Friction and wear analysis of milled surfaces at the micro-nano scale

Jianing Wang[1,2], Song Zhang[1,2,#]
1 School of Mechanical Engineering, Shandong University, Jinan 250061, China
2 Key Laboratory of High-efficiency and Clean Mechanical Manufacture, Ministry of Education, Shandong University, Jinan 250061, China
Corresponding Author / Email: zhangsong@sdu.edu.cn, TEL: +86-136-5861-8698, FAX: 0531-88392747

KEYWORDS: Micro-nano surfaces, Friction coefficient, Wear depth, Normal load, Displacement amplitude

The friction and wear properties of milled surfaces directly affect the stability and reliability of mechanical equipment, and its friction and wear mechanism are not clear enough because it is affected by many factors. In this paper, the friction and properties of milled surfaces of the metallic material HT300 at the micro-nano scale were investigated. First, milling experiments were carried out on HT300 metallic materials to obtain milled surfaces on the micro-nano scale with machined textures. Then, the friction and wear experiments on the milled surface were carried out under different normal loads and displacement amplitudes. Next, the friction coefficient curves during frictional wear were analyzed, and the effects of normal load and displacement amplitude on the average friction coefficient were investigated. Finally, the wear profiles in the friction and wear process were analyzed and the relationship between normal load, displacement amplitude and maximum wear depth were revealed. In this paper, the friction and wear laws of milling surfaces at micro-nano scales under different loading conditions are investigated, which provides theoretical support for the study of friction and wear on machined surfaces.

NOMENCLATURE

v_c = Cutting speed
f_z = Feed per tooth
a_e = Radial depth of cut
a_p = Axial depth of cut
F_n = Normal load
D = Displacement amplitude
f = Frequency
N = Number of cycles
T = Temperature

1. Introduction

Mechanical equipment contains a large number of mechanical bonding surfaces, which are usually machined by turning, milling and grinding. On the micro-nano scale, these machined surfaces are not smooth planar surfaces, but rather rough surfaces consisting of numerous rough peaks [1]. Therefore, under vibration, load and other factors, friction will be generated between the machined surfaces, which will lead to wear and tear of the machined surfaces, and ultimately affect the normal operation of mechanical equipment [2].

In terms of friction, the friction coefficient reflects the intensity of friction between machined surfaces. However, in the actual friction process, the friction coefficient is not a constant value, but a curve. Due to its complexity, researchers often simplify and fit the friction coefficient. Cai et al. used a single and constant friction coefficient for modeling the micromotional wear of CuNiAl alloy [3]. Zhang et al. used the average value of the steady-state friction coefficient for different working conditions as a reference and input it into the friction and wear model for studying the friction and wear characteristics of AgNi10 alloy [4]. To take the effect of operating conditions on the friction coefficient into account in the friction and wear study, later, Zhang et al. obtained the curves of the friction coefficient for different operating conditions and established a functional relationship between different operating conditions and the steady-state friction coefficient [5]. While, Poon et al. directly used all the friction coefficient curves for friction wear modeling after obtaining the friction coefficients under different operating conditions [6].

In terms of wear, researchers have also established different criteria to evaluate wear. Li et al. studied the wear of Ti60 titanium alloy with APS YAG coating and found that the wear width increased with the increase in the number of cycles [7]. Wei et al. investigated the effect of wear on M50 bearing steel and explored the pattern of normal load, displacement amplitude and wear depth [8]. Similarly, Hu et al.

carried out a study on high temperature micromotional wear of IN738LC alloy and found that the wear area increased with increasing load [9]. Song et al. considered the wear volume as the wear volume and investigated the effect of displacement amplitude and frequency on the wear volume [10].

In conclusion, the friction and wear properties of machined surfaces vary under different loading conditions and evaluation methods. Therefore, this paper investigates the friction and wear characteristics of milled metal surfaces on the micro-nano scale and analyzes the effects of normal load and displacement amplitude on the friction coefficient and wear depth. The paper is organized as follows: The milling experiments on the metal material HT300 are carried out, and further, friction and wear experiments on the specimens of this metal material are carried in Section 2. The trends of the friction coefficient curves are analyzed and the effect of normal load and displacement amplitude on the initial average friction coefficient are investigated in Section 3. Wear profiles are analyzed and the effects of normal load and displacement amplitude on the maximum wear depth are investigated in Section 4. Conclusions are given in Section 5.

