Structuring of Tribological Active Surfaces for Reduction of Frictional Losses

A. Schubert[1,2], J. Edelmann[1], D. Sylla[2], M. Hackert-Oschätzchen[2]
[1]*Fraunhofer Institute for Machine Tools and Forming Technology IWU, Chemnitz*
[2]*Chemnitz University of Technology, Chair in Micromanufacturing Technology, Chemnitz, Germany*

jan.edelmann@iwu.fraunhofer.de

Abstract

Surfaces in a wide range of engineering applications are subject to tribological loads. Many of these surfaces have a profound effect on the efficiency of manufacturing processes and products during service. This paper focuses on the effect of surface microstructure geometry on the friction coefficient between lubricated sliding partners. Initially, the Computational Fluid Dynamics (CFD) package COMSOL Multiphysics was used to determine the effect of geometry parameters of semi-spherical cavities on hydrodynamic pressure. The simulations showed that surface microstructures act as micro pressure chambers that would allow the sliding partners to reach hydrodynamic lubrication at lower operating speeds. Patterns of the microstructure that showed the highest pressure build-up in the simulations were then manufactured by Jet-ECM and tested in a tribometer. It was determined that patterned spherical segment cavities 10 µm deep and 500 µm wide yield a friction coefficient reduction of up to 35 %.

1 Introduction

Significant potential to increase the energy and cost efficiency of manufacturing processes as well as of products during their service cycle lies in the optimization of the tribological behaviour of sliding components. Surface morphology has a critical influence on friction and wear and these can be reduced considerably by a specific change of sliding surface structure [1-3]. However, there exists no uniform agreement with regard to the effect of microstructure geometry on frictional behaviour of lubricated sliding partners. In this paper, spherical segment cavities of varying diameter and depth were first examined using the Computational Fluid Dynamics (CFD) package COMSOL Multiphysics. The geometry parameters that showed the highest hydrodynamic pressure build-up were then manufactured by electrochemical machining with closed electrolytic free jet (Jet-ECM). This process was chosen due to its capability of high-precision material removal without mechanical or thermal damage of the workpieces. Lubricated ring-on-disc tests—with only the ring counterpart featuring the surface microstructures—were conducted to study the effect of microstructure geometry on friction coefficient.

2 Simulation

The CFD package COSMOL Multiphysics was used to analyse the effect of the geometric parameters of spherical-segment-cavity patterns on hydrodynamic pressure. The model was based on the Navier-Stokes equation for incompressible fluid. It simulates the gap between a static, microstructured body and a smooth counter body which moves at a constant speed parallel to the former. The gap is filled with lubricant. Hydrodynamic pressure profiles for different depths (2...500 µm) and diameters (50...500 µm) of spherical segment cavities were calculated.

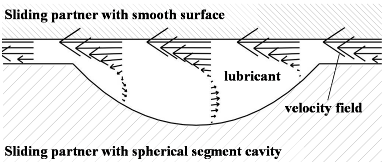


Figure 1: FEM simulation of lubricant circulation in a microstructure

The following conclusions were reached from the simulation results:

- The lubricant circulates in the cavities due to the relative motion of the two friction partners (Figure 1) and increases hydrodynamic pressure above the cavities
- Pressure increased nearly linearly with increasing cavity diameter
- A pressure maximum was determined for a cavity depth of 10 µm.

3 Experimental

A tribometric ring-on-disc test procedure was selected for the experimental investigation (Figure 2a). Samples were manufactured with a contact surface of 4005 mm^2. The discs consisted of 42CrMo4 steel with an outer diameter of 100 mm and a thickness of 8 mm. The rings were made of CuSn8 bronze with an outer and inner diameter of 100 mm and 70 mm, respectively, and a thickness of 10 mm. Ring and disc were loaded with a normal force F_N of 40 N. Relative tangential velocities v between 0.05 m/s to 3 m/s at the outer perimeter were tested. Friction moment was measured in a Wazau TRM500 Tribometer (Figure 2b). Engine oil Castrol EDGE 5W-30 with a temperature of 60°C was applied as lubricant.

