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An in situ mechanism for self-replenishing powder transfer films: Experiments and modeling

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Abstract

Pellets were formed by compacting MoS_2 powder. A series of tests were conducted on a tribometer that consisted of simultaneous pellet-on disk and pad-on disk sliding contacts. The purpose of the tests was to intentionally transfer MoS_2 third-body particles to a disk where its lubrication characteristics could be studied. This work also showed that the MoS_2 pellet actually acted as a self-repairing, self-replenishing, oil-free lubrication mechanism. In the experiment, a pellet is sheared against the disk surface while the loaded slider rides on the lubricated surface and depletes the deposited powder film. A control-volume fractional coverage modeling approach was employed to predict both (1) the friction coefficient at the pad/disk interface and (2) the wear factor for the lubricated pellet/disk sliding contact. The fractional coverage varies with time and is a useful modeling parameter for quantifying the amount of third body film covering the disk asperities. In the model, the wear rate of a pellet and pad friction coefficient can be determined as a function of the pellet load, slider pad load, disk speed, and material properties. Results from the model qualitatively and quantitatively predict the tribological behavior of the experimental sliding contacts reasonably well.

Keywords: Powder lubrication; In situ solid lubrication; Transfer film; Fractional coverage; Particulate lubrication

1. Introduction to powder lubrication

Advancements in engine technologies and the continuing depletion of the world's petroleum oil supply have increased the need for oil-free lubrication. Additionally, conventional liquid lubricants have proven inadequate in extreme-temperature and load environments. Fortunately, lamellar powders or "powder lubricants" such as molybdenum disulfide (MoS_2), titanium dioxide (TiO_2) and tungsten disulphide (WS_2) have demonstrated excellent tribological capabilities [1]. In powder lubrication, powders lubricate by forming transfer films from compact, spray, or composite forms. In this paper, the lubricant source is obtained from powder compacts intentionally sheared against a rotating disk surface. Consequently, a thin transfer film is formed on the surface on the order of the surface roughness. Therefore, thick film powder lubrication theory, such as Heshmat's quasi-hydrodynamic theory, does not apply to these thin asperity-covering transfer films.

1.1. Compacted powder transfer films

Powder lubricants, pelletized to serve as a deposition source, present a novel approach to lubricating machine components in future applications. Research has shown that pellets can be successfully applied as transfer films to tribosurfaces [2–4]. Additionally, Haltner compacted powder lubricants as a mechanism for transferring a thin lubricious film to a rotating disk [5]. He studied MoS_2 compacts in both vacuum and in room air (relative humidity of 50%), at a velocity of 0.84 m/s. In these tests, the steady-state friction coefficient was $\mu = 0.17$. Compacted MoS_2 powders have also exhibited transient frictional behavior in tests done under both non-vacuum [1] and vacuum [6] conditions. Johnson and Vaughn, who did their tests in vacuum, concluded that the "buildup" in initial friction values was due to an amorphous layer of sulfur generated at the initial point of sliding. Higgs and Heshmat, who conducted tests under non-vacuum (i.e., atmospheric conditions at room temperature) introduced an alternate explanation to the build-up friction relating it to disorder as quantified by entropy [1]. The traction behavior of powder graphite compacted at Hertzian pressure levels was studied to characterize the behavior of the powder particles in the contact

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region [7]. In the disk-on-disk tribometer used in their experiments, the speed was $U = 3.98$ m/s (100 rpm) and the Hertzian pressure $P_c = 690$ MPa. From their work, a method was developed for predicting the film thickness of a powder film in a Hertzian contact, and the traction coefficient of a powder film in rolling element bearing configurations. Higgs et al. showed that MoS_2 pelletized powder lubricants acted as a velocity accommodating third-body in high-speed sliding contacts [1]. Extending Godet's third-body approach [8], Fillot et al. [9] used a computational wear simulation to glean mass balance laws for describing wear between tribosurfaces when a third-body is formed.

The scope of this work presents experimental results from a competing transfer film deposition and lubricant depletion process. To predict this process, a control volume fractional coverage (CVFC) model has been developed that extends the mass-balance concepts of Fillot et al. [9] to analyze the competing pellet transfer film (i.e., lubricant deposition) and pad wear (i.e., lubricant depletion) mechanisms on a pellet-on disk with slider pad tribometer configuration. Results from the pellet-on-disk with slider experiments are compared to the theoretical results from the CVFC model.