2. Experimental procedure

The material required in the study was HT300 metal. The milling experiments are carried out on EU5 700 vertical machining center (US Wheeler, China), the required tool type is JH970100-TRIBON (Seco tools, Sweden) and the process parameters are shown in Table 1. The wear experiments on the machined surfaces were carried out on the MFT-5000 micro-motion friction and wear experimental machine (Rtec Instruments, USA). Carbide balls of material GCr15 were selected for the wear parts. The working conditions of the micro-motion friction and wear experiment are shown in Table 2.

Table 1 Cutting parameters

Parameters	v_c(m/min)	f_z(mm/tooth)	a_e(mm)	a_p(mm)
Values	260	0.28	0.36	0.3

Table 2 Loading parameters

Parameters	Values
F_n (N)	40,120,200
D (μm)	40,80,120
f (Hz)	30
N (Number)	18000
T (°C)	33

3. Friction properties analysis of milled surfaces

Fig. 1(a)-(c) illustrate the friction coefficient plots for different normal load and displacement amplitudes. As shown in Fig. 1-(a), the friction coefficient increases and then decreases and then stabilizes with the increase of the number of cycles when the displacement amplitude is 40 μm. However, when the displacement amplitude is 80 μm and 120 μm, the friction coefficient increases and then stabilizes with the increase in the number of cycles. Similarly, the friction coefficient increases and then decreases and then stabilizes with the increase in the number of cycles for a displacement amplitude of 40 μm, as shown in Fig. 1-(b). However, when the displacement amplitude is 80μm, the friction coefficient increases and then decreases slowly with the increase in the number of cycles. When the displacement amplitude is 120μm, the friction coefficient increases and then increases slowly with the increase of the number of cycles, and it fluctuates greatly. As shown in Fig. 1-(c), the friction coefficient increases and then decreases with the increase of the numberof cycles, and then tends to stabilize.

