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FEM simulation of tribological performance with structured surface

Ying Wang [1], Tianfeng Zhou [2], Oltmann Riemer [3], Julian Heidhoff [3], Bernhard Karpuschewski [3]

[1] *School of Mechanical Engineering, Beijing Institute of Technology, Beijing 100081, China*
[2] *Key Laboratory of Fundamental Science for Advanced Machining, Beijing Institute of Technology, Beijing 100081, China*
[3] *Leibniz Institute for Materials Engineering IWT, Laboratory for Precision Machining LFM, Badgasteiner Str. 2 28359 Bremen, Germany*

ywang@iwt.uni-bremen.de

Abstract
The investigation of tribological performance occurring between polished and structured surfaces is the core for understanding frictional mechanisms. Finite element method (FEM) is a simple, efficient and economical approach to study friction performance of microstructured surface. In this paper two dimensional finite element simulation with hardened steel (1.2379) structured workpieces and aluminium counterparts are reported which are supported by tribological experiments. Three samples exhibiting different micro structured surfaces with pitch between two structures (20µm, 25µm and 65.2µm) are simulated by Abaqus. And the depth of structures is kept constant. The result is evaluated by the coefficient of friction, which is calculated by contact reaction force, obtained from the simulation results. Furthermore, the stress distribution of the workpiece is visualized. The results show that the structured surfaces is beneficial to reduce coefficient of friction in simulation tests and been confirmed by experiments.

Frictional mechanisms, FEM simulation, Structured surface

1. Introduction

Micro metal forming is the technological field of micro manufacturing, which takes advantages of the excellent mechanical and functional characteristics peculiarities to metal, and is a vital forming technology that has been scaled down to the microscale range suitable for mass production[1]. However, the improve method of the adhesion between die and workpiece associated with size down in micro metal forming is one of the central issues. Surface engineering is advantageous to the micro metal forming process, especially the structured surface with micro milling manufacturing. Shubrajit Bhaumik et al. [2] demonstrated the friction reduction capability of micro-dimpled surface generated on a steel plate (disc) using a vertical milling machine. After the tribological tests the optimized dimple parameters exhibited a decrease of 49.76% coefficient friction over the non-dimpled surface. In recent years, tribological performance has been studied by FEM to examine the stress distribution and coefficient of friction[3,4]. Markus Schewe et al. [5] carried out the research on simulations about friction characteristics on metal forming dies. Sinusoidal surface structures are able to provide anisotropic structural resistance, at the same time one bionic surface structure shows quasi-isotropic structural resistance. The application of FEM simulation can significantly reduce the friction testing time.

In this paper, the structured surface modelling is built and coefficient of friction with different pitch between two structures is simulated through contact stress. The results show that FEM simulation is a reliable approach to research the tribological performance on structured surface, and the structured surfaces with higher or lower pitch provoked increased friction.

2. Modelling

Due to the shorter computational time compared to three dimensional simulations more simulations can be calculated in two dimensional what is necessary to study different scale structures, especially micro scale structure. The modelling of structured surface and friction pair is show in Fig. 1. Hardened 1.2379 (X153CrMoV12) tool steel is used as workpiece material. This material is suitable for micro metal forming dies and is characterized by micro structured. Three different structures with different pith (P=20 µm, 25 µm, 65.2 µm) are simulated, where depth (D) is kept constant at 0.0866mm. Besides the micro structured modelling, a reference polished workpiece (R) is simulated also.

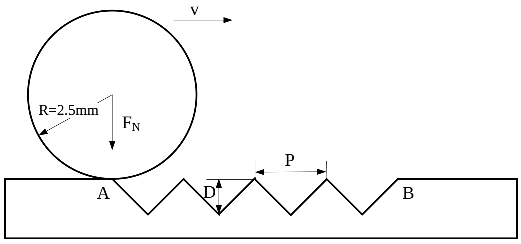

Figure 1. Modelling of structured surface and spherical friction pair

There are two parts in the simulation: the structured workpiece and Al99.9 ball with 5mm diameter. The upper surface of the workpiece is a uniform microstructure with different size. The bottom of the structured workpiece is fixed. The normal force (F_N) is 100mN. The stroke length of the relative motion (distance from A to B) is 5 mm and the simulation velocity is 4 mm/s from point A to point B. The average values of the coefficient of friction is calculated from simulated normal and tangential reaction force. And the mises stress received by the structured surface during friction process can also be obtained from the simulation results, which is very importent for analyzing friction mechanism.

