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Effect on lubrication regimes with silicon nitride and bearing steel balls

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A B S T R A C T

The wear characteristics and an effect of lubrication regime between silicon nitride and steel balls sliding against reference material discs under lubricated conditions were studied. The mild wear was observed for silicon nitride balls and the worn out particles confirms the adhesive wear and simultaneous cutting action of worn-out particles. The worn-out surface analysis confirmed the material transfer from steel disc to silicon nitride ball. Eventually the coefficient of friction (COF) value was reduced by 25% for silicon nitride ball when compared to steel ball due to the formation of mixed oil regime between the contact surfaces. The more depletion of anti-wear additives and oxidation was observed for steel ball due to boundary lubrication.

1. Introduction

The efficiency of the sliding systems was reduced by wear which in-turn cause's power losses and surface fatigue failures. The wear mechanism through surface interactions and asperity contacts are unavoidable in initial run-in period [1]. Wear and friction are not intrinsic material properties and it depends upon the engineering system. Any change in operating conditions like contact geometry, materials and environmental factors cause changes in the wear rate of contact surfaces [2]. The current trend in automobile industry pushes the component design to a limit. Fuel efficiency, lightweight compactness, and integrated design call for the utilization of ceramics in rolling bearings. Due to lightness, high temperature and wear resistance properties of engineering ceramic, bearing industries had been using ceramics for special application conditions such as aerospace, machine tool spindles, semiconductor manufacturing equipment [3,4]. The adhesive wear was very less in hybrid bearings due to lower affinity with the steel materials. The severe damage was prevented in hybrid bearings under insufficient lubrication conditions [5]. Though rolling motion is predominant in rolling bearing; under some loading conditions pure sliding or micro slip always exist. Ball on disc sliding wear test is performed to understand hybrid contact tribological behavior. Steel to steel wear mechanism under lubricant effect is explained by Kimura et al. with adhesion theory. Wang et al. Investigated wear by studying microstructure on sliding wear [6]. The high wear resistance was observed with more fracture and thermal stability materials due to consumption of more energy during the sliding process [7]. Jahanmir et al. found that the surface roughness influences wear rate at the initial state but not the steady state [8]. The elasto hydrodynamic lubrication oil film was formed when Lubricant is introduced into the non-confirming contact surfaces. The oil film shares the asperity load during effective oil film formation. The formation of this oil film during sliding decreases the friction and wears also interaction with surroundings [9]. The formation of oil film was defined based on separation of the informal contact surfaces. The three major types are defined as boundary lubrication, elasto hydrodynamic and mixed lubrication regimes [10]. Tallian et al. observed that the rolling element bearing life was improved when the lambda factor is greater than 3, i.e. elasto hydrodynamic lubrication regime [11]. Akagaki et al. observed a flow wear steel contacts under boundary lubrication [12]. Rigney et al. classified the ceramic wear as mild and severe nature based on material removal rate. The mild wear is mostly observed due to tribo-chemical reactions when the wear rate is lower than 10^{-6} mm^3 $(Nm)^{-1}$ and above that was considered severe wear which is due to delamination wear of tribo-films. Below 10^{-6} mm^3 $(Nm)^{-1}$ wear rate considered as mild wear, which is due to tribo-chemical reactions generate fine particles and above 10^{-6} mm^3 $(Nm)^{-1}$ is considered severe which is caused by delamination of tribo-films. The wear is not depending the load and sliding distance parameters an effective lubrication oil film was formed between the contact surfaces [13]. The Zinc Dialkyl Dithio Phosphate (ZDDP) is the most important commercially available anti wear additive which is used in most of the lubricating oils to reduce the wear under boundary lubrication regime. Spedding Et al observed that at high contact stress ZDDP decompose to phosphate and sulphide compounds which reduced wear [14,15]. John Et al was used Fourier Infra-red Spectroscopy (FTIR) to study ZDDP behavior under temperature & pressure. In their findings at high temperature, ZDDP was decomposed but at high pressure it was

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stable. Linkage between phosphate groups was observed by the FTIR to identify film formation [16].

The new materials mostly hold the promise of reducing the COF and wear on mechanical components during sliding applications. The study of oil film thickness and lubrication regimes with change of rolling element materials is of enormous practical importance in bearings. The reason for conducting this original research work is to understand the effect of wear parameters on various lubrication film regimes. The ball-on-disc wear tests of silicon nitride and steel balls slide against the reference steel material is conducted to understand the effectiveness of change of sliding contact material in oil film formation with constant sliding conditions. The oil film thickness formation during hertzian contact stress depends on speed, load and material parameters. The effect of change of material is analyzed by keeping the speed and load parameters as constants.

2. Experimental apparatus and procedure

The sliding wear test was performed as per ASTM G99 standards using a ball-on-disc tribo-meter apparatus (model: CETR UMT 3M). The silicon nitride and steel balls (SAE 52100) were the taken as test samples sliding against SAE 52100 disc steel. The sliding wear test parameters are given in the Table 1. The commercially available hydraulic oil ISO VG 68 is used as lubricant for sliding wear testing. It consists of 90% base oil, fraction of additives and other compounds The additives are mostly anti-wear, anti-foam, anti-oxidant, anti-rust and extreme pressure additives such as Zinc dialkyldithiophosphate, organic polysulfide, organo-phosphorus, phosphates, chlorinated paraffin's and other organic compounds. The three sliding wear tests were conducted with similar conditions to check the repeatability of values. The average values are considered for the plotting of graphs. During the testing, the tangential force was measured by DFH-100 dual friction/load sensors. The coefficient of friction (COF), contact acoustic emission (AE) and electrical contact resistance (ECR) were recorded.

