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Effect of Pin Diameters on the Wear Characteristics of Friction Pairs

Y. H. Wei,[a,1] X. L. Wang,[a,b] Y. P. Liu,[a] and L. J. Chen[c]

[a] School of Mechatronics Engineering, Zhengzhou University of Aeronautics, Zhenzhou, China

[b] Collaborative Innovation Center for Aviation Economic Development of Henan Province, Zhenzhou, China

[c] School of Mechanical Engineering, Tianjin Polytechnic University, Tianjin, China

[1] yangguangwyh@126.com

The tribological tests are carried out to assess the effect of pin diameters on wear characteristics via changing contact stresses and sliding speeds to provide support for choosing friction pair sizes. The friction couple is set as CuZn pins for medium carbon steel (No. 1045 steel) rings. The differential wear rate and its calculation formula are defined to express the line wear rate or the wear resistance of unit cross-section area. The effect of the pin end surface diameter on differential wear rate and its scale/increased multiplier are investigated. When the product ($P \times V = 0.095$) is kept constant, the abrasion loss for the specimens of a small diameter ($d_1 = 0.6$ mm) is lesser than that of the specimens of a large diameter ($d_2 = 4.0$ mm). As compared to the sliding speed, the change in contact stresses exerts a greater influence on the wear behavior, especially for small-diameter specimens. The differential wear rate of small-diameter specimens is always higher than that of the specimens of a large diameter. The scale multiplier of the differential wear rate is always larger than that of the contact pressure stress, especially for small-diameter specimens.

Keywords: size effect, dry sliding, friction, wear, diameter, differential wear rate.

Introduction. Controlling friction and wear becomes the main means of saving resources, prolonging the service life of equipment and increasing reliability [1–8]. Large changes take place at the size and scale aspect of the friction couple. In addition to the macro-size tribology (various mechanical devices, the crustal movement (earthquake), et cetera), microtribology and nanotribology are also appearing such as the micromotors and micromachines in integrated electric control system. Many studies point out that the mechanical properties of materials have a size effect [9], and the tribological properties of the materials are also the same [2, 10–18]. In 2011, Orlova [16] directly improved the friction and wear performance of the 18-100 type truck bogie by changing the size and shape of the friction wedge. Therefore, in order to provide support for the problem of the size selection of friction pairs, it is significance to study the effect of contact area or size on dry friction characteristics of friction couple.

In the study of the effect of magnetic field on the dry sliding tribological properties of metal materials [18], the size effect [9] of the tribological properties of the materials is noticed. Figure 1 shows the effect of magnetic field intensity on the line-wear-rate of CuZn pins and rings. If the parameter of magnetic field intensity is seen only as an additional variable, the size effect of the tribological characteristics is obvious (Fig. 1). This friction couple is set as the self-matching mode of CuZn pin to CuZn ring, the only difference between the pin and the ring specimens are their size (Fig. 2). The interaction between the pin and ring specimens maintains the relationship of action and reaction during the wear process, and whose actual contact area is identical at every moment. However, the testing results are different. The line-wear-rate of the rings are always larger than that of the pins. The ratio of line-wear-rate between ring specimens and pin specimens reaches about 19 at without magnetic field. In the friction process, the behavior of pins is similar to the action of turning tool, resulting in severe abrasion of rings.

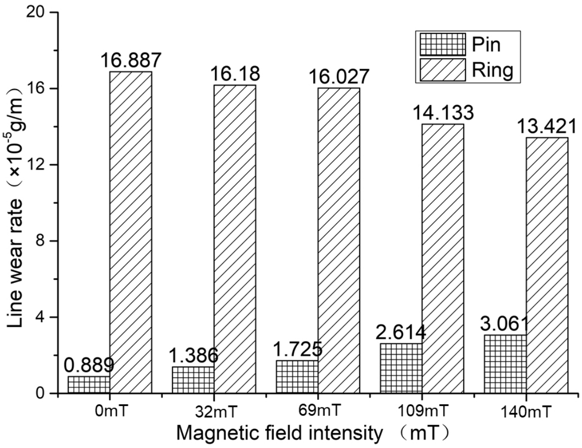

Fig. 1. Line-wear-rate of CuZn pins and rings under the influence of magnetic field intensity [18].

