TRIBOLOGICAL INVESTIGATION OF THE POLYMER-BASED LUBRICATION SYSTEM WITH MICROPORRUSES USED IN A MANUFACTURING TRANSFER LINE

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ABSTRACT

Flooded oil lubrication systems are commonly utilized for many manufacturing processes. However, there is an increasing concern with the flooded lubrication systems due to their biological and environmental impact as well as maintenance and disposal cost. A polymer-based lubrication system with micropores, a sponge like solid lubricant allowing the oil to weep out while in use, provides a promising alternative solution to satisfy the lubrication requirements for some manufacturing processes. In addition, it can minimize contamination of the coolant system, reduce waste processing and disposal costs, and alleviate the in-plant safety hazard from oil leakage on floor surfaces.

The goal of this study is to develop and improve the current lubrication system by applying a polymer-based lubrication system with micropores in order to replace the oil flooded transfer line lubrication systems currently in production use. Using a laboratory reciprocating bench test based on design of experiments, this study characterized the tribological performance of the polymer-based lubrication system with micropores under a variety of operating conditions, identified the main factor which impacts the tribological performance of the polymer-based lubrication system with micropores, and developed a model to predict the wear loss of the new lubrication system with micropores. These results provide the guidelines for possible applications of the polymer-based lubrication system used in the manufacturing process.

1. INTRODUCTION

Flooded oil lubrication systems are commonly utilized for some manufacturing processes. A primary concern with the flooded lubrication system is the biological and environmental impact. In addition to possible fumes, smoke, and odors, the fluid may also cause severe reactions on the skin and to various parts of the operator’s body. Maintenance due to oil degradation and ultimate disposal also cause additional cost and reduce the manufacturing efficiency. A polymer-based lubrication system with micropores, a solid lubricant that is a mixture of polymers, oil, and selected additives, whose matrix is in a sponge like form allowing the oil to weep out while in use, provides a promising alternative solution to satisfy the requirements of some manufacturing processes. It minimizes contamination of the coolant system, reduces waste processing and disposal costs, and alleviates the in-plant safety hazard from oil leakage on floor surfaces.

This study aims to develop and improve a polymer-based near-dry lubrication system with micropores to replace the oil flooded transfer line lubrication systems currently in use. In this study, the feasibility and durability of the proposed polymer-based lubrication system was investigated using a reciprocating bench durability test based on an experimental design. The experimental observations were further analyzed statistically. A weight loss model of this lubrication system was also developed, and SEM and XPS determined the related surface characteristics.

2. EXPERIMENTAL DESIGN

2.1. Experimental setup and test conditions

To investigate the tribological performance of the proposed polymer-based lubrication system with micropores, a leaded bronze plate (hardness HB 32.8) with micropores was used in this study. This plate was 38.1 mm by 50.8 mm (1.5 inch × 2.0 inch), and contained twelve impregnated holes with polymers and solid lubricants. Inside each hole was a mixture
of polymers, oil, and selected additives, and the oil oozes out from the hole during the service period. The coupon was made of P20 steel with a hardness of HRc 55. The surface roughness ($R_a$) of the steel coupon, which slides against the impregnated plate, was 0.2250 µm.

To evaluate the tribological performance of the polymer-based lubrication system with micropores, a high frequency friction and wear tester was modified to serve as a test bed as shown in Figure 1. A reciprocating bench tester can provide the following features: (1) a reciprocating contact motion, similar to that which exists in a manufacturing process and/or transfer line; (2) a range of loads and sliding speeds; (3) accurate friction coefficient information; and (4) contact potential information to represent the lubrication film thickness along the sliding interface.

![Figure 1. Photo of the reciprocating bench test](image)

To keep the impregnated plate in the same sliding direction, two rails were manufactured to maintain the impregnated plate moving direction during testing. The friction force between the Impregnated plate and the rails was assumed negligible compared to that between the Impregnated plate and the steel plate under the applied normal loads (100 N and 250 N).

Test conditions were determined based on the typical operating conditions for a transfer line system provided by a manufacturing factory in Michigan, USA. The operating temperature was controlled at 30 °C. For real transfer line systems, the interface temperature will be a little higher than 30 °C because of frictional heating. This temperature rise along the sliding interface is a function of load and sliding speed and was considered negligible under lubricated conditions.

The applied pressure in the factory ranges from 7.5 psi to 25 psi. Simulation of this condition in this test required a load range of 100 N to 333 N for a 38.1 mm × 50.8 mm (1.5 inch × 2.0 inch) plate. Since the highest load that can be provided by the Cameron Plint machine used is 250 N (equal to 18.75 psi), this highest load (250 N) and 100 N were chosen as the two load conditions to be simulated.

The transfer speed in the factory ranges from about 150 inch/min to 350 inch/min. Since the amplitude of the stroke of the Cameron Plint machine used was set at 15mm, the frequencies of 2.5 Hz and 5 Hz were chosen here, which are equal to average sliding speeds of 75 mm/s (177.2 inch/min) and 150 mm/s (354.3 inch/min), respectively.

2.2. Design of experiments

To determine the effects of operating conditions on the Impregnated plate weight loss, a two-factor, two-level, full-factorial design of experiments was performed. The two factors for this testing were load and sliding speed. Each factor had two levels. Each condition was run for 15 hours. Three replications of each factor level combination were conducted, resulting in a total of 12 runs. The response variable was the Impregnated plate weight loss.

To further investigate the tribological performance of this polymer-based lubrication system with micropores as a function of time under severe conditions (high pressure and high sliding speed, that is, 250 N and 5 Hz), additional tests for the durations of 60, 150, and 250 hours were run for comparison.

3. SUMMARY AND CONCLUSIONS

The tribological performance of the polymer-based lubricant system has been investigated, and a weight loss model of the impregnated plate has been developed. Based on experimental observations and surface analysis, the research results can be summarized as follows:

1. Friction coefficients fell in the range of 0.01~0.035 under the typical transfer line operating conditions. The low friction coefficient will help reduce wear in manufacturing processes.

2. After the lubrication film was built-up, the contact potential approached an asymptotic value (50 mV). This steady state lubricant film prevented the surface from wear or scuffing. It was also observed that the weight loss approached an asymptotic value after about 250 hours of sliding. Therefore, it is concluded the wear rate was gradually reduced after long sliding durations.

3. Based on the output of an ANOVA table, if the one-sided confidence level is set as 95%, both sliding speed and load have significant effects on weight loss while at this level the interaction of load and sliding speed is not significant. If the one-sided confidence level is set as 90%, load, sliding speed, and their interaction all have significant effects on the impregnated plate weight loss.

4. Both green and brown residues were observed on the surfaces of both the steel plate and the Impregnated plate after testing. The green residue is mainly composed of C, O, and Cu, while the brown residue contained mainly C. The organic brown residue is considered to be the result of abnormal degradation of the polymer-based lubricant with micropore structure.