as shown in "Fig. 2(a)". Wear specimens (CK50 steel) were of dimensions (6x6x20) mm as shown in "Fig. 2(b)". Face of each block was refine with ASTM grits of 220, 400, 600, 800 and 1200 empery papers then polished these faces with alumina paste grade 0.3µm. The block was kept pressed against a rotating steel ring in suitable position under load condition. The tests were carried out for the following cases:

1. Constant load (155N), constant sliding speed (500 rpm), constant test time (15 min), constant sliding distance (824.6 m), and lubricant oil with different additives concentrations (0.5, 1, 2 and 4) wt. % hybrid and compared with pure SN500.
2. Constant sliding speed (500 rpm), constant test time (15 min), constant sliding distance (824.6 m), different applied load (75, 95, 115, 135, 155, 175, 195, 215, 235) N, and lubricant oil with different additives concentrations (0.5, 1, 2 and 4) wt. % hybrid and compared with pure SN500.
3. Constant load (155 N), constant sliding distance (824.6 m), different sliding speed (100, 300, 500, 700, and 900) rpm, and lubricant oil with nominal additive concentration that give the optimum enhancement in wear rate and compared with pure base oil.



(a) (b)

Figure 2. (a) Wet sliding wear region, (b) Wear samples, scar width and projector profile machine

2.4. Wear rate calculation

The wear rate was determined by the volume losses of the sample after each test and was calculated depending on the scar width by using ASTM G-77 mathematical relation [12]:

$$\theta = 2\sin^{-1}\frac{b}{D}$$

$$\text{Scar Volume (V)} = \frac{D^2 w}{8}(\theta - \sin\theta)$$

$$\text{Wear rate} = \frac{V}{F_n S}$$

Where:

- w: is width of block mm
- r: is ring radius mm
- θ: is angle sector radian
- F_n : is applied load on ring N
- b: is average width of scar mm
- d: is depth of scar mm
- S: is sliding distance m.
- D: is ring diameter mm

3. Results and discussion

Friction effect of hybrid powders of copper and zirconium oxides added, on the tribolorgical characteristics of lubricant base oil SN500 was studied for the concentration (0.5, 1, 2 and 4) wt. % as shown in “Fig. 3” and “Fig. 4”. The lubricating behavior of the hybrid powders was explained by the strong polarization of the particles that lead to produce a layer structure with good adhesion to sample surfaces, easy sliding in the zone of contact and the formation of a uniform continuous tribo-film. The hybrid film layers carrying part of the load on the asperities of the metal surface. The results can be explained by the fact that the hybrid powders, as a solid lubricant lead to produce, through the process, a solid lubricant film that reduce the coefficient of friction in the solid bodies under relatively sliding movement. It was evident that (0.5) wt. % of the hybrid powder in the examined lubricant is not sufficient to produce a tribo-film on the worn surfaces that separates from the rubbing surfaces. However, increasing the amount of the hybrid over (2) wt. % results in a thick loose film that lead to reduce the effect of tribo-film in wear action with an increase in coefficient of friction.

Experimental results also revealed in “Table 2” which shows that minimum friction coefficient was obtained at a concentration (2) wt. % of the hybrid addition. The friction coefficient and power losses were reduced because of the mechanism of the fine particles (converting sliding into rolling friction) and the producing of tribo-film on the sliding faces. This reduction in frictional power losses could further enhance the automotive engine efficiency, besides hybrid additives are effective in sliding contact during mixed and boundary lubrication regimes. The results showed that the use of hybrid additives with SN500 base oil reduced the friction coefficient by (20.8%) as compared with pure SN500 regime lubrication.