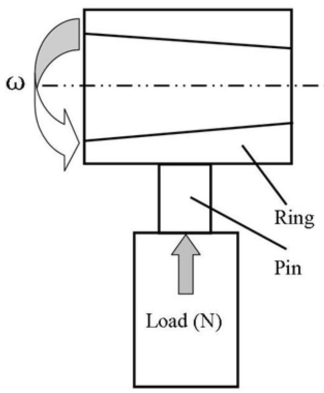

Fig. 2. The contact method of pin and ring.

This paper explores the effect of contact area or size of specimens on the dry wear characteristics of the friction couple made of CuZn and medium-carbon-steel (No. 1045 steel), when the product of contact stress P and sliding speed V is kept constant, namely $P \times V = 0.095$. To this end, the differential wear rate and its calculation formula are defined to express the line wear rate of a unit cross-sectional area.

1. **Test Methods and Materials**. Figure 2 shows the contact method of pin and ring (GB/T12444-2006). The friction couples are set as CuZn pin to medium-carbon-steel ring. When $P \times V = 0.095$ is kept constant, the friction testings are carried out by adjusting the parameters of contact stress and sliding velocity shown in Table 1. The specimen pins have a cylindrical shape made of CuZn. And their corresponding diameters of cross sections are 0.6 and 4.0 mm, respectively. The chemical composition of CuZn [18] pins are shown in Table 2. Each friction testing last for 1 h. After each friction testings, the specimen pins are cleaned by anhydrous ethanol, then dried. The weight loss is measured by an electronic balance BS210S with a precision of 0.1 mg. In order to minimize the error, the abrasion loss is calculated before and after the tests. The average value is obtained from three times testings. Equation (1) is used to calculate the abrasion loss.

Calculation equation of the abrasion loss ΔW:

$$\Delta W = W_1 - W_2. \tag{1}$$

Table 1

The Test Parameters

Serial number	Sliding speed V, m/s	Contact stress P, MPa
1	0.190	0.5
2	0.063	1.5
3	0.031	3.0

Table 2

The Chemical Composition of CuZn (wt.%)

Element	Cu	Pb	Al	Fe	Zn	Ni
CuZn	57–60	0.8–1.9	< 0.2	0.5	36–42	1.0

The difference of contact area of the friction couple may directly affect the actual contact stress (P_a) of the friction pairs, the distribution of the local force and the amount of elastic deformation caused by a positive pressure, the transmission efficiency of frictional heat and the vibration caused by friction sliding, et cetera. These statuses may affect the friction and wear properties, so that the abrasion loss change correspondingly with the contact area between pin and ring changing. When the diameters of the pins change, the actual contact area of friction couple will be different. Therefore the abrasion loss [Eq. (1)] and the line wear rate [Eq. (2)] are not able to accurately express the wear properties when their size is different. For this purpose, in Eq. (2) $\Delta W''$ (g/m/m^2) is defined as the differential wear rate to express the line wear rate of unit cross-sectional area, which is used to express the wear resistance of unit contact area of friction. In Eq. (2), $\Delta W'$ (g/m) is the line wearrate represented the abrasion loss of the unit distance of friction sliding.

Calculation equation of the differential wear rate (the line wearrate of unit cross-sectional area) $\Delta W''$:

$$\Delta W'' = \Delta W' \frac{1}{\pi r^2} = \frac{\Delta W}{2\pi R n t} \frac{1}{\pi r^2}, \tag{2}$$

where $\Delta W'$ is the line wear rate (g/m), which represents the abrasion loss of the unit sliding distance, ΔW is the abrasion loss (g), R is the outer ring radius of the ring specimens (m), r is the radius of the pin specimens (m), t is the friction time (min), and n is the rotational speed of the ring specimens (rpm).

2. **Test Results and Analysis**. Figure 3 shows the changing of abrasion loss of the specimen pins with different diameters when the value $P \times V = 0.095$ keeps constant under some different testing parameters. From Fig. 3 the abrasion loss of the specimen pins with big diameter ($d_2 = 4.0$ mm) are much larger than that of the specimens with small diameter ($d_1 = 0.6$ mm) under each same testing parameter. For the abrasion loss, the contact area of the friction surface of specimens with big diameter is larger than that of the specimens with small diameter, so that its abrasion loss is larger than that of the specimens with small diameter. As shown also from Fig. 3, the abrasion loss of specimens with small diameter has a slight increase trend with the increase of contact stresses, however the abrasion loss with big diameter enlarges greatly. When the $P \times V$ value keeps constant, the sliding speed V decreases with the increase of contact stress P. In the case of the same friction testing time, as the sliding speed decreases, the distance of relative sliding between the pin and the ring reduces. In this way the abrasion loss should have a decrease trend. But the testing results are opposite, that is, the abrasion loss of the specimens both big and small diameter