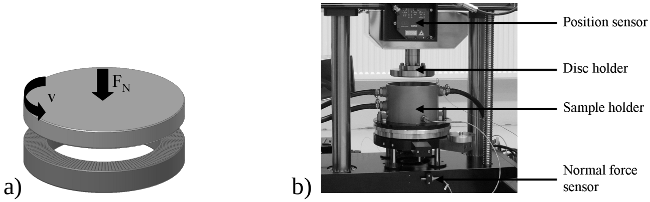


Figure 2: Ring-on-disc-test (a); Tribometer TRM 500 test rig (b)

The texturing of the rings (Figure 3a) was produced by Jet-ECM (Figure 3b). The anodic dissolution of a metallic workpiece in the electrolyte is reached by a cathodically polarized nozzle jet under a high velocity on an anodically polarized workpiece. The spherical segment cavities were manufactured with the diameters 200 and 500 µm and depths of 10, 40 and 80 µm.

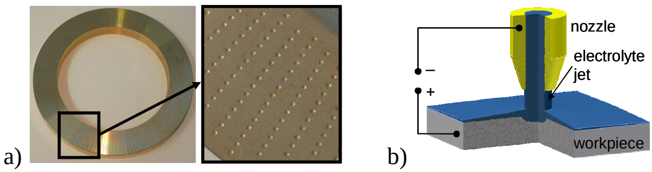
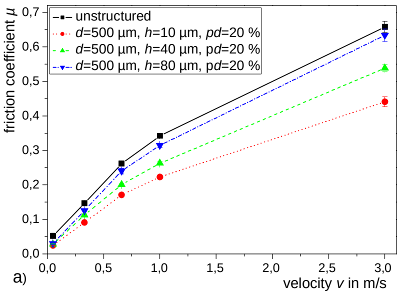


Figure 3: microstructured bronze ring (a); Electrochemical machining Jet-ECM (b)

4 Results

In Figure 4, the friction coefficient of 42CrMo4/CuSn8 sliding partners with various surface structure geometries is presented as a function of sliding speed. Figure 4a shows the influence of cavity depth h with a constant diameter d of 500 µm and a surface pattern density pd of 20 %. The unstructured reference pair showed a friction coefficient of 0.05 at the smallest speed of 0.05 m/s. With the rise of the speed the friction coefficient increases to 0.65 at a speed of 3 m/s. The structured surfaces showed the same monotonic increase characteristic of hydrodynamic lubrication regime. However, the surface textured sliding partners showed smaller friction coefficients throughout the speed range tested. It was determined that cavities with a depth of 10 µm yield the lowest friction coefficient.



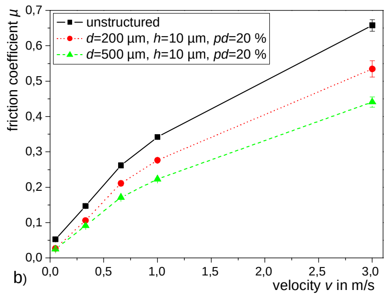


Figure 4: Influence of cavity depth (a) and diameter (b) on the friction coefficient.

Figure 4b presents the influence of cavity diameter on friction coefficient. In comparison to smooth sliding partners, structures with a diameter of 200 µm decreased friction coefficient by 20 %, whereas structures with a diameter of 500 µm yielded a 35 % reduction.

5 Conclusions

An investigation on the influence of microstructured surfaces on the tribological behaviour of lubricated sliding partners was carried out. From CFD simulations and tribometric tests, it was found that patterned spherical-segment cavities effectively reduce friction in lubricated sliding. It was found that cavities with the smallest depth and the broadest diameter tested in the study yield the lowest friction. Cavities with a depth of 10 µm and a diameter of 500 µm decreased friction coefficient by 35 % in the tribometer tests.

Future investigations will focus on the effect of surface finish prior to texturing on frictional behaviour. It shall be examined whether it is possible to manufacture low-friction lubricated sliding surfaces without recurring to pre-finishing operations such as grinding by use of suitable surface microstructures.

References:

[1] Dumitru, G. et al: Lasermicrostructuring of steel surfaces for tribological applications, Applied Physics A 70, (2000) pp. 485–487

[2] Wan, Y.; Xiong, D.-S.: The effect of laser surface texturing on frictional performance of face seal, Journal of materials proc. techn. 197 (2008) pp. 96–100

[3] Rapoport, L. et al: Friction and wear of MoS_2 films on laser textured steel surfaces, Surface & Coatings Technology 202 (2008) S. 3332–3340