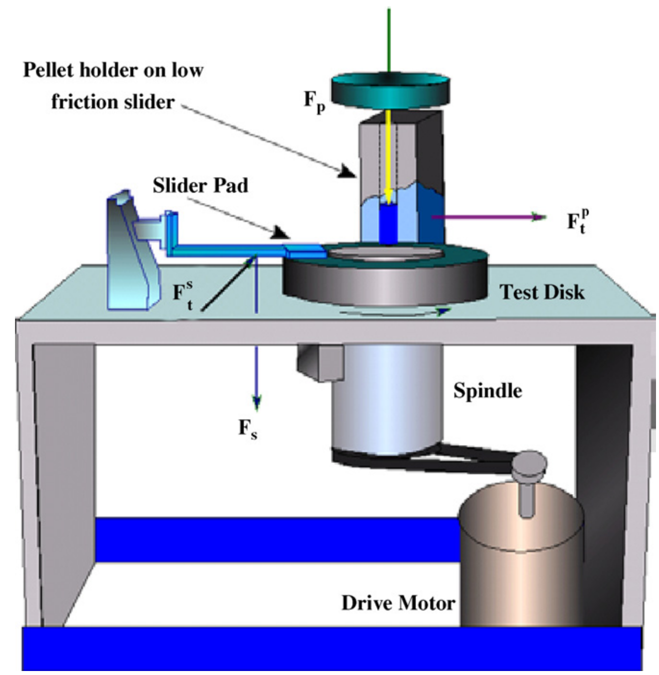

Fig. 2. Pellet-on-disk with slider tribometer for measuring the pellet wear and friction forces at pellet/disk and slider/disk.

2. Experimental details

2.1. Pellet-on disk experiments

To analyze an in situ powder transfer film mechanism, a setup consisting of in-line sliding of a MoS_2 pellet and slider pad (Fig. 1) was developed. Pellets fabricated from tap powder are wear tested on the pellet-on-disk tribometer (Fig. 2), using the in-line pellet and slider setup of Fig. 1. In the wear tests, MoS_2 pellets were sheared against the surface of the rigid rotating disk. The thin-film interfacial third body particulates produced by the pellet were depleted by the loaded slider pad riding on the lubricated surface.

2.2. Fabricating pellets for wear testing

Preliminary work identified MoS_2 powder as a suitable solid lubricant material for this investigation [2]. A powder compaction system was designed for forming the cylindrical MoS_2 pellets, consisting of a top and bottom die, which housed the powders during compaction. A thin sleeve of Inconel alloy encompassed the powders. A porous, split sleeve tube encasing the powder and the Inconel was placed in the bore of the top die. This encasing was rested on top of a porous disk located at the base of the bore. The disk had a porosity of 0.5 μm and allowed the air in the powders to escape during compaction. The piston was less than 100 μm smaller than the porous encasing to avoid metal-to-metal contact. Once filled with powder, the fixture was placed under a hydraulic press where it was compacted to the desired pressure. The resulting pellet had a diameter of 19 mm and a length of 51 mm. The pellets were made by compacting three different samples of MoS_2 powder with varying average particle sizes; Sample A with 13.64 μm; Sample B with 7.4 μm; Sample C with 1.56 μm. Similar to transfer films that are not self-replenishing [10], Sample A was used in previous pellet-on-disk tests conducted without slider pads and was excluded as a self-replenishing solid lubricant candidate for this work, so only Samples B and C are examined in this study. The mass, diameter, length, and density of the pellet were measured after compaction.

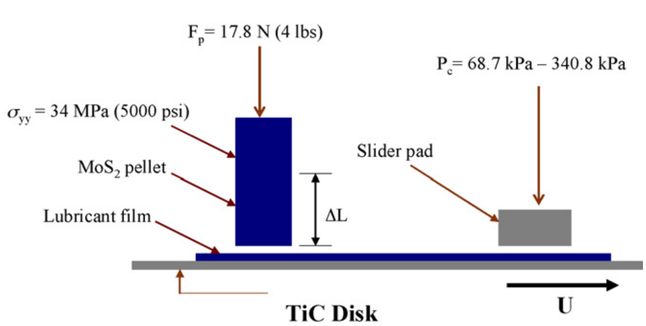

Fig. 1. Pellet-on-disk with slider apparatus enables the study of self-replenishing powder film transfer. The test parameters were as follows: $F_p = 17.8$ N; $P_c = 68.7$–340.8 kPa; $U = 4.5$–45 m/s.

2.3. Pellet-on disk with slider experiments

After the pellets were fabricated and measured, they were placed in the L-shaped pellet holder for wear testing. During the tests, a pellet was loaded against the disk, as it rotates. A slider pad, located in-line with the pellet, was also loaded against the disk. In this project, the investigation of the film transfer process was studied using the pellet-on-disk wear test. Fig. 1 shows a diagram of the pellet-on-disk with slider pad configuration. In the experiment, a powder transfer film from a pellet was deposited on the disk and a slider pad depletes the film when its load exceeds the film's load carrying capacity. Since the pellet is