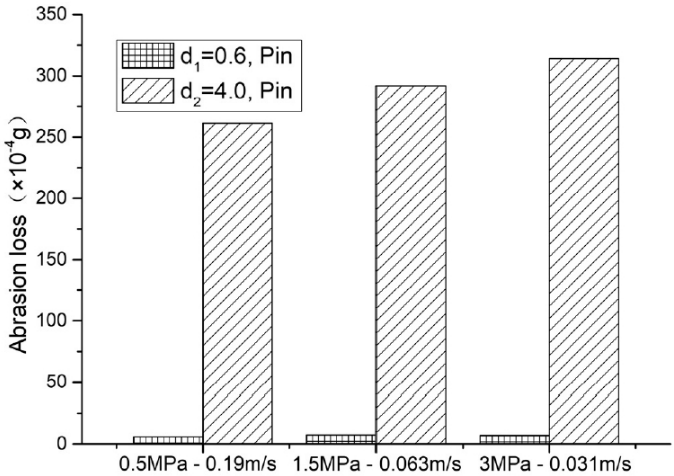

Fig. 3. Abrasion loss changing of specimens with different diameters when the $P \times V$ value keeps constant.

increases with the contact stress rise and sliding speed V decrease (Fig. 3). This indicates that the increase of abrasion loss is caused by the contact stress increase.

Figure 4 shows the friction surface morphology of the diameter 4.0 mm specimens under the different contact stresses. As shown in Fig. 4a, when the contact stress is small, the friction surface existing local bulges has a slight furrows and smoother relatively. With the contact stress increase, the friction surface appears a furrows morphology clearly (Fig. 4b). Combining Figs. 3 and 4, it can be concluded that, compared to the sliding speed, the change of contact stress has a great influence on the wear performance of the friction couple.

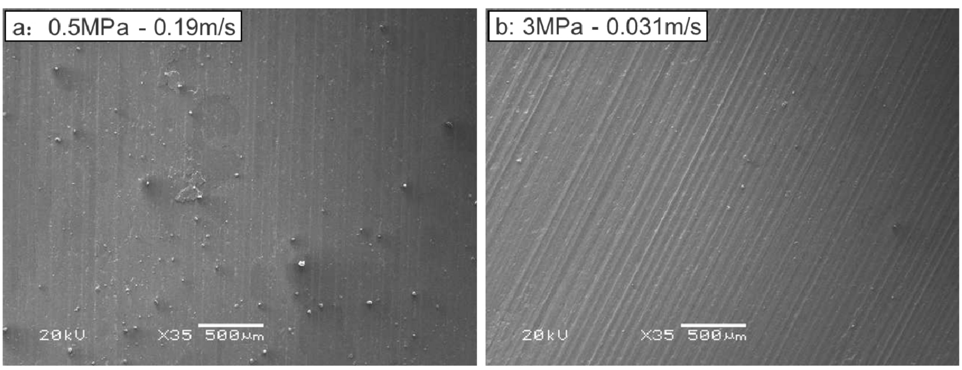

Fig. 4. Friction surface morphology of pins ($d_2 = 4.0$ mm) under the different contact stresses: (a) 0.5 MPa, (b) 3 MPa.

Figure 5 shows the differential-wear-rate [based on the Eq. (2)] of pin specimens with different diameters under some different testing parameters when the $P \times V$ value keeps constant. From Fig. 5, with the increase of contact stress and the decrease of friction speed, the differential wear rate increases, which indicates that the increase in contact stress exacerbates the wear and tear of the friction couple. Figure 5 also displays, at the same testing parameter 0.5 MPa–0.19 m/s (see the horizontal axis in Fig. 5), the difference in differential wear rates of the two kinds of specimens is small; next, at 1.5 MPa–0.063 m/s, the differential wear rate of specimens with a small diameter is larger than that of large-