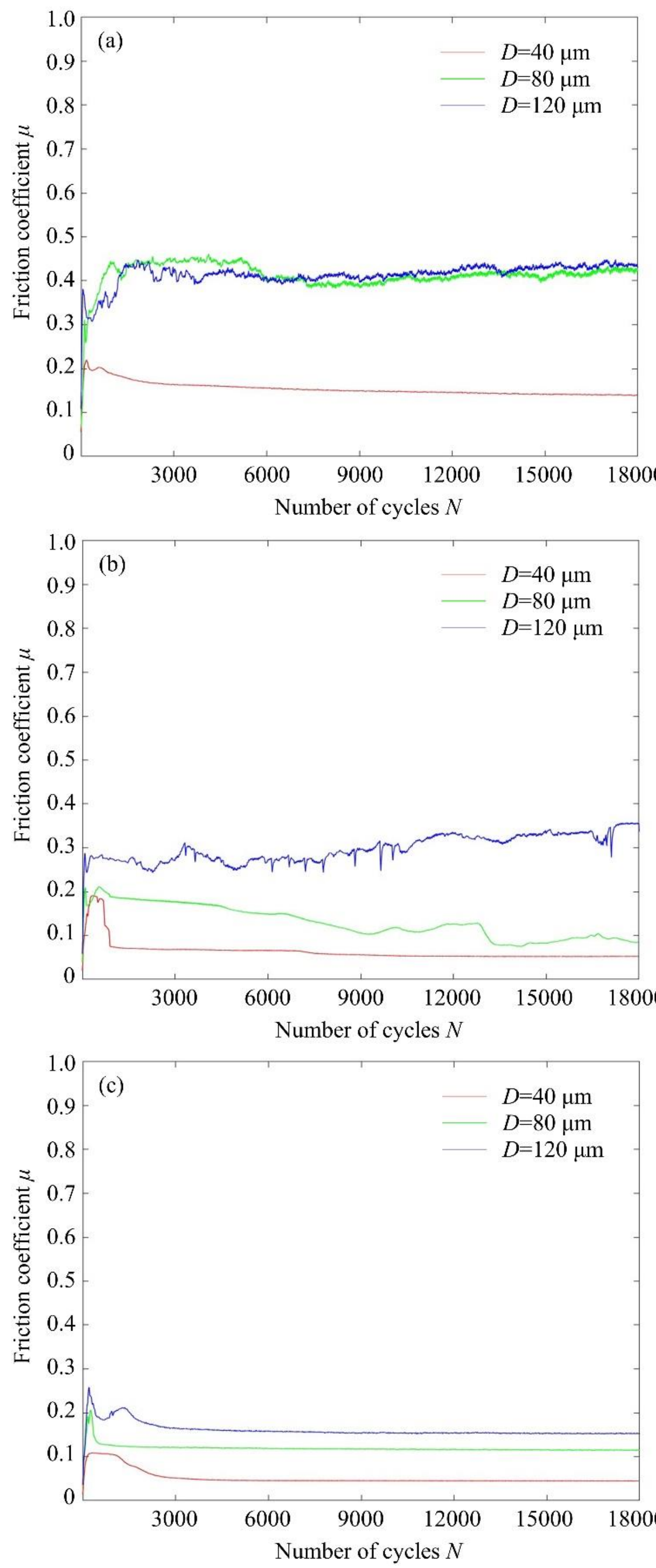


Fig. 1 Friction coefficient curves of different normal load and

displacement amplitudes. (a) Normal load F_n=40 N. (b) Normal load F_n=120 N. (c) Normal load F_n=200 N.

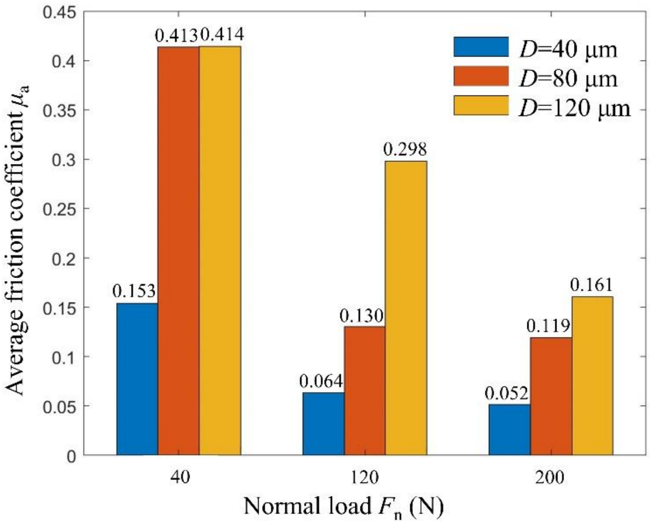
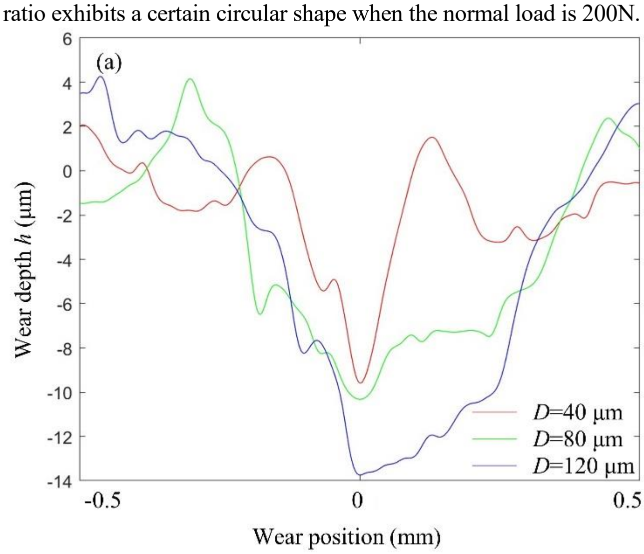