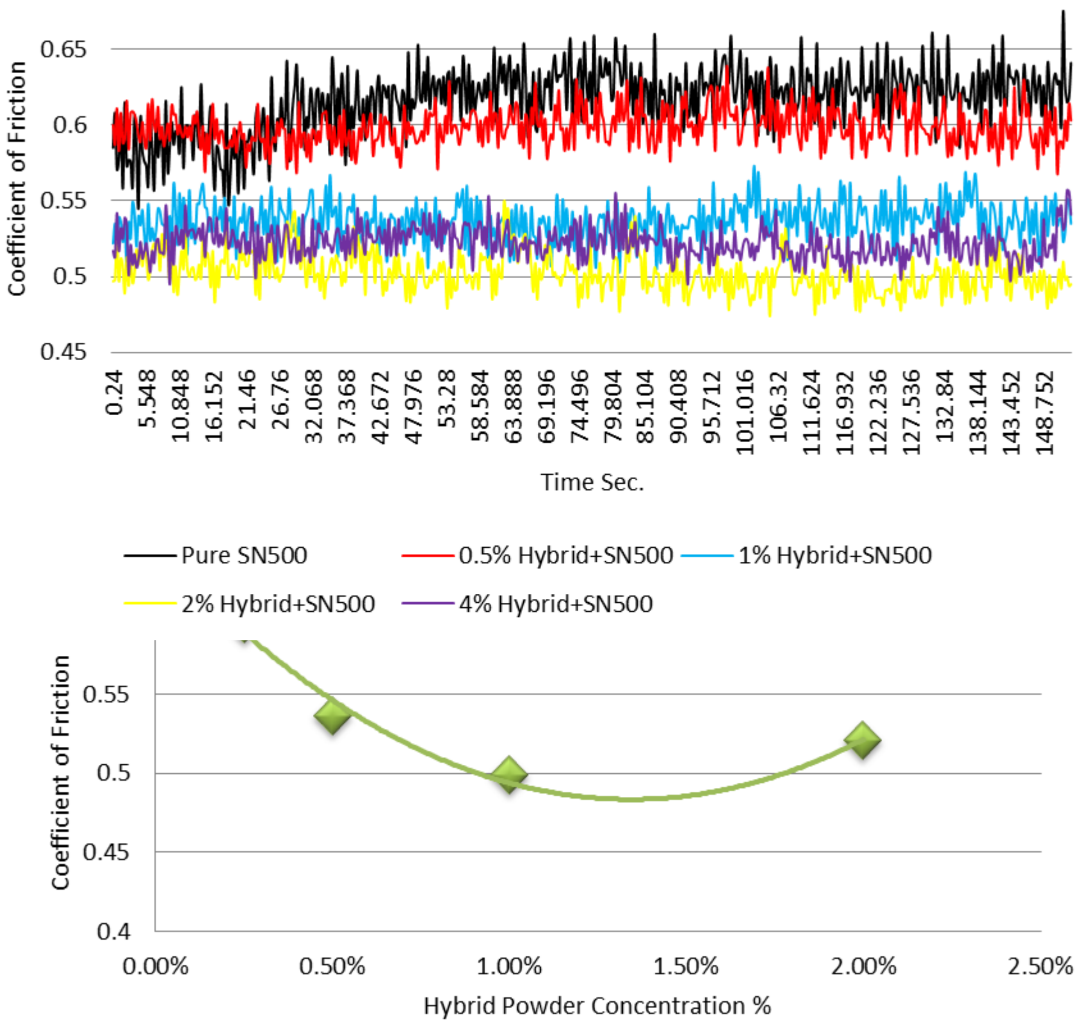


Figure 4. Coefficient of Friction values of SN500 with hybrid additives

Table 2. Coefficient of friction values

Hybrid (%)	Condition	Friction Coefficient
	Dry	0.782
	Pure SN500	0.63
0.5%	0.125% CuO+0.375% ZrO_2+SN500	0.595
1%	0.25% CuO+0.75% ZrO_2+SN500	0.536
2%	0.5% CuO+1.5% ZrO_2+SN500	0.499
4%	1% CuO+3% ZrO_2+SN500	0.521

"Fig. 5" shows the influence of CuO and ZrO_2 additives on the wear rate of the samples as compared with base oil SN500 without additives at different loads, while "Fig. 6" shows the result of hybrid additives on wear rate at constant load (155 N), constant test time (15 min), constant sliding speed (500 rpm) and constant sliding distance (824.6 m). The results revealed a decreases in the rate of wear about (46%) by the use (2 wt. %) of hybrid additives as compared with the use of the pure base oil SN500 without additives. The anti-wear mechanism can be explained by considering the situation when the oil film between worn surfaces becomes thinner during the mixed or boundary lubrication regime. Under these cases, the fine particles may carry a portion of the pressure and separate the worn surfaces to prohibit adhesion. However, the producing of a tribo-film on the rubbing surfaces by hybrid additive helps in delaying or preventing the beginning of scuffing.