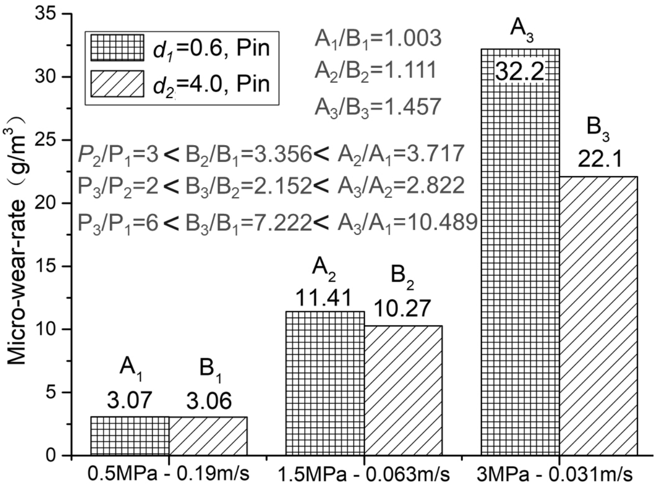

Fig. 5. The differential-wear-rates of specimens with different diameter when the $P \times V$ value is constant.

diameter specimens; while at 3.0 MPa–0.031 m/s, the differential wear rate of the small diameter specimens is much larger than that of big diameter ones. See Fig. 5, $A_1/B_1 = 1.003$ less than $A_2/B_2 = 1.111$ and $A_3/B_3 = 1.457$. In summary, the ratio of differential wear rate of specimens with different diameters increases gradually with the contact stress. Combining Figs. 3, 4, and 5, one can conclude that the contact stress has a significant effect on the abrasion loss and the differential wear rate. Noteworthy is also the fact that mechanical properties of materials have a scale effect. The hardness and strength of CuZn pins are lower than those of steel. Under the same contact stress, a smaller diameter or contact area of specimen pins corresponds to higher pressure/stress values. When the contact stress is much lower than the yield strength of the specimen, the impact of contact stress on the abrasion of CuZn pin is small. When the contact stress is increased to the contact pressure level close to its yield strength, the abrasion becomes quite severe. Therefore, the differential wear rates of the small-diameter specimens is higher than that of specimens with larger diameters. The increase in contact stress has an adverse effect on the abrasion of materials, especially for small-diameter specimens.

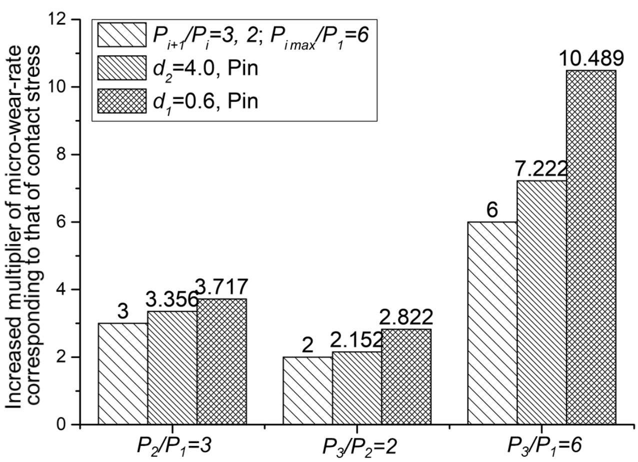

Fig. 6. Increased multiplier of differential wear rate corresponding to the multiplier of contact pressure stress.

See Fig. 5, as the contact stresses increase from P_x to P_y, such that

$$\text{From 0.5 to 1.5 MPa, } P_2/P_1 = 3 < B_2/B_1 = 3.356 < A_2/A_1 = 3.717, \tag{3}$$

$$\text{From 1.5 to 3.0 MPa, } P_3/P_2 = 2 < B_3/B_2 = 2.152 < A_3/A_2 = 2.822, \tag{4}$$

$$\text{From 0.5 to 3.0 MPa, } P_3/P_1 = 6 < B_3/B_1 = 7.222 < A_3/A_1 = 10.489. \tag{5}$$

These results are shown in Fig. 6. The increased multiplier of differential wear rate always exceeds the contact pressure stress multiplier for both large- and small-diameter specimens. As shown in Fig. 6, the increased multiplier of differential wear rate of small-diameter specimens is always higher than that of large-diameter ones [see Eqs. (3)–(5) and Fig. 6].

Conclusions. The tribological tests are carried out to explore the effect of contact area or size of pins on the dry tribological characteristics when the product ($P \times V = 0.095$) is kept constant. And the friction couple is set as CuZn pins to medium-carbon-steel (No. 1045 steel) rings. The differential-wear-rate and its calculation formula are defined to express the line-wear-rate of unit cross section area, and are used to express the wear resistance of unit contact area of friction, too. The following findings were made:

1. When the product ($P \times V = 0.095$) is kept constant, the abrasion loss of the specimens with small diameter ($d_1 = 0.6$ mm) is smaller than that of the specimens with big diameter ($d_2 = 4.0$ mm). In the friction process, the behavior of pins is similar to the action of turning tool, resulting in severe abrasion of rings.