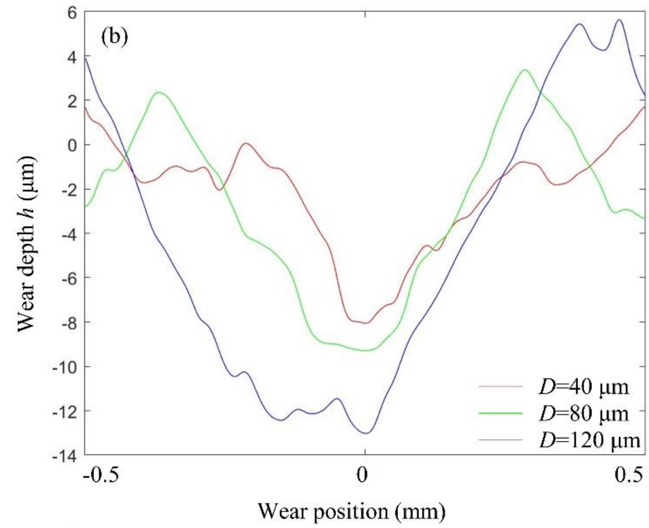
Fig. 2 Average friction coefficient of different normal load and displacement amplitudes.

As shown in Fig. 2, the average friction coefficient decreases with increasing normal load, however, it increases with increasing displacement amplitude. In addition, the higher the friction coefficient, the higher the friction force on the machined surfaces, then the contact performance between the machined surfaces can be ensured. Therefore, the friction coefficient of the machined surfaces can be increased by increasing the displacement amplitude and decreasing the normal load.

4. Wear properties analysis of milled surfaces

The wear profile of the milled surfaces under different loading conditions are demonstrated by Fig. 3(a)-(c). As shown in Fig. 3(a), when the displacement amplitude is 80-120 μm, the wear profile width is much larger than the wear profile width when the displacement amplitude is 40 μm. As shown in Fig. 3(b), the width of the wear profile becomes larger with increasing displacement amplitude. As shown in Fig. 3(c), although the pattern is similar to the former, the wear profile ratio exhibits a certain circular shape when the normal load is 200N.





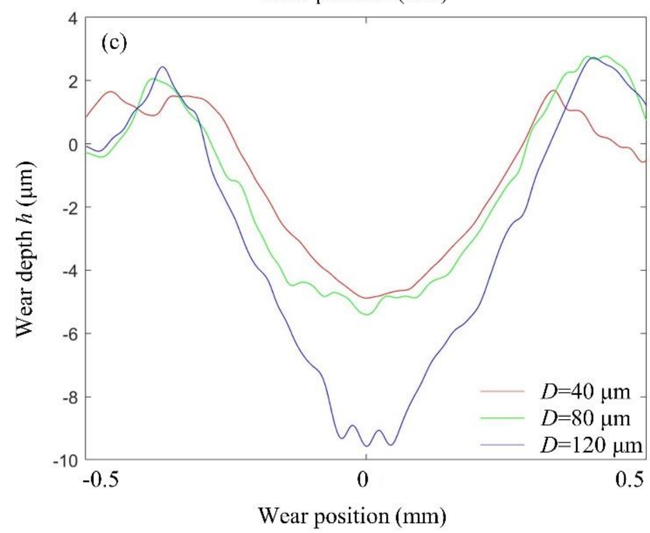


Fig. 3 Wear profile curves of different normal load and displacement amplitudes. (a) Normal load F_n=40 N. (b) Normal load F_n=120 N. (c) Normal load F_n=200 N.

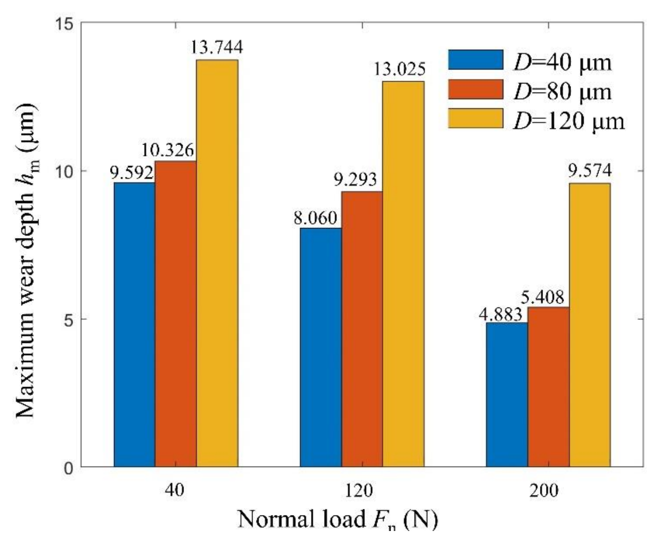


Fig. 4 Maximum wear depth of different normal load and displacement amplitudes.