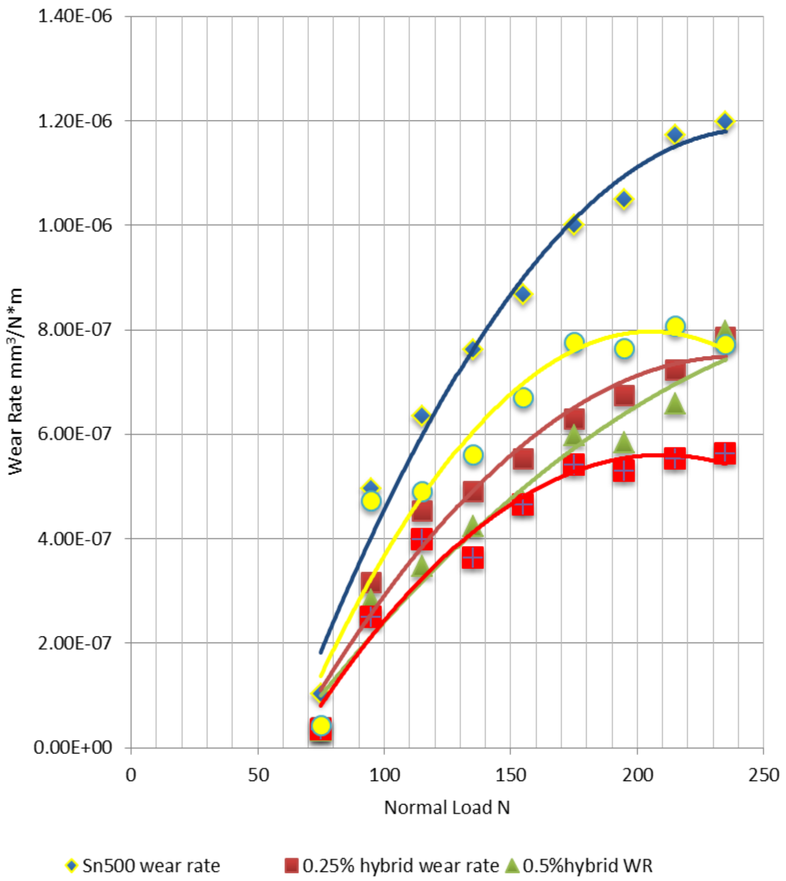


Figure 5. Model of wear rate curves of SN500 with hybrid (CuO, ZrO_2) additives at defrent load