2. As compared to the sliding speed variation, the contact stress variation has a stronger effect on the wear behavior, especially for small-diameter specimens.

3. The differential wear rate of small-diameter specimens always exceeds that of large-diameter onesr. The increased multiplier of differential wear rate is always higher than the multiplier of contact pressure stress. Moreover, the increased multiplier of differential wear rate of small-diameter specimens is the highest.

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1. Z. R. Zhou and L. M. Qian, "Tribological size effect and related problems," *Chin. J. Mech. Eng.*, **39**, 22–26 (2003).
2. Y. H. Wei and X. L. Wang, "Present status and prospects of the research on dry friction of metallic material under size effect," *Machinery*, **54**, No. 9, 1–4 (2016).
3. M. Reguzzoni and M. C. Righi, "Size dependence of static friction between solid clusters and substrates," *Phys. Rev. B*, **85**, No. 20, 76–83 (2012).
4. M. Paggi and A. Carpinteri, "Size-scale effects on the friction coefficient: from weak faults at the planetary scale to super lubricity at the nanoscale," in: G. Stavroulakis (Ed.), *Recent Advances in Contact Mechanics*, Part of the *Lecture Notes in Applied and Computational Mechanics* book series (LNACM, Vol. 56), Springer-Verlag, Berlin–Heidelberg (2013), pp. 67–84.
5. S. Fouvry and R. Merhej, "Introduction of a power law formulation to quantify the contact size effects on friction and wear responses of dry oscillating sliding contacts: Application to a chromium steel interface," *Wear*, **301**, Nos. 1–2, 34–46 (2013).
6. R. Kampmann, M. Roddenberry, and W. V. Ping, "Contribution of specimen surface friction to size effect and rupture behavior of concrete," *Aci. Mater. J.*, **110**, No. 2, 169–176 (2013).

7. K. G. Holmberg, "Tribology in reliability engineering," in: The Second World Tribology Congress (Sept. 3–7, 2001, Vienna, Austria), pp. 13–20.
8. M. Scherge, "Scale dependence of friction," in: The Second World Tribology Congress (Sept. 3–7, 2001, Vienna, Austria), pp. 31–38.
9. http://wiki.cnki.com.cn/HotWord/32694.htm.
10. H. C. Kou, Y. Z. Zhang, B. L. Shen, et al., "Influence of counterpair volume ratio on dry tribological properties of cast iron," *J. Iron. Steel. Res. Int.*, **12**, No. 3, 59–62 (2000).
11. B. Song and D. W. Zuo, "Effects of joining parameters and tool geometry on properties of friction stir welding joint of 2024 aluminum alloy and az31 magnesium alloy," *Mater. Rev.*, **30**, No. 10, 134–138 (2016).
12. J. Chen, X. R. Lv, and S. J. Wang, "Effect of sand size on tribological behavior of nitrile rubber in crude oil medium," *Lubr. Eng.*, **41**, No. 3, 71–75 (2016).
13. W. Zhu, X. F. Wang, X. R. Wang, and Y. Fu, "Research on the friction and wear property of different geometrical size fiber reinforced polymer-based composite," *New Chem. Mater.*, **45**, No. 5, 179–181 (2017).
14. J. Chen, H. Fan, W. Zhang, and N. Chang, "Effect of abrasive size on friction and wear characteristics of sealed rubber," *Tech. Innov. Appl.*, No. 20, 64–64 (2017).
15. H. Zhu, Y. Zhao, Z. Guo, and S. P. Cui, "Influence of mixing head size on temperature field and residual stress field of friction stir welded joint of 7075 aluminum alloy," *Weld. Tech.*, **45**, No. 5, 59–63 (2016).
16. A. M. Orlova, "Effect of geometrical dimensions of friction wedges on performance of freight car bogies," *Fore. Rol. Stoc.*, **48**, No. 5, 20–23 (2011).
17. J. N. Ding, Y. G. Meng, and S. Z. Wen, "Size effect on the mechanical properties and reliability analysis of micro-fabricated polysilicon thin film," in: IEEE 39th Annual International Reliability Physics Symposium (Orlando, USA, 2001), pp. 106–111.
18. Y. H. Wei, Y. Z. Zhang, and Y. Chen, "Dry-sliding tribological characteristics of CuZn Self-matched pairs under interfering of magnetic field," *J. Mater. Eng.*, No. 8, 23–27 (2013).

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