As shown in Fig. 4, the maximum wear depth of the machined surface decreases with the increase of normal load, but it increases with the increase of displacement amplitude. Moreover, the maximum wear depth does not change much when the displacement amplitude is 40-80 μm, while the maximum wear depth increases sharply when the displacement amplitude reaches 120 μm. So, to make the machined surface more wear-resistant, measures should be taken to reduce the displacement amplitude and increase the normal load.

5. Conclusions

In this paper, surfaces with machined textures were obtained through milling experiments and friction and wear experiments were conducted under different normal loads and displacement amplitudes in order to investigate the effects of normal loads and displacement amplitudes on the friction and wear characteristics of machined surfaces. The main conclusions are as follows:

(1) The friction coefficient curve of machined surfaces increases and decreases, and then stabilizes as the number of cycles increases.

(2) The average friction coefficient of machined surfaces decreases with increasing normal load, but it increases with increasing displacement amplitude.

(3) The width and shape of the wear profile of the machined surface are influenced by the normal load and displacement amplitude.

(4) The maximum wear depth of machined surfaces decreases with increasing normal load, but it increases with increasing displacement amplitude.

(5) The average friction coefficient and maximum wear depth have similar trends under normal load and displacement amplitude.

ACKNOWLEDGEMENT

This work was supported by Key R&D Program of Shandong Province (Grant No. 2023CXGC010201), and Taishan Scholar Project of Shandong Province (Grant No. ts201712002).

REFERENCES

1. Ren, Z., Li, T., Ju, Y., Xie, H., Zhang, Q., "Characterization of the nonuniform friction behaviors in rough surfaces for the initial slip by the micro-contact and deformation zones," Opt. Lasers Eng., Vol. 183, pp. 108503, 2024.
2. Song, Y., Yan, P., Zhao, W., Guo, Z., Gu, H., Gao, S., Zou, S., Wang, X., "Effect of laser shock peening on cylinder-on-flat torsional fretting wear resistance performance of titanium alloy," Tribol. Int., Vol. 198, pp. 109919, 2024.
3. Cai, M., Zhang, P., Xiong, Q., Cai, Z., Luo, S., Gu, L., Zeng, L., "Finite element simulation of fretting wear behaviors under the ball-on-flat contact configuration," Tribol. Int., Vol. 177, pp. 107930, 2023.
4. Zhang, C., Shen, F., Ke, L., "Electrical contact resistance endurance of AgNi10 alloy under fretting wear: Experiment and numerical prediction," Wear, Vol. 530-531, pp. 205009, 2023.
5. Zhang, P., Xiong, Q., Cai, Y., Zhai, W., Cai, M., Cai, Z., Zhu, J., Gu, L., "Dry fretting and sliding wear behavior of 7075-T651 aluminum alloy under linear reciprocating motion: A comparative study," Wear, Vol. 526-527, pp. 204942, 2023.
6. Poon, C., O'Halloran, SM., Connolly, A., Barrett, RA., Leen, SB., "Fretting wear and fatigue in submarine power cable conductors for floating offshore wind energy," Tribol. Int., Vol. 186, pp. 108598, 2023.
7. Li, L., Xie, F., Wu, X., He, J., Li, G., Zhang, T., "Effect of the APS YAG coating on the fretting wear properties of Ti60 titanium alloy," Surf. Coat. Technol, Vol. 489, pp. 131061, 2024.
8. Wei, W., Ke, J., Liu, Z., Chen, Y., Liu, G., Hua, L., "The influences of normal load and displacement amplitude on fretting wear behavior of M50 bearing steel," Tribol. Int., Vol. 199, pp. 109944, 2024.
9. Hu, Y., Zhang, X., Jia, H., Yang, X., Chai, L., Wang, S., "High-temperature fretting wear behavior of IN738LC alloy formed by laser powder bed fusion," Tribol. Int., Vol. 199, pp. 110017, 2024.
10. Song, Y., Yan, P., Zhao, W., Guo, Z., Gu, H., Gao, S., Zou, S., Wang, X., "Effect of laser shock peening on cylinder-on-flat torsional fretting wear resistance performance of titanium alloy," Tribol. Int., Vol. 198, pp. 109919, 2024.