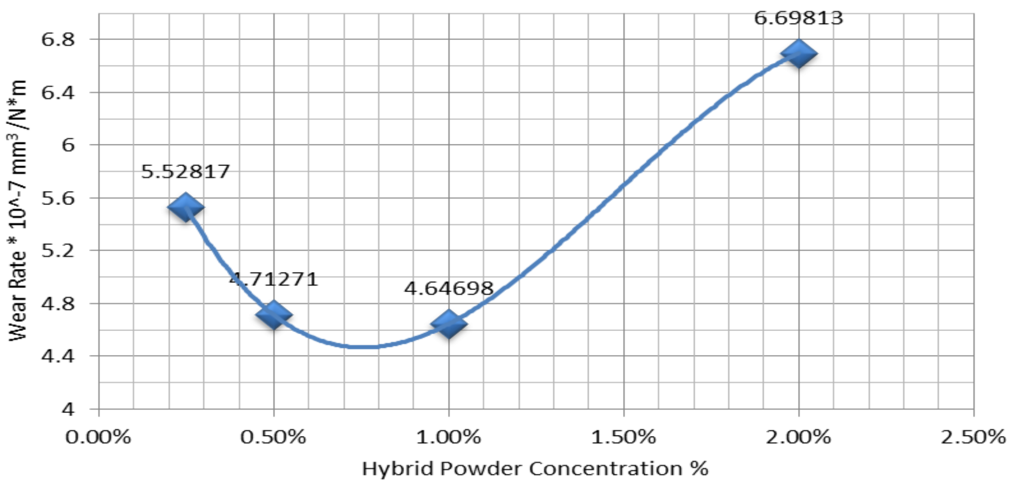


Figure 6. Effect of hybrid (CuO, ZrO2) additives on the wear rate at constant load (155N), constant test time (15 min), constant sliding speed (500 rpm) and constant sliding distance (824.6 m)

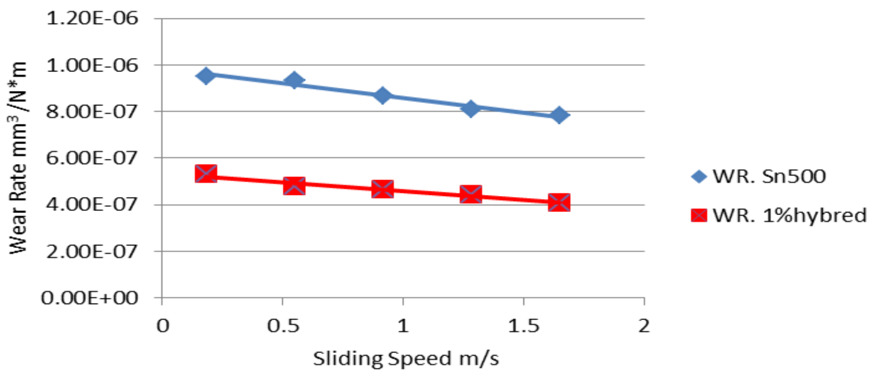


Figure 7. Wear rate at deferent sliding speed and constant load (155 N)

"Fig. 7" shows the effect of the sliding speed on the rate of wear of the optimum hybrid additives (2 wt. %) as compared with pure base oil SN500. The comparison was made for different sliding speed and for a fixed contact load of 155 N.

The results revealed a decreases in the rate of wear for the use of the hybrid addives by (23%) as the sliding speed incresed from (0.183) meter per second to (1.65) meter per second over a sliding distance of 824.6 meters, while the decrases of wear rate incase of pure oil (without additives) was (17.5%). It can be concluded that the sliding speed has little influence on wear rate for the case of hybrid additive to the base oil compared with pure oil without additives. The essential cause for the decreases in rate of wear is the producing of a tribo-film on rubbing faces, acting as a solid lubricants or an very fine thin lubricating coating layers that decreases shear stress. Moreover, the rolling action of the hybrid powders between the rubbing faces leads to change friction behavior from pure sliding friction behavior to rolling friction behavior, a mechanism that provides a decrease in the coefficient of friction and the wear. The increase in surface temperature with an increase in sliding speed can be helped to the producing of a stable tribo-film.

4. Conclusions

On the basis of the results presented above, it can be concluded that:

1. The investigations observed an increases in the performence of the mixed lubricating oil at sliding surfaces with the addition of the hybrid additives to the SN500 base oil.
2. The optimum concentration of the hybrid fine particles blended with the base oil was 1 wt%.
3. The friction coefficient decreased by (20.8%) for the use of hybrid additives as compared with the used of the pure SN500.
4. The wear rate was reduced by (46%) for the use of hybrid additives after a 1500 m sliding distance, as compared with the used of the pure SN500. The anti-wear mechanism was created by tribo-film through a physical mechanism and a chemical reaction.

5. The sliding speed has little influence on wear rate for the case of hybrid additive to the base oil compared with pure oil without additives over a constant sliding distance of 824.6 m.

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