3. Discussion

The coefficient of friction and stress distribution are core factor to analyse the structured surface tribological performance. The simulation results compared with experiment results, in order to verify the accuracy of simulation results. The manufacture of the micro structured surfaces is carried out on a DMG Sauer US 20 linear micro milling machine tool under dry conditions. Tungsten carbide ball endmills of 1.5 mm diameter are applied and the tool is aligned normal to the machined surface to enforce the generation of quasi-deterministic surface structures. The selection of process parameter is derived from preliminary studies with the aim to provide a spectrum of micro structured surfaces relevant for the application to tribologically experiments. Besides the micro structured samples a reference sample (R) was manufactured by polishing. An overview of samples and machining parameter is given in Table 1.

Table 1 The overview of samples and machining parameters

Sample No.	Rotation speed n [1/min]	Feed velocity v_f [mm/min]
No.1 (P=20)	20000	800
No.2 (P=25)	20000	1000
No.3 (P=65.2)	40000	5000
R	Polished	

3.1 Coefficient of friction

The coefficient of friction μ for three structured surfaces and the polished reference surface are calculated by normal and tangential force from simulation results, which shows in Fig. 2. A clear relationship between frictional performance and surface structure is found. Surface structure is beneficial to reduce coefficient of friction. The highest friction is obtained from the polished surface up to μ=0.83. And the minimum coefficient of friction μ=0.42 is observed in surface with P=20 μm. The law of friction coefficient is the same as Florian Böhmermann's experiments[6].

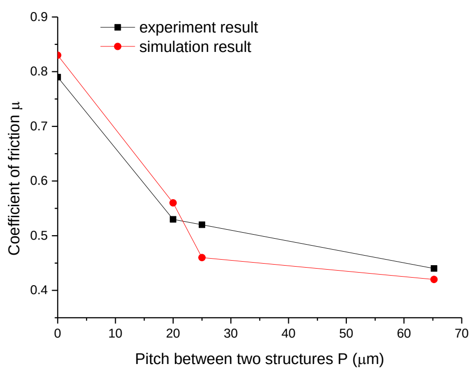

Figure 2. Coefficient of friction μ at different pitch

In the structured surface with P=25 μm and 65.2 μm, the simulation results of coefficient of friction μ is relatively close to the experimental results. But the coefficient of friction μ with P=20 μm has a large error compared with experiment result. As observed by Florian Böhmermann[6]: microscopic structures, can serve as lubricant reservoirs to achieve hydrodynamic separation of forming dies and work pieces and, thus, reduce friction and wear. But it's difficult to achieve in the current simulation model. The structured surface with lager geometric size regulate the coefficient of friction through control the material flow. It's can be achieved in simulation by setting material parameters.

3.2 Stress distribution

With the simulation results the effects of the structure geometries are analyzed on the coefficient of friction as well as the stress distribution. The mises stress in structured surface is showed in Fig. 3.

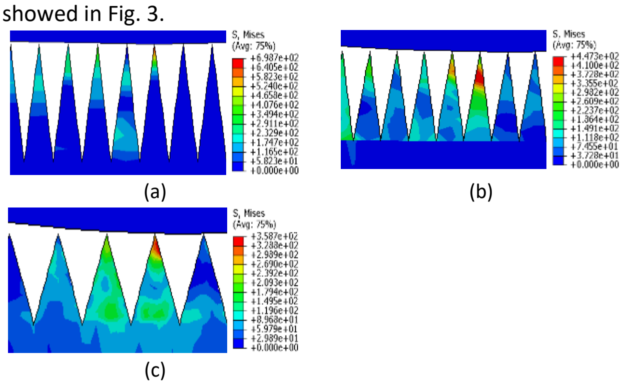

Figure 3. Stress distribution on structured surface at different pitch: (a) P=20 μm, (b) P=25 μm, (c) P=65.2 μm

As pitch P increases, the mises stress in the structured workpiece decreases, and the greatest mises stress appears on the polished surface. The maximum stress S=1214.4 MPa is observed in polished surface. Otherwise the minimum stress S=378.6 MPa is obtained in surface with P=65.2 μm.

4. Conclusion

With the simulation results the effects of the structure geometries on tribological performance are analyzed through coefficient of friction and mises stress. A clear correlation between the coefficient of friction and the structured surface's geometries paremeters is observed. Surface structure is beneficial to reduce coefficient of friction. The highest average coefficient of friction is measured on the polished surface with μ=0.83. The minimum coefficient of friction μ=0.42 is observed in surface with P=20 μm. As pitch P increases, the mises stress in the structured workpiece decreases, and the greatest mises stress appears on the polished surface, which is up to 1214.4 MPa. In the future work, the influence of workpiece stress on tribological performance should be focused on.

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