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ORIGINAL ARTICLE

# Development of $SiO_2$ nanolubrication system to be used in sliding bearings

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**Abstract** New technology using nanoparticles as an additive in lubricants is recently becoming an attractive topic of study. The performance of $SiO_2$ nanoparticles in the lubrication system is investigated. Tests were conducted for nanolubrication mixing ratios of 0.0, 0.1, 0.2, 0.5, 0.55, 0.6, and 0.8 wt% with plain bearings rotated by a 2,750-rpm high-speed motor. For each mixing ratio, the frictional temperature and wear rate of the rotating sliding bearings were recorded and compared. During surface testing, the surface roughness values of the sliding bearings were compared and the results showed an improvement in surface roughness after the tests. According to the outcome, the optimum tribological performance of nanolubricant was obtained at 0.5 wt% mixing ratio.

**Keywords** Nanolubricant · $SiO_2$ · Wear · Bearing

## 1 Introduction

Thanks to the industrial revolution of the eighteenth century, bearings approached the forefront of engineering endeavors. Machine speed increased dramatically and bearings were central to rotary and linear movement. In addition, accuracy and repeatability of positioning gained emphasis. The advent of railroad trains in the nineteenth century sparked further development in bearing technology. So, not only did bearings need to operate at high speed, but also heat, vibration, and shock loads greatly increased, and since railroad cars were a commodity, cost was paramount. Today, bearing design continues to progress with advanced materials and new geometries enabled by computer-aided design. Computer-aided manufacturing, such as computer numerical-controlled machining, has drastically improved the accuracy of mass-produced bearings. Accurate and position-repeatable bearings, especially linear ones, have become crucial for robot implementation.

Bearings are required whenever one part of a machine slides against another, and they can be classified as either providing sliding or rolling contact. A sliding bearing typically uses a lubricant to reduce friction between the sliding surfaces. The fluid lubricant forms a film between the sliding surfaces so there is no contact between solid components. Rolling bearings have balls or rollers to minimize rubbing, and lubricant can also be used. In sliding bearings, the load is transmitted over a considerable area while in rolling bearings, the contact area and load transmission are both actually small. The use of sliding bearings is fairly widespread. Some of the areas in which sliding bearings are employed include the following: oil and gas pipelines, waterways and water pipelines, conveyor systems, boiler plants, minor bridges, and power plants. The compact size and overall effectiveness of the bearing makes it an ideal choice in lower load applications (below 100 t). Furthermore, the simplicity of slide bearing design ensures that as long as the basic design specifications are adhered to, there is plenty of latitude as to the exact dimensions and form of the bearing. This is valuable for clients who prefer to design their structures independently and have the bearing modified to suit their overall design.

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With respect to sliding bearings, Dilbag and Rao [1] revealed that surface roughness generally plays an important role, as it affects the fatigue strength, wear rate, coefficient of friction, and corrosion resistance of the machines' components. In order to investigate surface characteristics, surface roughness, morphology as well as the friction coefficient, are investigated. Many papers from literature show the relationship between surface roughness or surface textures and friction in machine components [2–4]. Correct lubricant application has been proven to greatly reduce friction, which results in significantly enhanced surface roughness. Although the significance of lubrication is widely recognized, the usage of conventional lubrication processes has become an enormous liability. Not only does the Environmental Protection Agency regulate the disposal of such mixtures, but many states and localities have also classified them as hazardous waste.

Recently, studies on lubricants with additives such as nanoparticles have attracted the interest of many researches. Polytetrafluoroethene, graphite, and molybdenum disulphide are the more common commercial particles employed. Besides these materials, current research is involved with the effects of additives, whereby the performance of inorganic composites and ceramics as additives is to be further determined. One type of nanoparticles, silicone dioxide ($SiO_2$), is well known as a hard material and is easily acquired on the market at affordable prices. It can be found in sizes ranging from 5 to 100 nm. The mechanical properties of $SiO_2$ are listed in Table 1. $SiO_2$ nanoparticles are known as a hard material that helps reduce direct surface contact in friction applications. Market availability is another principal consideration, which enables the commercialization of research at affordable cost. Besides, regarding material safety concerns, low doses of $SiO_2$ particle were not found to be toxic in experiments performed on laboratory animals (in vivo) [5]. $SiO_2$ can safely be utilized as an additive to nanolubricant in this present research, and its performance is investigated. Nanolubricant is prepared by blending nanoparticles with ordinary mineral oil. A few nanoparticle types are available commercially [6] and regular mineral oil is effortlessly obtained on the market. Sarhan et al. [7] prepared a nanolubricant by adding $SiO_2$ (0.2 wt%) nanoparticles with average size of 5–15 nm to neat mineral oil (ECOCUT SSN 322, Fuchs, Malaysia) with 40.2 cSt at 40 °C. Sonification (240 W, 40 kHz, 500 W) was done for 48 h in order to suspend the particles homogeneously in the mixture. Rahmati et al. [3] reported that cutting force and power were considerably reduced when using a nanoparticle lubricant, since lubricant functions via billions of rolling elements in the tool-chip interface. Correct application of lubricants has been proven to greatly reduce friction, which results in reduced power consumption.

According to Lee et al. [8], 0.1 vol% of graphite particles (average size of 55 nm and specific gravity of 2.26), 0.5 vol% of dispersant (alkyl-aryl-sulfonate), and commercial mineral oil (Supergear EP220, SK, Korea) were mixed using an ultrasonic homogenizer at ambient temperature. The surfaces of the nanoparticles were modified by the dispersant, facilitating the suspension of particles in the as-prepared nanolubricant. The nanolubricant was more stable by having added the dispersant. This is mainly accredited to the repulsive force provided by the dispersant between the nanoparticles' surfaces inside the nanolubricant. Li et al. [9] revealed that nanolubricant, a mixture of nanoparticles and lubricating oil, increases the extreme pressure of the lubricant and reduces the friction coefficient, making the bearing more durable. Their research observed smoother contact surfaces when using nanolubricant compared to raw lubricant. Nanolubricants with different mixing nanoparticle ratios were tested. The comparison results indicate that 0.1 wt% fraction concentration of nanoparticles provided optimum tribological effects in terms of wear rate, surface analysis, and average friction coefficient. On the other hand, the embedding effect of nanoparticles was observed in several cases and reported [9, 10]. The reports demonstrate how the nanoparticles get embedded in the friction surfaces or fill surface grooves. In addition, the deposition of nanoparticles on rubbing surfaces can contribute to lessening of the applied load, duration, and operating temperature [11]. The present study aims to investigate the effect of various mixing concentrations with $SiO_2$ nanoparticles on lubricity to be used in sliding bearings.

**Table 1** The mechanical properties of $SiO_2$ [1]

| Properties | $SiO_2$ |
|---|---|
| Structure | Amorphous |
| Melting point (°C) | Approx 1600 |
| Density (g/cm3) | 2.2 |
| Refractive index | 1.46 |
| Dielectric constant | 3.9 |
| Thermal conductivity at 300 K (W/cmK) | 0.014 |
| Dielectric strength | $10^7$ |

**Table 2** Physical and chemical characteristics of FUCHS Ecocut HSG 905 lubricant

| Properties | FUCHS Ecocut HSG 905 |
|---|---|
| Density at 15 °C | 0.826 g/ml |
| Viscosity at 20 °C | 8.0 $mm^2/s$ |
| Viscosity at 40 °C | 4.6 $mm^2/s$ |
| Flash point | 130 °C |
| Evaporation loss | 90 % |