The mechanical properties of silicon nitride and SAE 52100 steel balls are given in Table 2. The chemical composition of SAE 52100 steel disc was tabulated in Table 3. The automatic Vickers micro hardness tester (model: CMT with MMT X7) was used to make indentations. The hardness was measured at three different places and the average value was considered. The Disc hardness was measured as 750 ± 20 HV. The 3D

Table 1
Test conditions.

Parameter	Description
Module	Ball-on-disk, unidirectional sliding, disc is rotating
Ball	SAE 52100, Silicon Nitride, 6.35 mm in diameter
Disc	SAE 52100, 69.85 mm diameter,
Sliding distance	5000 m
Sliding velocity	0.5, 0.75, 1.00 and 1.50 m/s
Load	170 N
Contact pressure	3500 MPa in JIS SUJ2 (Steel – Steel), 3950 MPa in Si3N4 (Ceramic – Steel),
Lubricant	Mineral oil, ISO VG68 oil
Atmosphere	Air, relative humidity 40–50%. Temperature 25 °C

Table 2
Mechanical properties of ceramic and steel balls provided by the manufacturer.

Material	Silicon Nitride	SAE 52100
Elastic Modulus [GPa]	320	190–210
Poisson's Ratio	0.26	0.3
Density (g c^{-1} m^{-3})	3.2	7.8
Hardness [kg mm^{-2}]	1500–1600	700

Table 3
Chemical composition of steel disc.

Material	Amount (wt.%) of following elements					
	C	Si	Mn	P	S	Cr
SAE52100	1.00	0.28	0.36	0.007	0.001	1.4

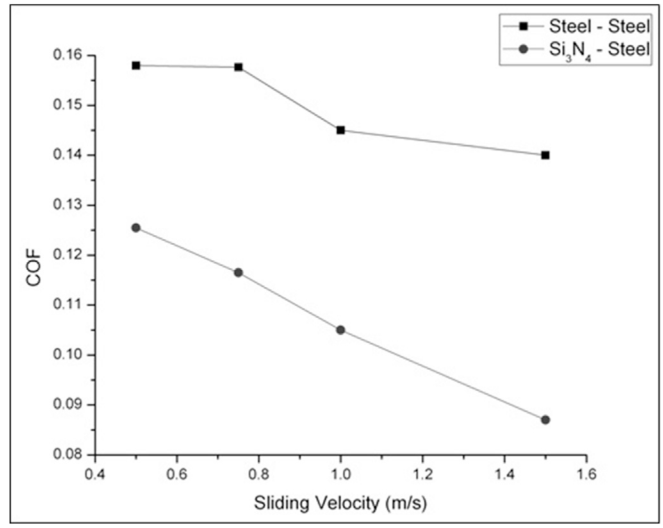

Fig. 1. Relationship between COF and sliding velocity of tested material combinations.

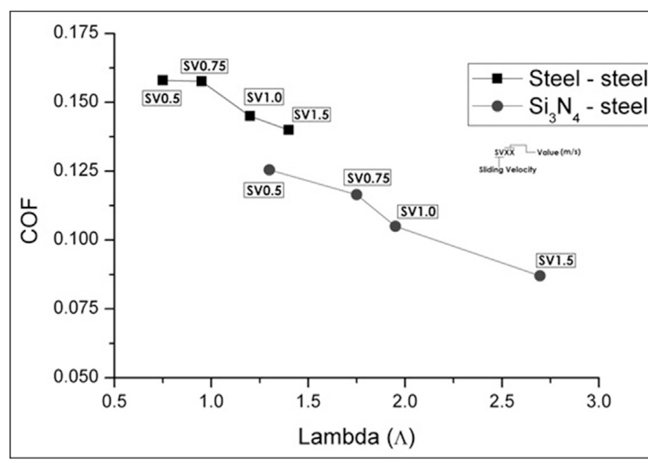

Fig. 2. Relationship between theoretically calculated Lambda value and COF.

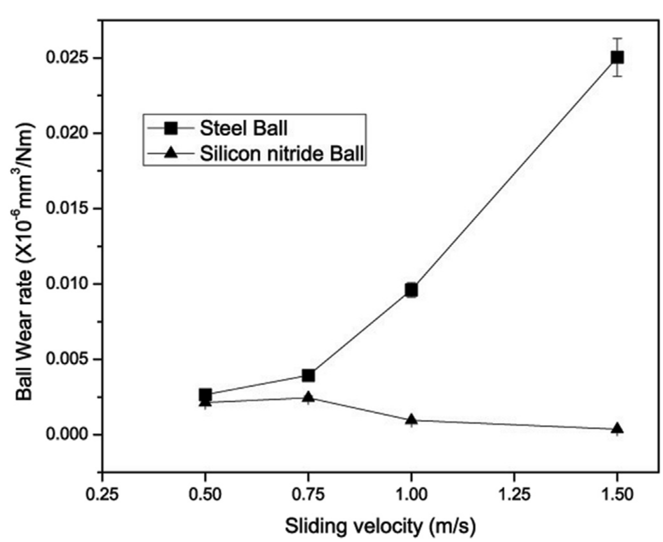

Fig. 3. Relationship between wear rate and sliding velocity for ball materials.